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# Community-based falls prevention for older persons: a case study in economic modelling of geriatric public health interventions

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# Statement of authorship and dissemination

Chapters 2 and 4 and Appendix C feature contents that have been published or submitted for publication. Chapter 2, Appendix C, and a part of Chapter 4 have been published in *BMC Health Services Research*. A further part of Chapter 4 has been published in *Cost Effectiveness and Resource Allocation*. The references for these papers are listed below:

**Chapter 2:** Kwon, J., Lee, Y., Young, T., Squires, H., and Harris, J. Qualitative research to inform economic modelling: a case study in older people’s views on implementing the NICE falls prevention guideline. *BMC Health Services Research* September (2021) 21:1020; DOI: 10.1186/s12913-021-07056-1.

**Appendix C:** Kwon, J., Squires, H., Franklin, M., Lee, Y., and Young, T. Economic evaluation of community-based falls prevention interventions for older populations: a systematic methodological overview of systematic reviews. *BMC Health Services Research* (2022) 22:401; https://doi.org/10.1186/s12913-022-07764-2.

**Chapter 4:** Kwon, J., Squires, H., Franklin, M., Lee, Y., and Young, T. Economic models of community-based falls prevention: a systematic review with subsequent commissioning and methodological recommendations. *BMC Health Services Research* (2022) 22:316; DOI: 10.1186/s12913-022-07647-6.

**Chapter 4:** Kwon, J., Squires, H., Franklin, M., and Young, T., 2022. Systematic review and critical methodological appraisal of community-based falls prevention economic models. *Cost Effectiveness and Resource Allocation* (2022) 20:33; https://doi.org/10.1186/s12962-022-00367-y.

See the Appendix for the statements on author contributions for each article.

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# List of abbreviations

|  |  |
| --- | --- |
| AC | All-Cause |
| ADL | Activities of Daily Living |
| A&E | Accident and Emergency |
| Aged 65+ | Aged 65 and over |
| AIC | Akaike Information Criterion |
| AMSTAR | A Measurement Tool to Assess systematic Reviews |
| ARC | Assessment and Rehabilitation Centre |
| AS&R | Active Support & Recovery |
| BCF | Better Care Fund |
| BIC | Bayesian Information Criterion |
| BMD | Bone Mass Density |
| BODE3 | Burden of Disease Epidemiology, Equity and Cost-Effectiveness |
| CALY | CASP-Adjusted Life Year |
| CASP-19 | Control, Autonomy, Self-realisation and Pleasure, 19 items |
| CBA | Cost-Benefit Analysis |
| CBT | Cognitive Behavioural Therapy |
| CCA | Cost-Consequence Analysis |
| CCG | Clinical Commissioning Group |
| CD | Community-Dwelling |
| CEA | Cost-Effectiveness Analysis |
| CEAC | Cost-Effectiveness Acceptability Curve |
| CG | Clinical Guideline |
| CI | Cognitively Impaired |
| CICI | Context and Implementation of Complex Interventions |
| CICS | Community Intermediate Care Service |
| CInt | Confidence Interval |
| CMO | Chief Medical Officer |
| CPI | Consumer Price Index |
| CRC | Constrained Recommended Care |
| CSP | Chartered Society of Physiotherapy |
| CUA | Cost-Utility Analysis |
| DCEA | Distributional Cost-Effectiveness Analysis |
| DJ | Double Jeopardy |
| DSA | Deterministic Sensitivity Analysis |
| DSU | Decision Support Unit |
| ECEA | Extended Cost-Effectiveness Analysis |
| ED | Emergency Department |
| EDE | Equally Distributed Equivalent |
| eFI | Electronic Frailty Index |
| ELSA | English Longitudinal Study of Ageing |
| FaME | Falls Management Exercise |
| FRAT | Falls Risk Assessment Tool |
| FRID | Fall Risk Increasing Drug |
| FRS | Falls Risk Screening |
| GBD | Global Burden of Disease |
| HAM | Home Assessment and Modification |
| HES | Hospital Episode Statistics |
| HNA | Health Needs Assessment |
| HSE | Health Survey for England |
| HTA | Health Technology Assessment |
| ICER | Incremental Cost-Effectiveness Ratio |
| ICT | Integrated Community Therapy |
| INHB | Incremental Net Health Benefit |
| INMB | Incremental Net Monetary Benefit |
| Int. | Intervention |
| ISPOR | International Society for Pharmacoeconomics and Outcomes Research |
| ITT | Intention-To-Treat |
| LED | Life Expectancy Differential |
| LTC | Long-Term Care |
| MA fall | Fall requiring Medical Attention |
| MC int. | Multiple-Component intervention |
| MF int. | Multifactorial intervention |
| MMSE | Mini-Mental State Examination |
| NCD | Non-Communicable Disease |
| NHS | National Health Service |
| NICE | National Institute for Health and Care Excellence |
| OMAS | Ontario Medical Advisory Secretariat |
| ONS | Office for National Statistics |
| OOP | Out-Of-Pocket |
| OT | Occupational Therapy |
| PA | Physical Activity |
| PHE | Public Health England |
| PHP | Public Health Principal |
| PMG | Process and Methods Guideline |
| PPP | Purchasing Power Parity |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-Analyse |
| PSA | Probabilistic Sensitivity Analysis |
| PSI | Postural Stability Instructor |
| PSS | Personal Social Services |
| PSSRU | Personal Social Services Research Unit |
| PT | Physiotherapy |
| QALY | Quality-Adjusted Life Year |
| QTUG | Quantitative Timed Up-and-Go |
| RaR | Rate Ratio |
| RC | Recommended Care |
| RCN | Royal College of Nursing |
| RCT | Randomised Controlled Trial |
| ROI | Return On Investment |
| RR | Relative Risk |
| SCC | Sheffield City Council |
| SD | Standard Deviation |
| SE | Standard Error |
| SES | Socioeconomic Status |
| SPA | Single Point of Access |
| SR | Surveillance Report |
| STH | Sheffield Teaching Hospitals |
| STIT | Short Term Intervention Team |
| SVE | Single-Vehicle Evaluation |
| TTO | Time Trade-Off |
| TUG | Timed Up-and-Go |
| UC | Usual Care |
| VoIM | Value of Implementation |

# Abstract

**Background:** Falls are one of the key geriatric syndromes that significantly impact geriatric health. This study aims to seek methodological solutions in developing a credible economic model of community-based falls prevention for older persons (aged 60 and over) which would inform the local commissioning decision between current, recommended, and alternative falls prevention strategies.

**Methods:** The study involved: (1) problem conceptualisation involving stakeholder consultations and qualitative study of older persons; (2) systematic review of existing models to identify key modelling challenges/solutions; and (3) model development based on stages (1)-(2) results, model analysis, and formulating commissioning recommendations. Key methodological developments in (3) included: (i) incorporating a wide range of societal outcomes; (ii) parameterising dynamic falls-frailty feedback; (iii) incorporating intervention capacity constraints; and (iv) assessing joint equity-efficiency impacts. Base case comparisons evaluated the performance of UK guideline-recommended strategy (RC) versus usual care (UC) representing current practice. Sensitivity, subgroup, and scenario analyses were conducted. RC was then compared to 22 alternative intervention strategies based on several decisional criteria before formulating commissioning recommendations.

**Results:** RC had 93.4% probability of being cost-effective versus UC at cost-effectiveness threshold of £20,000 per QALY gained under 40-year societal cost-utility analysis and improved equity delineated by socioeconomic status. RC is unlikely to be the optimal strategy when compared to alternative intervention strategies based on efficiency, joint efficiency-equity, or individual-level lifetime outcomes. Feasibilities of RC-level intervention capacity and environmental interventions significantly affected strategy rankings. If not feasible, then capacity-constrained form of RC supplemented by targeted risk screening of socially vulnerable subgroups by community organisations is likely the optimal strategy.

**Conclusion:** Guideline recommendations on community-based falls prevention should be qualified by capacity implications, efficiency-equity impact, and environmental strategies. Modelling can inform economic evaluation of diverse geriatric public health interventions and integration of diverse geriatric policies, including wider welfare policies and community mobilisation.

# Chapter 1. Introduction

## 1.1 Chapter outline

The main research question addressed by this study is ‘How can a credible model of falls prevention interventions for older persons living in the community be developed to inform commissioning decisions by local health authorities?’ Methodological developments to falls prevention modelling are pursued to improve model credibility (e.g., simulating intervention capacity constraints that exist in reality), and these developments should inform model-based evaluations of further falls prevention initiatives as well as those of other geriatric public health programmes. Section 1.2 describes the thesis aim and objectives and Section 1.3 explains the rationale for the research. Section 1.4 describes my personal, academic and philosophical positions and Section 1.5 introduces the thesis structure.

## 1.2 Thesis aim and objectives

The aim of this thesis is to seek methodological solutions in developing a credible economic model of community-based falls prevention interventions for older persons (aged 60 and over) which will assess the health economic performance of the UK guideline-recommended falls prevention strategy relative to current practice and alternative intervention strategies at the local health economy level. The objectives are to:

1. Apply a published conceptual framework for developing a credible economic model of a public health intervention [1]. This framework was chosen because it remains the only published one to date on conceptualising public health economic models. The application involves: (i) understanding the decision problem in the local context by engaging with commissioners, professionals and older persons; and (ii) understanding the key methodological challenges associated with the development of a falls prevention economic model.
2. Conduct a systematic review of previous falls prevention economic models and evaluate how they handled the key methodological challenges of model development, which in turn would help formulate methodological recommendations for subsequent modelling.
3. Develop a *de novo*, validated falls prevention economic model for Sheffield as a representative local health economy. The model should address the methodological challenges and recommendations identified in objectives (1) and (2). It should then evaluate the performance of the falls prevention strategy recommended by the UK guidelines relative to the current practice in Sheffield, as well as alternative intervention strategies suggested by the understanding of the decision problem in (1). This would be followed by commissioning recommendations using a wide set of decision criteria including efficiency, equity, capacity and budget constraints, and individual-level outcomes.

The intended audience of this thesis are health economists, commissioners and public health practitioners – falls prevention specialists, clinical professionals and lay volunteers – who seek a successful population-wide implementation of falls prevention in their local health economies. The modelling solutions achieved should aid modellers in this topic area. The current work also serves as a first full case study in applying the above-mentioned conceptual framework [1]. It would hence aid future projects in public health economic modelling, both geriatric and non-geriatric.

## 1.3 Rationale for the research

This section discusses the following topics that set the background to the research rationale:

1. Geriatric health challenges including falls and frailty (Section 1.3.1)
2. Geriatric public health interventions (Section 1.3.2)
3. Geriatric falls prevention (Section 1.3.3)
4. Health economic evaluation (Section 1.3.4)
5. Developing and evaluating a falls prevention economic model (Section 1.3.5).

Section 1.3.6 then concludes by summarising the rationale for the thesis aim and objectives.

### 1.3.1 Geriatric health challenges including falls and frailty

This research is concerned with the health of the population aged 60 and over (60+). Yet, to better understand the nature of health challenges in this population, a distinction is needed between the bio-social process of ‘ageing’ and advancement in chronological age (Section 1.3.1.1). Geriatric health research should consider the heterogeneous ways in which ageing is experienced by subgroups of the older population and the interactions between diseases and symptoms that give rise to geriatric syndromes including falls and frailty (Section 1.3.1.2). Finally, the continued increase in the absolute and relative sizes of the older population augments the importance of geriatric health research to ensure that population ageing is characterised by healthy ageing (Section 1.3.1.3).

#### 1.3.1.1 Ageing and old age

The concept of ageing encapsulates the multidimensional changes that occur over the life course in both the physical and psychosocial spheres of an individual [2]. At the physical level, ageing is associated with the gradual accumulation of a diverse range of molecular and cellular damages [3]. These damages lead to progressive, generalised impairments in physical capacities such as muscle strength, mobility, cognition, vision and hearing [4-6], increased risks of chronic diseases [7], greater vulnerability to environmental challenges such as immuno-senescence [8], and ultimately death [3]. At the psychosocial level, ageing typically involves shifts in social roles and circumstances, including increased risks of financial stress and social isolation and emotional toll of bereaving the loss of close relations. These psychosocial stressors can combine with physical frailty to induce poor mental health and conditions such as anxiety and depression [9].

The ageing process is not confined to individuals above a certain *chronological* age such as 60 or 65. Indeed, the decline in physical capacity is thought to begin in the mid-twenties for the general population [2]; and premature ageing is on average more pronounced for those from socially deprived backgrounds who tend to show significant symptoms of ageing (e.g., mobility impairment) before they reach age 65 [10]. Yet, advanced age is undoubtedly characterised by accelerated ageing given the volume of diverse molecular and cellular damages accumulated over time [3]. Hence, chronological age is still widely used to demarcate the geriatric population. The United Nations defines ‘old age’ as 60 years and over [11]; while in the UK, 65 years and over has traditionally been used because it corresponded (no longer so) with the start of state pension eligibility [12].

Adopting a lower chronological age threshold to demarcate the research target population would help identify premature ageing among socially deprived subgroups. Therefore, despite its UK setting, the falls prevention model parameterised in Chapter 5 adopts the lower age threshold of 60 rather than 65 to demarcate the target population. The systematic review in Chapter 4 similarly adopts the lower threshold and include studies targeting populations aged 50-59 (at high falls risk) for earlier prevention. The qualitative research in Chapter 2 uses the threshold of 65 in line with the National Institute for Health and Clinical Excellence (NICE) guideline on community-based falls prevention [13]. This approach was required to explore the facilitators and barriers to implementing the NICE guideline. Yet the chapter also samples from those aged 50-64 eligible for earlier prevention.

#### 1.3.1.2 Unique features of geriatric health

The health of older populations is characterised by high levels of heterogeneity and dynamic complexity and high prevalence of geriatric syndromes including falls and frailty. Understanding the relationship between falls and frailty is important for capturing the full health and economic impact of falls and for understanding the nature of falls risk, both in how it progresses over time and how it is distributed across individuals and subgroups.

##### Heterogeneity and dynamic complexity

As noted, the ageing process is highly multidimensional, affecting a wide range of organ and physiological systems at different rates according to individuals’ genetics, accumulated lifestyle and environmental exposures, and random molecular/cellular damages [3]. This multidimensionality in the ageing process results in high levels of heterogeneity in geriatric health whereby some individuals face markedly worse health status than their peers [2]. The heterogeneity is heightened if one considers not just physical health but also the capability to translate physical health to desired levels of functional ability [2]. Moreover, disparities in geriatric health are shaped strongly by exposures to social and environmental factors including adequate income and nutrition, good quality housing, social connectedness and healthcare access – both contemporaneously in old age and over the preceding life stages [2, 10]. One study in Scotland, for example, found that the onset of multimorbidity – the concurrent presence of multiple non-communicable diseases (NCDs) in an individual – occurs 10-15 years earlier in people from the most deprived socioeconomic group than those from the most affluent one [14]. Therefore, heterogeneity brings issues concerning social inequities of geriatric health [15-17].

Another phenomenon is dynamic complexity wherein intertemporal interactions between heterogeneous individuals and their environment result in population- and individual-level outcomes that are difficult to predict. One key aspect of dynamic complexity is the presence of feedback loops: e.g., peer support for exercise encourages sustained exercise uptake which enlarges the peer support network [18]. Another example discussed below is the feedback between falls incidence, frailty progression, and falls prevention access. Dynamic complexity can reinforce heterogeneity if differences in initial endowments influence the subsequent interactions with biopsychosocial factors.

##### Geriatric syndromes including falls and frailty

Geriatric syndromes – including falls, frailty, delirium, dizziness, syncope and urinary incontinence – are clinical conditions experienced by older persons that do not correspond to discrete/binary disease categories but are symptoms of the age-related impairments to multiple organ and physiological systems (and hence closely associated with multimorbidity) [19, 20]. The syndromes impose significant barriers to normal functioning and can leave the older person permanently housebound and dependent on external care. Furthermore, their aetiology cannot be narrowed to a specific disease which can be prevented or cured with an equally narrow treatment strategy [21-23].

Falls are defined as: inadvertently coming to rest on the ground or other lower level (excluding coming to rest against furniture, wall, or other structure) with or without loss of consciousness and other than as a consequence of sudden onset of paralysis, epileptic seizure, excess alcohol intake, or overwhelming external force [24, 25]. More than half of falls in populations aged 65+ occur in community settings: i.e., excluding residential care settings such as nursing homes and hospital wards [26]. It is estimated that around a third of community-dwelling adults aged 65+ and half of those aged 80+ fall at least once each year [13]. Around half of fallers are known to experience one or more recurrent falls within a year from the initial fall [27]. Falls impose significant morbidity and mortality burdens on older people [28], including fear of falling [29-31], depression [32], and functional decline and dependence [33-36]. There is also a close relationship between falls and fractures with around 95% of hip fractures caused by falls [37]. Serious injuries such as hip fractures significantly raise the long-term mortality risk (if not immediately fatal) [38-40], while even non-injurious falls can be fatal if the person is unable to get up from the floor and summon help and is thereby exposed to dehydration and hypothermia [37].

Like other geriatric syndromes, falls have a *multifactorial* risk profile that includes age, sex, chronic diseases, sensory and physical impairments (e.g., vision problems, abnormal gait and balance), cognitive impairment, history of falls and environmental hazards [13, 41-43]. Presence of a single falls risk factor is seldom the sole cause of a fall but rather contributes towards a cumulative falls risk profile that can be expressed in a continuous probability scale [44].

Frailty is a major health challenge for older people and another geriatric syndrome [19, 45]. In frail persons, a minor stressor event such as a fall or a seasonal flu can trigger sudden and irreversible health status changes, resulting in acute hospitalisations, nursing home admissions and mortality [46-48]. Frailty, like the falls risk profile, can be expressed on a continuous scale of a multivariate frailty index which calculates the ratio between the actual and potential numbers of a wide range of pre-specified geriatric health deficits in an individual [49-51].

##### Relationship between falls and frailty

There is a close bidirectional relationship between falls and frailty. A fall can cause physical impairments and functional limitations that are components of frailty [33]. Frailty, in turn, is an independent risk factor for falls [52, 53]. Figure 1.1 – which was informed by the conceptual model developed and reported in Chapter 3 – illustrates this dynamic bidirectional relationship.

Diagram

Description automatically generated

**Figure 1.1** Dynamic relationship between falls and frailty. A&E: accident and emergency; OOP: out-of-pocket.

Incidence of a fall can first have several primary or direct effects, including acute health utility loss from injuries, fatality and various acute care costs. This is then followed by progression in frailty, and the new frailty level brings about secondary or indirect effects of falls, including permanently lower health utility level, increased mortality risk and prolonged care expenditures and non-health effects (e.g., lower productivity). Moreover, the new frailty level potentially influences subsequent risks of falls and serious injuries. It can also influence falls prevention intervention access (and efficacy) if decision-makers prioritise intervention access by frailty level (or a related variable such as gait and balance impairments). In all, understanding the dynamically complex relationship between falls and frailty enables full accounting of the primary and secondary effects of falls, subsequent falls risk trajectory and falls prevention intervention access.

#### 1.3.1.3 Population ageing and healthy ageing

The global demographic trend of population ageing – i.e., increase in the size of the older population (defined by chronological age) in absolute number (‘numerical increase’) and as a proportion of the whole population (‘structural increase’) [9] – will increase the need for greater understanding of geriatric health challenges and related policy responses [2]. In the UK, the proportion of the population aged 65+ is projected to increase from 18.3% in 2018 to 24.2% in 2038 [54].

However, whether an ageing population imposes significant pressures on care systems and wider society (e.g., productivity loss) depends on the prevalence of geriatric health challenges. It is feasible that an ageing population is accompanied by better health in old age – ‘compression of morbidity’ – so that the economic and social pressures are minimised [2, 9]. Empirical results are mixed as to whether recent decades in developed countries have seen morbidity compression or expansion. One secondary analysis of multiple prospective cohort data from the US, England and Europe found evidence of morbidity *compression* when morbidity was measured as limitation to activities of daily living (ADL) but of morbidity *expansion* when it was measured in chronic disease prevalence between 1995 and 2006 [55]. Regarding the near future, a simulation study using an English prospective cohort study predicted that prevalence of multimorbidity (four or more chronic diseases) among those aged 65-74 will increase from 45.7% in 2015 to 52.8% in 2035 [56]. These illustrate the need for sustained efforts – via public health interventions at all life stages – to ensure that population ageing involves healthy ageing.

#### 1.3.1.4 Consequences of unhealthy ageing

Failure to promote healthy ageing would result in further challenges for the care systems and wider society, which can be categorised as follows:

1. Increased pressures on health and social care systems
2. Illness-related poverty in old age
3. Opportunity cost of informal caregiving
4. Reduction in the contributions of older people

##### Increased pressures on health and social care systems

As noted, care expenditures are more closely associated with morbidity than chronological age. A study by the US Congressional Budget Office, for example, found that the increase in the median age of the population between 1940 and 1990 in the US contributed just 2% to the increase in per-capita healthcare expenditure, while the rising burden of NCDs and failure of primary prevention contributed somewhere between 38% and 62% [57]. A Swiss study similarly found that adults aged 65+ with multimorbidity reported three times the number of healthcare consultations and 5.5 times the total healthcare cost than those without multimorbidity [58]. Based on the recent demographic and morbidity trajectories, the European Union projects that public healthcare expenditures in its member countries will rise from 6.4% of the GDP in 2007 to 8.6% in 2060, and that long-term care (LTC) expenditures by public sectors will similarly rise from 1.3% of GDP in 2007 to 2.9% in 2050 [59].

Falls contribute a nontrivial amount to these care expenditures. It is estimated that falls cost the NHS around £2 billion per year (based on a study published in 2011) [60]. This includes costs of hospital inpatient care, ambulance callout, accident and emergency (A&E) attendance and outpatient and GP visits directly related to falls [61]. According to one UK trial, patients admitted to A&E for a fall comprised around 20% of all attendees for a six-month period, and the median length of hospital stay for fall patients was 17 days [62]. Falls also impose significant burdens on the social care system via short-term care support for daily functioning and long-term residential care and nursing home admissions [63, 64]. In the UK, it is estimated that the social care costs incurred by the Personal Social Services (PSS) comprise around 40% of all public sector burden of falls [61]. In the US, 50% of hospitalised falls resulted in short-term or permanent nursing home admission [65]; and compared to all other hospitalised conditions in old age, falls were found to be the most common cause of long-term nursing home admission [66, 67]. Moreover, the full economic cost of falls would include not only those directly and immediately associated with falls but also those incurred via long-run functional decline and frailty progression (i.e., the secondary effects of falls) [33, 64].

##### Illness-related poverty in old age

Unhealthy ageing and associated care expenditures may place pressure on the personal finances of older households who are likely to be without regular income-earning opportunities [59]. The causes of poverty in old age are complex and rooted in opportunities and decisions made in earlier life stages, including parental and early-life circumstances and upbringing, education, employment, living arrangements and pension and other welfare conditions [68], as well as contemporaneous behaviours and policy support in old age [2]. What is clear is that illness-related out-of-pocket (OOP) care expenditures would exacerbate any underlying financial vulnerability. This vulnerability in turn can restrict the basic activities and productivity of older persons [69, 70]. Evidence also suggests that economic development and public care systems do not eliminate the incidence of potentially catastrophic OOP care expenditures: according to the 2004 wave of the Survey of Health, Ageing and Retirement in Europe (SHARE) study of 11 wealthy European countries, older people’s OOP payments for health and long-term care accounted for 9.6% on average and up to 25% of their household income [59]. Minimisation of OOP expenditure should be one of the key aims of public care systems [71-73].

Falls, like other geriatric health conditions, impose significant OOP care expenditures, though the magnitude varies by the care financing arrangement. Hence, a US study found that OOP expenditure comprised 15% of the total cost of falls requiring secondary care [74]; while the figures were around 12% in a UK trial of fallers requiring ambulance callout [75] and 4% for hospitalised fallers after discharge in a Dutch study [76]. Secondary effects of falls would add to the total OOP care expenditure.

##### Opportunity cost of informal caregiving

Informal care is essentially the unpaid alternative (or complement) to the privately paid or publicly provided health, social and long-term care services for adverse health events. However, unlike paid/commissioned care, informal care imposes opportunity costs on the informal caregiver. If the caregiver is employed, the care burden may induce him/her to give up the employment partially or completely, thus incurring a productivity opportunity cost [75]. Such opportunity cost is less likely to be tolerated in modern societies characterised by weaker intergenerational solidarity and greater geographical distance between family members [77]. There are also concerns, particularly in developing countries, that extended commitment to informal caregiving, typically by daughter or daughter-in-law, exacerbates the lack of opportunity for women in finding secure and formal employment (and preparing for their own pension and care) [2]. Other concerns are that informal caregivers are often ill-equipped to handle the care burden associated with complex multimorbidity and frailty [78, 79], and/or that they are themselves older and frail and hence at risk of becoming emotionally and physically strained by their caregiving roles [80-82]. Therefore, reducing the informal caregiver burden through prevention of adverse health outcomes is a key goal of geriatric public health interventions [83].

Falls have significant impacts on informal caregiver burden and wellbeing. A UK qualitative study of 27 older people who recently had a fall found that informal care and local support networks including family, friends and neighbours were as important as formal care in the aftermath of a fall [84]. In a Canadian trial sample of older persons who had experienced at least one fall in the past year, informal caregiving cost comprised 22% of the total societal costs in the usual care group [85]. As for emotional/health impact on informal caregivers, a Taiwanese survey found 57% of 98 informal caregivers (mean age of 53) caring for older hip fracture patients reporting that ‘Taking care of the sick elder at home makes me feel exhausted’ [86].

##### Reduction in the contributions of older people

The final societal challenge associated with unhealthy ageing is the loss of economic productivity and other contributions of older people [2]. Old age can, with appropriate support, be a period of active contribution, a ‘third age’ of personal achievement after childhood and working life, rather than a pathological state [9, 87]. Such productive ageing would foster sustainable economic development by harnessing the contribution of an increasingly large segment of the global population [88]. Beyond paid work, older people are important contributors to voluntary activities in community settings, including implementations of various public health initiatives among peers [89, 90], volunteering in charities and childcare [91], and informal caregiving [83]. In all, promoting geriatric health complements other public policies to support older persons’ participation in workplaces and communities [92-94], such as the UK government’s abolishment of the default retirement age of 65 in 2011 [95].

To my knowledge, there is no study estimating the productivity loss exclusively attributable to falls, let alone the productivity loss associated with unpaid work such as childcare and volunteering. That said, both the primary and secondary effects of falls on health and functioning can be assumed to have a substantial negative impact on later life productivity.

### 1.3.2 Geriatric public health interventions

It is often feared that the current medical care paradigm is poorly equipped to handle the challenges brought by an (unhealthy) ageing population, including the high prevalence of multimorbidity and geriatric syndromes [96-98]. The paradigm is primarily single disease- or organ-specific and curative, which can result in care fragmentation, iatrogenic harm (unintended adverse effects of treatments) and neglect of prevention [80, 97, 99-101].

Geriatric public health interventions are primarily preventive (rather than curative) interventions targeting a broad geriatric population (rather than a narrow patient group with specific clinical need) that aim to address the above shortcomings. The desired characteristics or qualities of geriatric public health interventions can be categorised as follows:

1. Person-centred care with holistic outcomes (Section 1.3.2.1)
2. Handling heterogeneity at population level (Section 1.3.2.2)
3. High integration of care (Section 1.3.2.3)
4. Coherent implementation strategy (Section 1.3.2.4)

#### 1.3.2.1 Person-centred care with holistic outcomes

Person-centred care acknowledges the multidimensional need matrix of each older person that spans both health and non-health domains [2]. Thus, person-centred care would motivate two intervention features: (1) multidimensional risk/need assessment; and (2) use of holistic outcomes. An example of (1) is the approach of comprehensive geriatric assessment (CGA) which seeks to simultaneously assess an older person’s medical, psychosocial, functional, and environmental needs [23, 102]. A corollary of (1) is the resource-intensive nature of operating a multidisciplinary team for assessments and treatments.

Holistic outcomes of (2) are required to measure the impacts of multidimensional interventions. The ICEpop index of CAPability for Older people (ICECAP-O), for example, has been developed to capture older persons’ capability encompassing their social connectedness and independence [103-105]. Likewise, the Extending the QALY (E-QALY) measure is currently being developed to capture multidimensional impacts of public health interventions (for all age groups) that are broader than those captured by existing health utility measures such as EQ-5D [106]. The principle applies to the economic outcomes; the economic evaluation should capture not only the direct economic consequences of a given disease or syndrome but also the indirect and comorbidity care costs, including those incurred during life years extended by the intervention [83]. A corollary to (2) is that the outcomes should ideally be assessed at the *individual* level rather than as impersonal averages or totals. For example, the number of individuals enjoying productive later years is a more relevant outcome in the context of person-centred care than the total monetary value of productivity at the population level.

#### 1.3.2.2 Handling heterogeneity at population level

The complexity of needs at the individual level translates to heterogeneity at the population level. Geriatric public health commissioners would likely oversee several subgroups within the target population defined by heterogeneous risks, intervention needs and capacities to benefit. The first implication of heterogeneity is the need for commissioners to consider multiple parallel (i.e., non-mutually exclusive) intervention pathways accessible to different older subgroups depending on their characteristics and needs. The optimal commissioning strategy would place different resource priorities across the pathways rather than choose one as a mutually exclusive alternative to others. A corollary is the need for a population-wide risk identification infrastructure to identify distinct subgroups.

The second implication of heterogeneity is the introduction of priority setting challenges that extend beyond the consideration of cost-effectiveness alone [71]. Specifically, the frailest and/or the most socially deprived (these categories often overlap) older subgroups are unlikely to yield favourable cost-effectiveness outcomes due to: (i) shorter remaining life expectancy from which to derive health benefits; and/or (ii) the ‘double jeopardy’ problem whereby vulnerable subgroups derive lower intervention efficacy and/or poor implementation quality owing to underlying barriers (e.g., intervention contraindicated by comorbidities, intervention uptake hampered by low disposable income) [107]. A commissioning strategy that selects the most cost-effective intervention(s) may worsen the existing health inequities; alternative strategies may be preferred depending on the decision-maker’s pre-established equity criteria if these exist [72, 108, 109].

#### 1.3.2.3 High integration of care

This quality underscores the potential of geriatric public health schemes or packages to integrate diverse intervention options that influence geriatric health and thereby generate synergies between them. Indeed, a high level of integration is required to enable the person-centred multidisciplinary assessment and treatment described above. A distinction can be drawn between ‘multi-need’ integration practices that concurrently target multiple diseases and needs of individuals – e.g., a multimorbidity management scheme that integrates preventive practices for major chronic conditions and risk factors including diabetes, cardiovascular disease, asthma and smoking [110] – and ‘single-need’ integration practices that bring together multiple disciplines for addressing a single need. The latter would have several sub-categories of needs requiring the multidisciplinary contributions. Multifactorial falls prevention that integrates the inputs of geriatricians, physiotherapists, occupational therapists, among others to address the multivariate nature of individuals’ falls risk profile [27], is an example of single-need integration.

Two further integrative activities for geriatric public health are: (1) integration with initiatives taken at earlier life stages (life-course integration); and (2) environmental or intersectoral integration. Regarding (1), the determinants of health and wellbeing at old age are largely established at earlier life stages [10, 111, 112]. Key ‘upstream’ actions include increasing physical activity, improving nutrition, and preventing/controlling metabolic risk factors [2, 113, 114]. Upstream actions also present greater opportunities for addressing the social determinants of health that produce potentially unfair cumulative advantage or disadvantage at old age [10, 115]. However, even with successful upstream actions, it is likely that ‘downstream’ geriatric public health interventions are still required, particularly for those from marginalised backgrounds who were initially deprived of upstream interventions due to existing barriers [2]. Life-course integration between upstream and geriatric interventions is thus warranted. There should at least be an exploration of how the evaluation results of geriatric interventions would be impacted by upstream interventions that alter the baseline characteristics of the geriatric population (e.g., the proportion engaging in high physical activity).

Regarding (2), there is growing recognition of the significant interactions between older persons’ intrinsic capacity (e.g., chronic disease profile) and the environment extending across multiple sectors (e.g., physical environment, public transport, pension) that shape the older persons’ functioning [2]. Environmental interventions aim to directly reduce risk factors for a given condition (e.g., removing environmental hazards for falls) and alter health behaviours (e.g., physical activity level) that indirectly influence the risk factors. One such initiative is the creation of an ‘age-friendly city’ to improve urban older population’s living environment [94, 116]. Components include improving home safety, providing physically accessible and affordable public transport, redesigning public spaces to promote health (e.g., more parks), and changing social attitudes towards ageing and productivity in old age [116]. Separate but similarly thorough considerations are warranted for rural communities [117]. In all, for any geriatric interventions operating within the healthcare sector, their synergy with broader environmental initiatives should be explored.

In addition, a systematic review of integrated care schemes noted that not all schemes aimed to improve patient health directly. They instead focused on: (i) organisational and system changes; (ii) staff employment and working practice changes; and (iii) financial or governance aspects of integration [118]. These primarily aimed to increase service access and patient and staff satisfaction rather than therapeutic effectiveness, thereby contributing to patient health indirectly.

Integrated care schemes have drawn much policy attention. The 2019 *Long Term Plan* of NHS England, for example, earmarked £4.5 billion of investment over five years on out-of-hospital/community multidisciplinary teams (including GPs, pharmacists, district nurses, community geriatricians, dementia workers, physiotherapists, social workers and the voluntary sector) that would “work with [older] people to maintain their independence” through “a targeted and personalised approach” [98]. This will be complemented by the Better Care Fund (BCF) that would integrate health and social care, “so that people can manage their own health and wellbeing, and live independently in their communities for as long as possible” [119, 120]. Beginning in 2014, the BCF obliges local clinical commissioning groups (CCGs) and local authorities to create a shared budget for health and social care and other public services, and also invests its own capital (£6.4 billion in 2019-20) to facilitate integration [119]. Nevertheless, it should now be clear that the term ‘integrated care’ covers a wide variety of initiatives ranging from financial/governance integration to single-need integration around, say, falls prevention. Attention should be paid to what aspects of integration a given initiative promotes.

#### 1.3.2.4 Coherent implementation strategy

The three desired characteristics described above generate significant complexity in the implementation of geriatric public health interventions [121, 122]. Therefore, coherent implementation strategies are required to generate the intended access and efficacy levels. Attention should also be paid to how intervention access and experience vary across subgroups to ensure that already vulnerable groups are not further disadvantaged by inequitable access [109]. Moreover, the implementation strategies would likely require the close involvement of nonclinical staff in the community to manage several aspects of the intervention pathway that require intimate community knowledge (e.g., peer-to-peer marketing to raise intervention uptake) [123]. Accordingly, the UK Department of Health emphasises the need for “strong partnerships between communities, business and the voluntary sector” to address geriatric health challenges [93]. These implementation strategies could be classified as organisational integration promoting access and/or intersectoral integration if involving diverse community organisations.

### 1.3.3 Geriatric falls prevention

This section introduces the key strategies and components of geriatric community-based falls prevention as evaluated in randomised controlled trials (RCTs) (Section 1.3.3.1) and recommended in UK clinical and public health guidelines (Section 1.3.3.2). It then summarises how falls prevention can be seen as a representative geriatric public health intervention (Section 1.3.3.3).

#### 1.3.3.1 Range of efficacious community-based falls prevention interventions

In the comprehensive 2012 Cochrane Review of community-based falls prevention RCTs the following range of interventions were identified [124]:

* Exercise treatments – group exercise, home exercise and Tai Chi
* Home assessment and modification (HAM)
* Expedited cataract surgery
* Vision improvement interventions other than cataract surgery
* Medication review followed by withdrawal or modification if appropriate
* Vitamin D supplementation
* Cardiac pacing
* Podiatry
* Footwear change
* Assistive device
* Cognitive behavioural interventions
* Falls prevention education
* Multiple-component intervention – combination of two or more interventions above without individual tailoring
* Multifactorial risk assessment – multidisciplinary assessment of falls risk factors and referrals to individually tailored treatments but no direct provision of treatments
* Multifactorial intervention – multidisciplinary assessment of falls risk factors and direct provision of treatments

All intervention types above were found to significantly reduce the number of falls and/or fallers, except for vision improvement other than cataract surgery, vitamin D supplementation, cognitive behavioural interventions and falls prevention education alone [124]. More recent updates of the Cochrane Review for community-based exercise interventions [125] and multifactorial and multiple-component interventions [126] confirmed the results that these interventions are efficacious in trial settings. Moreover, the decision-maker also has available environmental interventions which have been evaluated to be effective in reducing serious falls and related costs in quasi-experimental studies [127, 128]. Thus, the decision-maker has available a wide range of falls prevention interventions with proven efficacy. How this trial and quasi-experimental evidence can be translated to real-world delivery and other settings remains the key issue.

#### 1.3.3.2 Guideline recommended community-based falls prevention strategy

In England and Wales, NICE published its clinical guideline (CG21) in 2004 on assessment and prevention of falls in older people (aged 65+) in community and extended care settings (e.g., nursing homes). In 2013, NICE updated CG21 to include a guideline on falls prevention in the hospital inpatient setting (CG161), but the guideline on community-based prevention from CG21 remained unchanged [13]. An accompanying quality standard document (QS86) was published in 2015 [129], and a surveillance was conducted in 2019 for a potential update of CG161 [130]. This update is due June 2024 but at the time of writing (February 2022), no major information has been released beyond the stakeholder list [131].

Two prevention pathways can be perceived in the NICE recommendations for community setting (see the conceptual model in Chapter 3 for greater detail): proactive and reactive. Under the proactive pathway, the guideline recommends: (i) falls risk screening at opportunistic contact between older persons and care professionals; and (ii) multifactorial intervention for those screened to be at high falls risk. At the screening process, older persons should be asked about falls in the past year and tested for abnormal gait and balance, ideally by applying tests such as timed-up-and-go (TUG) [132]. Those who report recurrent falls in the past year and/or demonstrate abnormal gait/balance are deemed to be at high falls risk and should be referred to multidisciplinary falls risk assessment conducted by a team of geriatrician, physiotherapists, occupational therapists and nurses in a dedicated setting such as a falls clinic. The range of falls risk factors assessed can include gait and balance abnormality (assessed using a wider range of tests), high blood pressure, vision impairment, polypharmacy and presence of hazards at home. Patients should then receive a tailored set of treatments, including exercise, HAM, medication modification and vision improvements.

Under the reactive pathway, older persons receiving medical attention for a fall (e.g., at A&E) should receive a multifactorial intervention at discharge. The guideline also mentions that those who were hospitalised and then discharged for a fall should receive HAM (within or without the multifactorial intervention). Hence, the NICE-recommended strategy encompasses reactive and proactive pathways working in tandem and catering to different population subgroups at a given point in time.

Another distinct pathway that is not explicitly considered by the NICE guideline is the self-referred pathway, wherein older persons who are not eligible for either of the reactive and proactive pathways enrol in a falls prevention intervention without professional referral. The 2019 UK Chief Medical Officers’ physical activity guideline for older people encourage such uptake of falls prevention exercises [113]. The commissioners’ role would then be to support marketing of such options and partially/fully subsidise participation cost. Single-component exercise is a less resource-intensive option and hence offers the possibility of wider population reach [133], although its reach of the most vulnerable individuals (perhaps contraindicated for exercise) may be poor. In all, the final intervention strategy should determine the relative importance of the three non-mutually exclusive pathways.

#### 1.3.3.3 Falls prevention as a representative geriatric public health intervention

Therefore, community-based falls prevention shares the four key desired characteristics of geriatric public health interventions discussed above. First, the emphasis on multifactorial assessment and treatment in the NICE-recommended pathways adheres to the principle of person-centred care. Uni-disciplinary self-referred exercise should also be individually tailored [134-136]. Regarding the holistic outcomes that enable person-centred care, the expert guideline to falls prevention economic evaluation recommends that evaluations incorporate the ICECAP-O capability measure and use *all-cause*, rather than fall-related, care costs as primary cost outcomes [105].

Second, the recommended falls prevention strategy encompasses three non-mutually exclusive pathways, thereby catering to the heterogeneity in the target geriatric population. The falls risk screening at opportunistic care contact would help identify the risk-based subgroups. Moreover, falls, as noted, are closely associated with frailty [52, 53], which is in turn closely associated with socioeconomic deprivation [48, 137]. Hence, the falls prevention strategy should consider the decision-makers’ priority over social inequities of health across target population subgroups.

Third, the principle of high care integration is highly applicable to community-based falls prevention. As noted, the multidisciplinary teamworking under falls prevention represents a single-need integration scheme. Life-course integration is desirable given that several risk factors for falls such as multimorbidity and physical inactivity may manifest before seniority [138]. Moreover, environmental integration is likely necessary to manage environmental falls risk factors, and interventions with an environmental modification component have been shown to be highly cost-effective [127, 128].

Fourth, falls prevention, like other geriatric public health interventions, faces major implementation challenges. A recent UK survey, for example, showed that only 31% of GPs routinely screened their older patients for falls history and that the median annual number of referrals per GP to falls prevention services was only 10 [139]. Even in relatively well-resourced trial settings, uptake rate for falls prevention exercise can be as low as 6% [135], and adherence to different components of multifactorial intervention as low as 28% [140]. Engagements with older persons and professionals are hence fundamental parts of locally relevant falls prevention design and evaluation [141]. Financial barriers to implementation may be addressed by additional funding, but non-financial (e.g., cultural) ones would require more innovative solutions [142]. The implementation challenges nevertheless present opportunities for intersectoral integration. The Public Health England consensus statement on community-based falls prevention, for example, advocates the active involvement of nonclinical and voluntary organisations in falls risk screening and physical activity promotion [143].

Overall, falls are one of the major geriatric syndromes with health and economic consequences spanning multiple care sectors and wider society, while a successful implementation of community-based falls prevention would face the ideals and challenges common to geriatric public health interventions. Therefore, economic modelling of falls prevention would generate significant lessons that are applicable to the modelling of geriatric public health interventions in general.

### 1.3.4 Health economic evaluation

The motivation for conducting a health economic evaluation of community-based falls prevention intervention is discussed (Section 1.3.4.1). Two important aspects of the evaluation framework are then introduced: type of analysis (Section 1.3.4.2); and evaluation perspective (Section 1.3.4.3). Return on investment analysis (ROI) is introduced separately since it is typically not regarded as a health economic evaluation but is nevertheless frequently used for public health service appraisal [144] (Section 1.3.4.4).

#### 1.3.4.1 Motivation for health economic evaluation of community-based falls prevention

Health economic evaluation is a comparative analysis of alternative healthcare strategies in terms of costs and consequences with the primary purpose of informing the efficient use of scarce resources under a constrained healthcare budget [145]. The key concept is that of opportunity cost: any healthcare expenditure from a constrained budget implies an opportunity cost in terms of health foregone from the alternative ways in which the resources could have been used to generate health (or more broadly, utility) for other patient groups [145].

Falls prevention interventions also make use of scarce healthcare resources, and evaluation of their opportunity costs is hence warranted. Moreover, the high economic impacts of falls [60] – via both their primary and secondary effects, and across public care systems and wider society – offer the possibility that successful falls prevention intervention introduces only small opportunity costs. This would provide a strong rationale for widespread commissioning of falls prevention interventions. A well-conducted health economic evaluation can present such findings using transparent and scientific methodology and the best available epidemiological and economic evidence [145].

The case for conducting an economic evaluation is particularly strong for the NICE-recommended falls prevention pathway. The initial NICE guideline CG21 was based on limited economic evaluation evidence, specifically on the results of a single Markov cohort model that evaluated a multifactorial intervention and an exercise intervention over the lifetime horizon [146]. The model has several limitations including the lack of Markov tunnel states to incorporate age-related increases in falls risk, non-incorporation of recurrent falls within a year, and simplistic characterisation of falls risk screening and intervention reach (e.g., the model assumed that the whole model target population receives multifactorial intervention and the process of screening and identifying the high-risk subgroup was not characterised); see Chapter 4 where this model is reviewed. The updated guideline CG161 contained no additional economic evaluation or review of previous evaluations [13]. The 2019 surveillance also mentioned no further plan for economic evaluation [130].

This is of concern since the NICE clinical guideline is seen as the normative reference point for community-based falls prevention in England and Wales [139, 147]. The guideline moreover recommends resource-intensive multifactorial interventions for both reactive and proactive pathways. This makes the non-consideration of resource opportunity costs particularly problematic for policymaking, potentially resulting in excessive commissioning of falls prevention at the expense of other more efficient use of resources or (more likely) a hesitant support for falls prevention when confronted with the substantial intervention costs and the lack of evidence on its long-term benefits. A thorough economic evaluation is warranted under thesis objective (3) to weigh these intervention costs against the substantial health and economic benefits that can potentially be gained from falls prevention.

The final motivation derives from falls being a representative geriatric syndrome and community-based falls prevention being a representative geriatric public health intervention. The economic evaluation of community-based falls prevention thus offers a methodological template for evaluations of further geriatric public health interventions. To that end, the economic evaluation should assess the range of strategies that reflect the ideals and challenges of common to geriatric public health interventions discussed above, including environmental interventions and involvement of community organisations. Insofar as these strategies are not part of the UK guidelines, they are alternatives to be evaluated against recommended and current practices under thesis objective (3).

#### 1.3.4.2 Types of analysis

Health economic evaluations differ in how the health and non-health outcomes of healthcare interventions being compared are measured and valued [145]. Underlying the alternative types of analysis are different philosophies on how social welfare and the purpose of healthcare are viewed [148, 149]. The four main types of analysis are: (i) cost-benefit analysis (CBA); (ii) cost-effectiveness analysis (CEA); (iii) cost-utility analysis (CUA); and (iv) cost-consequence analysis (CCA).

##### Welfarism – Cost-benefit analysis

CBA is closely associated with Welfare Economics – the branch of Economics regarded as the origin of Health Economics [145] – which deals with choices of individuals to maximise their welfare (termed ‘utility’) and, by extension, with choices by the government over states of the world that would maximise social welfare [150]. Under CBA, individuals are the best judges of their preferences and welfare; and they make optimal consumption decisions based on their preferences and budget constraints. These disaggregated decisions interact in the form of market demand and supply to set the prices of goods and services including healthcare which, under certain assumptions (e.g., perfect information), represent the *social* value of the goods and services. Therefore, individual consumption decisions to purchase healthcare in the market to enhance health (and thereby utility) should be the primary, if not the sole, determinant of resource allocation [148, 151]. Interpersonal comparisons of utilities are unnecessary, as is a societal decision-maker who specifies then maximises a characteristic that contributes to utility (i.e., health) [148]. This approach is termed ‘Welfarist’ or ‘Welfarism’ [145].

Where health economic evaluations are required – e.g., due to some unwarranted distortions of the market that result in under- or over-provision of a healthcare intervention – they should respect the primacy of the market and individual choice. This is done by using market prices where they are undistorted, and revealed and stated monetary valuations of outcomes by individuals where not [148].

##### Extra-welfarism – Cost-effectiveness analysis and Cost-utility analysis

The main criticism of the Welfarist approach is that markets rarely function to this standard, especially the healthcare market characterised by high informational asymmetry between patients and providers, uncertainty over the incidence and severity of health crises, and under-consumption of merit goods (e.g., vaccination) that bring additional social benefits beyond the private benefits [145]. Health is also a primary good, or *capability*, that enables the obtainment of further goods and individual flourishing [151, 152]. This implies that the overall level and equitable distribution of the primary good should not be left to individual choices but be used as explicit measures of social welfare [153]. This approach of selecting a good or characteristic with an ‘objective’ (i.e., beyond subjective preference) value as a measure of intervention evaluation is labelled ‘Extra-Welfarist’ or ‘Extra-Welfarism’ [149].

Two types of analysis fall under the Extra-Welfarist approach: CEA and CUA. CEA takes the natural health event (e.g., the number of falls avoided) as the measure of outcome, while CUA uses a generic measure of health gain [145]. In the UK, the reference case generic health outcome is the QALY that combines length of life and preference-based health utility [154]. The latter is measured by a generic instrument (reference case of EQ-5D in the UK) that defines a health state over several dimensions and levels and can be applied to diverse disease areas and healthcare interventions [155]. The general adult public are asked to value the health states generated from the instrument by engaging in choice experiments: e.g., to trade off years lived in a given health state against being restored to perfect health under the ‘time trade-off’ experiment [156]. The resulting health utility ranges between 0 representing death and 1 perfect health, though values below 0 (i.e., health states worse than death) exist.

For CEA and CUA, the summary outcome is often the incremental cost per unit of health gained – or incremental cost-effectiveness ratio (ICER) – for the intervention relative to its comparator. A cost-effectiveness threshold can be specified (e.g., £2,000 per additional fall prevented or £20,000 per additional QALY gained) which attempts to reflect the productive efficiency of the healthcare system in the decision-making context [157]. Hence, the threshold is the monetary value of displacing one unit of health gain (e.g., the value of a QALY which is lost by curtailing existing treatments and services to fund the new technology or service). The NICE reference case specifies a threshold between £20,000 and £30,000 per QALY [154], although an empirical study estimated the productive efficiency of the UK healthcare system at around £13,000 per QALY [157]. If the ICER is below the threshold, the intervention is said to be cost-effective relative to its comparator since it generates more health units per £ than those displaced by withdrawing or overlooking the comparator [145]. ICERs can also be translated into incremental net monetary benefit (INMB) which is the monetary value of health gain – i.e., health units multiplied by the cost-effectiveness threshold – minus the incremental cost. Net benefit can also be expressed in terms of health rather than monetary units.

##### Cost-consequence analysis

The main disadvantage of CEA and CUA is that the outcomes of healthcare interventions are limited to the natural health unit and QALY gains, respectively. It is likely that healthcare interventions, especially integrated geriatric interventions addressing multiple health and non-health needs of older persons, have non-health impacts that cannot be synthesised into a natural health or QALY unit [83]. These impacts and intervention costs may also be distributed across multiple sectors beyond healthcare. Therefore, CCA presents the costs and consequences in a disaggregated form across the affected sectors. It has thus been recommended for economic evaluation of public health interventions [158, 159]. CCA shares the Extra-Welfarist notion that certain goods (e.g., prevention of illness-related poverty in old age) should not be left to individual choice and could be directly used as decision criteria.

The main limitations of CCA are that: (i) it focuses on the *presentation* of the various costs and consequences without accounting for the cost-effectiveness thresholds; (ii) it is difficult to ascertain whether the items included in the analysis fully reflect the social welfare function for the decision-making setting and whether they have been valued properly; (iii) if not all impacts are in the same direction (e.g., health utility improvement but survival reduction), there can be difficulties in determining the value of the technology/service; and (iv) it presumes that intersectoral cooperation is frictionless such that trans-sectoral budget sharing and compensations can occur [160, 161]. Nevertheless, the presentation of various intersectoral outcomes may still be useful for decision-makers. The extended cost-effectiveness analysis (ECEA),[[1]](#footnote-1) for example, presents diverse intersectoral outcomes including QALY gains and number of individuals avoiding catastrophic OOP care expenditures without translating them all into monetary values [72].

#### 1.3.4.3 Perspectives of economic evaluation

The perspective of an economic evaluation concerns the range of outcomes and costs covered for the analysis. The public sector perspective solely considers the resource and cost impacts on the publicly funded health and social care systems, including the impacts of the disease and costs incurred by the intervention and comparator. The societal perspective considers outcomes and costs accruing to the wider society such as co-payments for the intervention by participants and productivity loss due to illness. A case could be made that the societal perspective accounting for wider consequences of geriatric conditions is particularly relevant for economic evaluation of geriatric public health interventions [83, 161]. Stakeholders should be consulted before the perspective is chosen [1].

The societal perspective can be operationalised within CEA and CUA studies by accounting for costs and consequences beyond the public healthcare system. Yet, under a constrained public sector healthcare budget, the health opportunity cost of additional healthcare expenditure must still be accounted for, typically by comparing the ICER to the cost-effectiveness threshold expressing the productive efficiency of the healthcare system [145, 157]. For non-health outcomes and non-healthcare intervention costs, their incremental ratios should be compared separately to thresholds that express the productive efficiencies of their respective sectors [161]. The societal perspective is embedded in CBA studies which use the consumption value of health to monetise all health and non-health outcomes; yet the health opportunity cost of additional healthcare expenditure should still be accounted for [145].

#### 1.3.4.4 Return on investment analysis

Like CBA, ROI analysis also reports the results in a monetary unit or ratio [144]. However, unlike CBA which values the health outcomes in monetary terms, ROI analysis does not measure any health outcomes and simply compares the costs and economic consequences of two or more interventions to produce a net cost or ratio. This comparative element distinguishes ROI analysis, as defined in this thesis, from non-comparative evaluation of a single service [162]. An intervention that generates more than £1 within a given time frame for every additional £1 invested relative to its comparator is said to generate a positive ROI and represents an efficient investment from a purely financial perspective. ROI is the main evaluation framework for commissioning decisions on public health and social care in the UK setting [144]. It is also embedded in most evaluations of integrated care schemes that target reduction in general care expenditures relative to usual care [163]. Its strength is the ease of use, only requiring information on intervention costs and downstream service utilisations obtainable from routine administrative data. However, its main limitation is the neglect of intervention effects on health and broader wellbeing and hence is not regarded as a standard health economic evaluation.

### 1.3.5 Developing and evaluating a falls prevention economic model

The motivation for developing and analysing a decision model for falls prevention economic evaluation is discussed (Section 1.3.5.1), alongside the challenges involved (Section 1.3.5.2). These also inform the challenges involved in *reviewing* previous falls prevention economic models (Section 1.3.5.3).

#### 1.3.5.1 Motivation for decision modelling

A health economic evaluation can either be conducted alongside a single clinical study such as RCT – referred here as a single-vehicle evaluation (SVE) – or as a decision model [145]. Decision models represent the key disease-specific factors which are relevant to the decision problem in terms of mathematical and statistical relationships [164]. They then assess the impact of hypothetical changes (‘what if’ scenarios) to individual components of the causal chain on the final model outcomes.

Decision models enjoy several advantages relative to SVEs [145, 165, 166], including:

1. Consideration of all relevant costs and outcomes of interventions over long time horizons
2. Comparison of all potential intervention strategies and scenarios
3. Making evaluation results applicable to the population-level decision context

First, decision models can link the limited range of intermediate outcomes found in one set of epidemiological and clinical studies to the broad range of final outcomes found in another [164]. This is particularly important for the consideration (likely under a societal perspective) of holistic outcomes relevant to geriatric public health [161]. Models can also incorporate the long-term trajectories of key risk factors and thereby capture the full range and dynamic complexity of costs and consequences that manifest gradually as well as immediately [164].

Secondly, decision models can evaluate the intervention strategies that are most relevant to the decision problem rather than be confined to those examined in a single clinical study [166]. As noted, a comprehensive geriatric public health strategy would encompass risk screening, multiple pathways, implementation strategies, among other integrative elements. The range of possible strategies would quickly multiply; models offer the flexibility in evaluating any number and type of permutations.

Finally, decision models can produce results that are relevant to the full target population of the decision-making jurisdiction rather than specific populations of individual clinical studies [164]. A falls prevention model could, for example, use a survey or administrative dataset that is representative of the target population to derive the baseline falls risk and other characteristics. This would capture the heterogeneity in the target population characteristics including differences delineated by socioeconomic and other variables that raise priority setting challenges [109]. Trial-based efficacy data and resource use/cost data could then be applied to subgroups within the target population who share similar characteristics as the trial participants. This would help characterise the multiple intervention pathways and the heterogeneous reach and impact of intervention types [167]. Certain model types can also incorporate the jurisdiction-specific capacity constraints [168]. Indeed, the model developed in this study evaluates scenarios with capacity constraints as plausible alternatives to those without.

#### 1.3.5.2 Challenges in falls prevention economic model development and evaluation

Challenges in using a decision model for falls prevention economic evaluation can be divided into two categories: that of model structure development and that of model evaluation. First, poor assumptions and choices regarding model structure reduces model credibility and impairs its ability to inform decision-making in the context of complex geriatric health patterns and integrative intervention elements [160, 169]. Such structural uncertainty can be assessed prospectively and retrospectively [160]. Retrospective methods assign probabilities to scenarios representing alternative structural assumptions and obtain the weighted model outcomes [169, 170]. By contrast, prospective methods aim not to quantify structural uncertainty but to reduce it [160]. A systematic and transparent process should be followed from decision problem formulation and conceptual model development to evaluation of the final implemented model [1]. The key methodological challenges to public health economic modelling should also be considered throughout [18].

Model evaluation should be equally comprehensive. Two further sources of uncertainty are parameter uncertainty and heterogeneity [145]. The former concerns the uncertainty around the estimates of model input parameters due to sampling error [171]. Heterogeneity introduces potentially inequitable differences in subgroup outcomes; intervention strategies should thus be evaluated by their impacts on both efficiency and equity [109]. The presence of heterogeneously sized subgroups with different intervention needs can also affect the ranking between interventions [144]. An intervention that targets a small subgroup (e.g., cardiac pacing for patients diagnosed with carotid sinus hypersensitivity) may generate a highly favourable incremental cost-per-unit ratio (e.g., ICER) but a smaller aggregate impact (e.g., total INMB) compared to a moderately cost-effective intervention with a much larger client base (e.g., exercise). Under a constrained budget, if both interventions are within the budget individually but not together, the commissioner may choose the second option (i.e., it would be the optimal solution under constrained maximisation) [172]. A similar consideration is warranted for targeting strategies that increase the cost-effectiveness but reduce the total impact. Consideration of a wider set of (individual-level) outcomes, presented alongside efficiency and equity in CCA, may also change the strategy ranking.

Another consideration is that the model should be sufficiently informative for guiding commissioning at the *local* health economy level. The current NICE health technology assessment (HTA) guideline for England and Wales (process and methods guideline 9; PMG9) recommends that local CCGs and public health authorities identify implementation barriers preventing the commissioning of an intervention within three months of its NICE HTA approval (recommendation 1.5.1) [154]. Hence, the guideline presumes that the national-level HTA *precedes* the confirmation of local relevance. Yet, ideally, the HTA and the local confirmation should be conducted together since local features (e.g., availability of relevant professionals) may change the economic outcomes. At the least, the national HTA evidence should be supplemented by results of a locally relevant model. The latter should incorporate information on the local population (size, demographics, epidemiology, etc.) and local capacity constraints and other implementation issues (recommendations 4.5.3 and 6.1.6); the aggregate impact of the intervention on the local population (and its healthcare budget) should also be evaluated (recommendation 5.12.3) [154].

#### 1.3.5.3 Reviewing previous falls prevention economic models

A systematic review of existing economic models in the field is an important stage within the model development process [1]. Specifically, the review can: (1) assess previous model structures; (2) identify variables that have important impacts on outcomes; (3) inform the types of data available; (4) consider methodological strengths and limitations of previous models; and (5) verify whether there is an existing model that can be adapted and used [1]. A systematic review can also inform commissioning decisions by providing a comprehensive and up-to-date pool of economic evaluation results; but such a review would still need to appraise the methodological quality of identified models to identify credible evaluation results. Therefore, a methodologically rigorous systematic review would aim to comprehensively assess how the previous models have handled the methodological challenges in model development and evaluation and formulate methodological and commissioning recommendations. The methodological recommendations can appraise the strengths and limitations of any newly developed model and identify points of methodological advance. The commissioning recommendations can cross-validate the new model: i.e., compare the model’s results against those of previous models, and in case of significant divergence, explore the possible causes [173]. In Chapter 4, this study implements a *de novo* systematic review to inform the model development and commissioning.

### 1.3.6 Summary of research rationale

To recap, the aim of the study is to seek methodological developments in the economic modelling of community-based falls prevention interventions for older persons which would credibly inform commissioning at the local health economy level. This is motivated by the need for geriatric health promotion in response to the foreseeable demographic trend of population ageing. Economic evaluation is motivated by the need to account for the resource opportunity costs associated with the population-level delivery of falls prevention. Specifically, the NICE clinical guideline on community-based falls prevention has yet to undergo a rigorous economic evaluation, while alternative strategies consistent with the ideals and challenges of geriatric public health interventions should also be evaluated. Such evaluations are best conducted via a decision model that can characterise the complexities of geriatric health conditions and integrative operations of geriatric public health initiatives. Methodological developments in the modelling techniques should accordingly be sought and implemented. The final model should provide timely analytic support for the upcoming update to the NICE falls prevention guideline [131].

The rationale for the study objectives follows from the aim. First, the structure of a credible falls prevention economic model will be informed by a conceptual model that addresses the key aspects of the decision problem and the methodological challenges associated with geriatric public health economic modelling. This will involve a synthesis of the relevant literature on falls epidemiology, falls prevention and priority setting challenges and engagement with local stakeholders to understand the decision-making context. Second, a methodologically rigorous systematic review will be conducted as part of the model development. Finally, the *de novo* falls prevention economic model will be developed based on the conceptual model and the best modelling practice and data sources identified from the systematic review and elsewhere. It will seek to evaluate the strategy recommended by the UK guidelines relative to current practice in Sheffield alongside alternative strategies that reflect the ideals and challenges of geriatric public health interventions. A broad set of decisional criteria will be considered, including efficiency, equity, capacity and budget constraints, aggregate impacts, individual-level outcomes, and feasibility. Meeting these study objectives will inform how a similar sequence of research steps could be applied to other geriatric public health areas.

## 1.4 Personal, academic and philosophical position

I come from a country, South Korea, that is experiencing one of the fastest rates of population ageing in the world; this motivated the choice of the topic of geriatric health. My academic background is in Health Economics and Health Economic Evaluation with some experience in decision modelling to inform clinical decision-making. The first year of my four-year PhD programme gave me the opportunity to study several Public Health modules including Health Needs Assessment. Understanding the conceptualisation process for the development of a public health economic model was an active learning area, as was the process of engaging local stakeholders (including qualitative research with older persons in Sheffield) to better understand the decision problem.

Ontology concerns the nature of reality and what can be known about it [174], while epistemology concerns how valid knowledge can be produced about reality [175]. A realist ontology posits the existence of reality independent of human perception; positivist epistemology aligns with realist ontology and privileges measurable, quantitative outcomes for analyses, the findings of which approximate truths about the objective reality [175]. Using the frequentist approach to statistics, falls prevention RCTs (and clinical guidelines based on them) are closely aligned with the positivist epistemology since they collect falls data to falsify the null hypothesis about the objective reality (e.g., that the given intervention does *not* reduce the number of falls); the analytic approach is hence deductive [176]. By contrast, interpretivist epistemology aligns with non-realist or relative ontology – which denies the existence of a reality that is independent of human perception – and is often adopted by qualitative researchers to understand how subjective, local values and perspectives have shaped the collection and interpretation of data; the analytic approach is hence inductive [175].

The falls prevention model developed in this thesis relies on: (i) subjective views and assumptions generated from qualitative data and stakeholder consultations that inform the model structure; and (ii) quantitative data from positivist research (e.g., RCT-based intervention efficacy). Therefore, the ontological position of the thesis is one of critical realism which proposes that reality exists independently of human perception (i.e., realism) but can only be apprehended imperfectly and probabilistically [174]. The falls prevention model, for example, will approach the causal mechanisms and outcomes of the decision problem via structural assumptions that introduce uncertainty. The epistemological position could be described as post-positivist where model outcomes are considered circumstantial, rather than absolute, truths [174, 175].

## 1.5 Thesis structure

Figure 1.2 shows the thesis structure by chapter. Chapter 2 conducts a qualitative study with older persons in Sheffield to elicit their views on implementing the NICE-recommended falls prevention pathway. This research informs not only the implementation strategies for falls prevention but also the conceptual model development. Chapter 3 describes the conceptual model for falls prevention economic evaluation in Sheffield, informed by the qualitative research, wider stakeholder consultations and the falls prevention and geriatric health literature. The conceptualisation is informed by the guideline on developing the structure of public health economic models [1]. The conceptual model will inform all subsequent chapters.

Conducting a systematic review of existing models is an important step in the development of a falls prevention model [1]. Chapter 4 conducts a *de novo* systematic review of falls prevention economic models which formulates methodological and commissioning recommendations based on the methodological features and outcomes of identified models. The review methodology is informed by a systematic overview of previous systematic reviews of falls prevention economic evaluations, presented in Appendix C.

Chapter 5 brings together the lessons from the previous chapters to develop the *de novo* falls prevention economic model. It also describes the methods and results of model validation and the model analysis methods. Chapter 6 presents the model analysis results, formulates commissioning recommendations, and discusses the strengths and limitations of the model. Chapter 7 summarises the key contributions of this study to the literature, explores how the key lessons can be applied to further geriatric public health modelling, suggests areas of further research, and concludes.

Diagram

Description automatically generated

**Figure 1.2** Thesis structure by chapter.

# Chapter 2. Qualitative research to inform implementation and economic modelling of falls prevention

## 2.1 Chapter outline

This chapter aims to capture the subjective views of older people in Sheffield on implementing the NICE CG161 guideline on community-based falls prevention and use the qualitative data to help develop the conceptual model of falls prevention in Chapter 3. The data could also directly inform commissioning decisions in Sheffield and in other similar local health economies seeking to implement CG161. The research objectives are to:

1. Identify the facilitators and barriers for implementing key components of the CG161 community-based falls prevention pathway – including falls risk screening and assessment, falls risk awareness, and uptake and adherence of treatments within multifactorial intervention – and contextual factors influencing the pathway implementation in Sheffield.
2. Inform potential local commissioning strategies on falls prevention by understanding the causal mechanisms in context, supply, need and demand that influence implementation.
3. Identify the methodological and evaluative challenges associated with developing an economic model of falls prevention in the local context.

As noted, the facilitators and barriers identified under the first objective would be generalisable to other urban community settings in England and Wales and hence be of interest to professionals and patient groups seeking to implement NICE CG161. Findings from the second objective would likewise inform commissioners overseeing similar urban community settings. Methodological steps taken to achieve the third objective should inform economic modellers and qualitative researchers working jointly under projects that involve both research designs, whether in falls prevention or other public health areas. Section 2.2 provides further background to the qualitative study. Sections 2.3 and 2.4 provide the study methods and results. Section 2.5 discusses the findings and Section 2.6 summarises the chapter.

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## 2.2 Qualitative study background

As discussed in Section 1.3.3.2, the range of components involved in the NICE-recommended falls prevention programme (e.g., routine falls risk screening, multifactorial intervention) introduces substantial complexity to the programme implementation [22, 178-180]. This complexity is common to geriatric public health interventions in general (Section 1.3.3.3). The implementation quality of falls prevention can be suboptimal even in well-resourced trial settings [135, 140]. Low implementation reduces the effectiveness and population reach/impact of falls prevention [181].

Accordingly, NICE CG161 incorporated a systematic synthesis of older people’s views on the facilitators and barriers to falls prevention (covering the period 1990-2003), but found no study that explored their views on multifactorial interventions (p. 101) [13]. More recent qualitative works have likewise focused on specific components of the falls prevention pathway, including receptiveness to falls prevention advice [182], falls risk assessment [183], and exercise uptake [184, 185] and adherence [186]. This is an important evidence gap given that complexity results from the interaction of facilitators and barriers across different pathway components. A more holistic exploration of the facilitators and barriers to the NICE-recommended pathway is thus warranted and motivates the first chapter objective.

Two further uses of qualitative data can be discerned in the context of falls prevention model development: (a) eliciting appropriate commissioning strategies (second chapter objective); and (b) understanding the key methodological and evaluative challenges to public health economic modelling (third chapter objective).

Concerning (a), the model-evaluated commissioning strategy should fully reflect the complex network of intervention-related casual mechanisms influencing implementation. Several frameworks exist to capture such complexity [187], including the Context and Implementation of Complex Interventions (CICI) framework [181] which was developed as part of the INTEGRATE-HTA project to consider a comprehensive set of factors influencing the assessment of complex health technologies [188]. CICI distinguishes between contextual factors (e.g., socio-cultural, legal) and implementation mechanisms (e.g., professionals, organisations) that shape implementation quality. Priority-setting challenges – e.g., reducing social inequities of health [71] – also arise from the implementation context [187].

One limitation of CICI is its lack of focus on demand-side mechanisms – e.g., motivations of the older persons to engage in healthy behaviour [189] – which can operate independently of supply. Hence, CICI could be supplemented by the health needs assessment (HNA) framework that incorporates demand, supply and need/eligibility as distinct yet overlapping domains [190]. Inductive qualitative data analysis could commence with themes sourced from this combined CICI-HNA framework, and thereafter interact with new themes emerging from the data to arrive at the final thematic framework informing the commissioning strategies [191, 192].

Concerning (b), the nature of falls being a public health problem faced by a broad spectrum of older populations – rather than a clinical problem faced by a well-defined, narrow patient group – presents further complexity to model development [1]. According to a systematic methodological review, the key methodological challenges to public health economic modelling include: (i) capturing non-health outcomes and societal intervention costs; (ii) considering dynamic complexity in health determinants and intervention need; (iii) considering theories and models of human behaviour based on psychology and sociology; and (iv) considering social determinants of health and issues of equity [18]. Addressing such challenges is part of the INTEGRATE-HTA recommendations (part 3) [188], and is necessary for improving the structural validity of the decision model [1]. The same inductive analysis can identify how these challenges relate to the local decision problem and hence to the decision model structure [1].

In all, a *de novo* qualitative study of older people is warranted, first to holistically explore the facilitators and barriers for implementing the NICE-recommended falls prevention pathway, and second to proactively use the resulting qualitative data to inform economic modelling. The latter would improve upon the siloed approach that is widely prevalent in the literature, whereby qualitative research is conducted and interpreted separately from economic evaluation, even when both designs are included in the same project [146, 193, 194].

## 2.3 Qualitative study methods

The qualitative research involved focus groups and interviews with older persons living in the Sheffield community. The ethics approval was obtained from the Research Ethics Committee at the School of Health and Related Research (ref. 025248). Written consent was obtained from willing participants after they were informed about the research orally and in writing. See Appendix A for the ethics approval letter, participant information sheet, and informed consent form.

### 2.3.1 Target population and sampling

The target population comprised persons aged 65+ in Sheffield, England, and persons aged 50-64 who are at high falls risk. The latter group was included to explore the rationale for earlier prevention as is currently recommended for inpatient settings by CG161 [13]. Purposive sampling covered multiple categories of participant characteristics in terms of falls risk and service use as illustrated in Figure 2.1.

Table

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**Figure 2.1** Categories for qualitative study participant characteristics.

According to CG161, those with history of fall(s) requiring medical attention or recurrent falls (of any severity) in the past year and/or mobility and balance problems were defined as high-risk [13]. Low-risk individuals were sampled because they are still eligible for falls risk screening and/or interested in early prevention.

Recruitment continued until all participant categories were covered and themes saturated. Specifically, two focus groups were formed from two separate cohorts enrolled in Dance to Health, a falls prevention programme that combines evidence-based Otago and Falls Management Exercise (FaME) components in dance routines [195, 196]; these groups contained high and low risk service users. Two further groups were formed from a Patient and Public Involvement group meeting regularly at the Northern General Hospital and a social group meeting at Zest Community, a local social enterprise offering leisure, health and work support services to diverse age groups; these contained high and low risk service non-users. Two interview participants were recruited from Dance to Health and Zest Community.

Focus groups were held directly before/after the regular meetings. Community organisation staff confirmed before research commencement whether their members could give informed consent. One participant declared memory problems while another a recent diagnosis of Alzheimer’s disease; but both were regular attendees of community groups and expressed confidence in participating. After obtaining written consents, questionnaires were administered to collect data on demographics, falls history and fear of falling, current physical activity, and contact with falls prevention services (Appendix A).

Focus group participants were previously acquainted from attending the same activity and were comfortable sharing their experiences in the group. The PhD researcher introduced himself and the PhD aim and presented himself as someone wanting to learn from the participants. Participants were motivated to help the interviewer understand their perspective on falls and falls prevention. For interviews, around 15 minutes were spent for the participants and the interviewer to become acquainted in conversing (at interviewees’ homes) before the research commenced.

### 2.3.2 Discussion topics and data collection

The main discussion topics were structured around the sequential steps of the proactive prevention pathway recommended by CG161 [13], namely: (i) falls risk screening/assessment by professionals; (ii) participant suggestions on raising falls risk awareness in the community; (iii) initial uptake of different treatments; and (iv) long-term access to treatments. If mentioned by participants, the reactive and self-referred pathways were also discussed. See Appendix A for the topic guide.

A simplified graphical summary of the proactive pathway, as shown in Figure 2.2, was used to explain the main topics to participants. Four treatment types – exercise, HAM, medication change and vision improvement – were explained while emphasising that other types exist, such as chiropody. It was also highlighted that reactive pathway after a serious fall is commonly used, and that self-referred pathway is recommended by experts [113]. Further contextual factors influencing falls risk and prevention (e.g., safety of pedestrian walks in Winter) were actively explored as they emerged during discussion.

Diagram

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**Figure 2.2** Graphical summary of the recommended falls prevention guideline used to introduce the discussion topics to focus group and interview participants.

For data collection, recorded audio data were transcribed and anonymised. The questionnaire data were similarly transferred to an Excel spreadsheet and anonymised. Both data were stored securely in the University designated folder.

### 2.3.3 Data analysis

Framework analysis was employed for the analysis of obtained data [191, 192]. The approach involved five stages: (a) familiarisation – which involves repeated listening to audio and reading of transcripts for immersion in the data; (b) identifying a thematic framework – which is based on an *a priori* set of issues related to the research objectives and themes emerging from the data; (c) indexing – which systematically applies the thematic framework to the transcripts; (d) charting – which ‘lifts’ the data from the transcripts and rearranges them (e.g., in a tabular format) according to the thematic framework; and (e) mapping and interpretation – which seeks associations and develops policy-related strategies from the charted data based on *a priori* issues and emerging themes.

From stage (b) onwards, three frameworks related to the research objectives were constructed using *a priori* concepts and themes emerging from the data:

1. Framework to understand the facilitators and barriers to components of the NICE CG161 falls prevention pathway and cross-component and contextual factors.
2. Framework to inform potential commissioning strategies by accounting for causal mechanisms in context, priority setting, need/eligibility, supply and demand.
3. Framework to understand the key methodological challenges to public health economic model development.

#### 2.3.3.1 Framework (I): Facilitators and barriers and cross-component and contextual factors

This framework closely followed the structure of the discussion topics and charted the main themes identified from the data. Facilitators and barriers for the pathway implementation that emerged from the data were arranged by *a priori* thematic categories corresponding to the NICE CG161 pathway components – i.e., (i) falls risk screening/assessment by professionals; (ii) raising falls risk awareness; (iii) initial uptake of treatments; and (iv) long-term adherence to treatments. Cross-component factors – i.e., facilitators and barriers influencing multiple pathway components – were highlighted. Additional contextual factors influencing the pathway implementation were noted as they emerged from the data.

#### 2.3.3.2 Framework (II): Potential commissioning strategies

This framework rearranged the main themes under Framework (I) into a format that guides commissioning strategies (actual or model-evaluated). An *a priori* CICI-HNA framework was constructed that combined the thematic categories within the CICI [181] and the HNA frameworks [190]. This is illustrated in Figure A1 in Appendix A with accompanying descriptions. In brief, the CICI framework distinguished between implementation context (e.g., socioeconomic, legal) and mechanisms (e.g., provider, funding) [181]. The HNA framework distinguished between supply, demand and need/eligibility [190]: supply corresponded to the CICI implementation mechanisms; demand encompassed personal and external factors influencing uptake/adherence decisions (e.g., health-related motives for healthy behaviour [189], community marketing, self-efficacy promotions [197, 198]); need/eligibility was determined by normative clinical and public health guidelines and intervention studies that demonstrated a group’s ability to benefit from an intervention [190]. Further thematic categories that emerged from the data were noted (e.g., priority setting challenges for commissioning [71]). The mapped themes informed commissioning strategies by highlighting which CICI-HNA factors were modifiable (i.e., lie within the decision space) and to what extent.

#### 2.3.3.3 Framework (III): Challenges for public health economic modelling

The thematic categories of key methodological challenges for public health economic modelling were taken from a systematic methodological review [18]: (i) capturing non-health outcomes and societal intervention costs; (ii) considering dynamic complexity in health determinants and intervention need; (iii) considering theories and models of human behaviour based on psychology and sociology; and (iv) considering social determinants of health and issues of equity. See Section 3.5 below for further description of these challenges. Additional challenges associated with economic modelling and evaluation were also identified from the emerging data.

## 2.4 Qualitative study results

Participant characteristics are described (Section 2.4.1), followed by themes organised under the three frameworks (Sections 2.4.2 to 2.4.4).

### 2.4.1 Participant characteristics

Twenty-seven persons participated in research across four focus groups (FG1-4) and two interviews (INT1-2) between October 2019 and January 2020. Table 2.1 summarises their characteristics.

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| --- | --- | --- | --- |
| **Table 2.1** Summary of qualitative study participant characteristics. | | | |
| **Field** | **Variable** |  | **N (%)** |
| Demographics | Sex | Female | 20 (74) |
| Male | 7 (26) |
| Age | <60 | 5 (19) |
|  | 60-64 | 1 (4) |
|  | 65-69 | 5 (19) |
|  | 70-74 | 5 (19) |
|  | 75-79 | 7 (26) |
|  | 80-84 | 2 (7) |
|  | 85-89 | 1 (4) |
|  | >=90 | 1 (4) |
| Fall history and fear of falling | Experienced fall in previous year | Yes | 14 (52) |
| No | 13 (48) |
| Number of falls in previous year | 0 | 13 (48) |
| 1 | 6 (22) |
| 2 | 4 (15) |
| 3+ | 4 (15) |
| Whether fall(s) required medical attention1 (% among fallers) | Yes | 8 (57) |
| No | 6 (43) |
| Fall resulted in fracture (% among fallers) | Yes | 3 (21) |
| How worried are you about falling while walking or balancing? | 1 Never | 4 (15) |
| 2 Hardly | 5 (19) |
| 3 Sometimes | 11 (41) |
| 4 Often | 4 (15) |
| 5 All the time | 3 (11) |
| Current physical activity level | Currently engaged in some exercise group/activity2 | Yes | 19 (70) |
| No | 8 (30) |
| History of falls risk screening | Whether spoken to a GP or other professionals about risk of falling in previous year | Yes | 11 (41) |
| No | 16 (59) |
| If yes, where was it? (% among Yes for previous question) | GP | 5 (45) |
| Social care | 0 (0) |
| Falls clinic | 3 (27) |
| A&E | 0 (0) |
| Hospital | 2 (18) |
| Other | 1 (9) |
| Falls prevention service use in past year | Type of falls prevention service use3 | Physiotherapy | 12 |
| Occupational therapy | 1 |
| HAM | 4 |
| Medication change | 0 |
| Vision surgery | 5 |
| Vit D supplement | 6 |
| Assistive device | 7 |
| Footwear change | 6 |
| Falls education | 12 |
| **Abbreviation:** HAM: home assessment and modification  1 At least GP visit.  2 Suggested options were Chairobics, Pilates, dancing, swimming and group walks with additional space for participants to state other exercise/physical activity types.  3 The list of services was taken from Cochrane systematic review of falls prevention trials [124]. However, the questionnaire did not explicitly label these services as falls prevention interventions in order to invite responses from participants who may have received a multi-purpose service (e.g., physiotherapy or vitamin D supplementation) without awareness of its falls prevention property. Overall, 21 participants (78%) indicated use of one or more service. | | | |

Regarding current access to falls prevention, 11 reported having spoken to a professional about falls risk. Nevertheless, 21 reported recent use of services with some falls prevention properties [124], suggesting that the main falls prevention pathway under current practice is self-referral by older persons. Of the 21 users, 13 reported accessing multiple interventions. The most widely accessed services were physiotherapy and falls education.

### 2.4.2 Framework (I): Facilitators and barriers and cross-component and contextual factors

Table 2.2 summarises the identified facilitators and barriers to implementation by pathway component. The themes are numbered to facilitate mapping to later frameworks. Table A1 in Appendix A shows the direct transcript quotes for each theme, and Figure A2 in Appendix A graphically illustrates how themes were mapped from qualitative data to Framework (I) and subsequently re-mapped to Frameworks (II) and (III).

|  |  |  |
| --- | --- | --- |
| **Table 2.2** Summary of identified facilitators and barriers to the falls prevention pathway components. | | |
| **Pathway component [Theme #]** | **Facilitator [Theme #]** | **Barrier [Theme #]** |
| Falls risk screening and assessment by professionals [1] | ***(A) Professional competence*** | |
| * General approachability of professionals [1-1] | * Lack of proactive professional approach [1-5] * Lack of professional attention to environmental risk factors [1-6] |
| ***(B) System-level approaches and resources*** | |
| * Proactive, data-based approach to falls risk screening [1-2] * Specialist expertise and equipment [1-3] | * Time constraint in routine practice [1-7] |
| ***(C) Motivation and awareness of older persons*** | |
| * Older person’s motivation to maintain health [1-4] | * Older person’s lack of falls risk awareness [1-8] |
| Raising awareness of falls risk [2] | * Awareness from earlier life-course stage [2-1] * Awareness of falls risk by informal caregivers [2-2] | * Lack of awareness of the physical ageing process [2-3] |
| Initial uptake of falls prevention treatments [3] | ***(A) Motivation and awareness of older persons*** | |
| * Older person’s experience of falling [3-1] * Older person’s experience of the physical ageing process [3-2] * Older person’s motivation to maintain health [3-3] | * Older person’s lack of falls risk awareness [3-15] * Low motivation of older persons [3-16] |
| ***(B) Facilitators and barriers in the community*** | |
| * Community marketing [3-4] * Peer recommendations [3-5] * Marketing health benefits of interventions [3-6] | * Lack of information in community [3-17] * Barriers related to socioeconomic class [3-18] * Linguistic barriers to information uptake [3-19] |
| ***(C) Intervention characteristics*** | |
| * Intervention is free/cheap [3-7] * Intervention is enjoyable [3-8] * Intervention is of suitable difficulty [3-9] * Intervention is safe [3-10] * Intervention is conveniently located [3-11] | * High intervention cost [3-20] * Inconvenient timing of intervention [3-21] * Lack of safe venues for intervention [3-22] * Transport access and cost issues [3-23] |
| ***(D) Professional competence and funding*** | |
| * Professional recommendations are more important than peer recommendations [3-12] * Professional awareness of community initiatives [3-13] * Person-centred professional referrals [3-14] | * Lack of professional awareness of community initiatives [3-24] * Commandeering attitude of professionals [3-25] * Reactive professional approach [3-26] * Mismatch between area-based demand and supply [3-27] |
| Adherence and long-term access to falls prevention treatments [4] | ***(A) Motivation and health of older persons*** | |
| * Older person’s motivation to maintain health [4-1] | * Older person’s illness and comorbidities [4-10] |
| ***(B) Positive and negative experiences of intervention characteristics*** | |
| * Experience of intervention reducing falls risk [4-2] * Experience of wider health benefits of interventions [4-3] * Intervention is enjoyable [4-4] * Intervention enables high social participation [4-5] * Intervention is individually tailored [4-6] | * High intervention cost [4-11] * Intervention is of unsuitable difficulty [4-12] * Intervention is not individually tailored [4-13] * Inconvenient timing of intervention [4-14] * Transport access issues [4-15] |
| ***(C) Professional availability and competence and funding*** | |
| * Availability of staff [4-7] * Proactive professional approach to sustain adherence [4-8] * Good professional-participant relationship [4-9] | * Lack of professional and volunteer staff [4-16] * Insufficient public sector funding [4-17] |

#### 2.4.2.1 Falls risk screening and assessment by professionals

Factors influencing falls risk screening and assessment by professionals could be divided into three groups: (A) professional competence; (B) system-wide approaches and resources; and (C) motivation and awareness of older persons. Participants were aware of the importance of professional competence in conducting the falls risk screening, particularly incompetence as barriers. For example, one participant had noticed the narrow scope of professional risk assessment:

(FG1) “I’d think it was important if somebody went to a health professional, the health professional would check on a whole lot of background information apart from immediate health thing – you know, what is your living, housing situation.” (Theme [1-6])

Nevertheless, participants were also aware of the impact of system-level approaches and resources beyond individual professional competence and made suggestions on improvement. One such suggestion was to adopt a proactive, data-based approach to risk screening akin to mass vaccination:

(FG1) “And with regards to hooking people in, when flu jab time comes up, we all get a text or a message or we get told that we need a flu jab. So, follow that lead, really. I’m sure there’s a record showing age groups and then tell them ‘Look, this service is available. Come on in!’” (Theme [1-2])

Moreover, a few comments suggested that older person’s motivation to maintain health would facilitate professional efforts to discuss falls risk and prevention:

(FG4) “If I was at risk, I would be happy to talk to [the professionals]. Because I would be happy to take any advice on anything that keeps me good as possible for as long as possible, if that makes sense.” (Theme [1-4])

#### 2.4.2.2 Raising awareness of falls risk

Participants generally recognised that falls risk awareness is a matter of understanding the ageing process, not only from a certain senior age but from earlier adult life stages. For example, one participant expressed the difficulty of staying aware of falls risks at home during the gradual ageing process:

(FG1) “Well, it happens so gradually, doesn’t it… when it is part of ageing and degenerative thing, it’s not like they go over night from being perfect to being in a wheelchair. It’s such a gradual thing. And you get used to stuff. You get used to the fact that the rug was curled up at the end.” (Theme [2-3])

The role of informal caregivers in maintaining awareness of falls risk, particularly in the living environment shared with older persons, was also highlighted.

#### 2.4.2.3 Initial uptake of falls prevention treatments

Factors influencing the initial uptake of treatments could be divided into four main groups: (A) motivation and awareness of older persons; (B) facilitators and barriers in the community; (C) intervention characteristics; and (D) professional competence and funding.

For (A), experiences of falls and increasing physical constraints associated with ageing were important catalysts for treatment uptake. That said, one participant declined to enrol in falls prevention despite an experience of falling and professional referral; the fall experience was thought to be the result of a specific situation (postprandial syncope) rather than a symptom of general vulnerability:

(FG4) “The only time I had fallen over is if I’m standing up suddenly. I go dizzy and I had a blackout and fall over. The nurse at the medical centres offered for me to go on a course to avoid falling. But I thought it wasn’t really necessary because I only fall in that situation. So I didn’t go on the course. I just have to be careful when I stand up.” (Theme [3-15])

For (B), the level of information on the treatment in the community – spread via marketing and peer recommendations – was an important determinant of uptake, while participants perceived socioeconomic and linguistic barriers in how the information is received and acted upon:

(FG3) “I think it’s the actual area, and I do actually think it’s class related in terms of whether people would actually get up and go to something even if it’s advertised, unless there’s somebody actually suggesting having it up in GP surgeries.” (Theme [3-18])

Important intervention characteristics included cost, enjoyability, suitable difficulty, safety, location, timing, support facilities (e.g., lack of handrail at venue entrance), and transport issues (availability and cost). Individuals considered whether the specific combination of these characteristics suited their preference and ability to pay. For example, one participant perceived modest private cost as an acceptable trade-off to enjoyability, while another perceived transport costs as a key main barrier:

(FG3) “I do think people would find the three odd pounds if they found [the intervention] absorbed them and really interested them.” (Theme [3-8])

(FG1) “And also, money and transport, not a lot of us can afford to go, because it’s usually, what, a fiver to get you where you want to go and back and return. Not a lot of people can afford to. When you are on universal credit or job seeker’s allowance and benefit, I think when you’ve got a disability like I have long enough. I think it should be like the over 60s [person was under 60], they have a bus pass.” (Theme [3-23])

Participants acknowledged the influential role of professionals in determining their treatment uptake, more influential than their peers according to theme [3-12]. The key steps were professional awareness of falls prevention initiatives in the community, followed by proactive recommendations or referrals made in a respectful and person-centred manner:

(FG1) “One person when we had a meeting found out that so many doctors were handing out too many drugs instead of an alternative. There was an alternative. [My doctor at surgery] said, ‘I’d want you to go and do an aquarobics’ and that helped me, that helped me so much that I didn’t need the drugs.” (Theme [3-14])

#### 2.4.2.4 Adherence and long-term participation in falls prevention treatments

Factors influencing long-term treatment adherence could be divided into three main groups: (A) motivation and health of older persons; (B) positive and negative experiences of intervention characteristics; and (C) professional availability and competence and funding.

Significant illness or comorbidity impeded older persons’ adherence to interventions (theme [4-10]); but preventing an adverse health/functional status also served as a motivation for adherence:

(FG3) “Wanting to maintain what you’ve got. Not wanting to lose your independence. And hang on [to] independence as long as possible because I live alone as well.” (Theme [4-1])

Positive intervention experiences or characteristics that sustained adherence included falls risk reduction, wider health benefits, enjoyability, high social participation, and tailoring to individual ability. Negative ones included high cost, unsuitable difficulty, lack of tailoring, inconvenient timing and transport problems. Active involvement of healthcare professionals was not a guarantee that the intervention experience would be positive:

(FG3) “[The GP] set up [a programme] for people to stop falls. And I was in a group of about 8 people. And it was like a small version of going to the gym. And I went to that once and then I postponed it because it’s too hard for my hands.” (Theme [4-12])

Discontinuities in staff availability and funding unsurprisingly impeded long-term adherence. Otherwise, good bonding between the professional leader and participants was an important facilitator:

(INT1) “She [the Dance to Health instructor] goes out of her way to have friendly relationship with everyone that goes. And I think it works. You always get a cuddle when you arrive. And she always shows interest in you, what you are doing and what difficulties you have, and so on.” (Theme [4-9])

#### 2.4.2.5 Cross-component factors

Two common themes across components were older persons’ health motives (themes [1-4, 1-8, 2-1, 3-3, 3-16 and 4-1]) and professional competence ([1-1, 1-5, 1-6, 3-12 to 3-14, 3-24 to 3-26, 4-8 and 4-9). First, older persons’ health-related goals such as maintaining independence facilitated risk screening by professionals ([1-4]), risk awareness ([2-1]) and intervention uptake ([3-3]) and adherence ([4-1]). Secondly, participants perceived that it is professionals’ responsibility to identify all relevant falls risk factors and prescribe relevant treatments (e.g., [1-6 and 3-14]); incompetence resulted in iatrogenic harm despite patient’s awareness:

(FG2) “I’ve got loads of medication variation problems. For me, I don’t really expect GPs to improve things, but they never told me ‘Oh we could change this into that’. He [the GP] just expects me to just keep pre-ordering the medications. So I leave it that way.” (Theme [3-26])

There was a close overlap in factors determining treatment uptake and adherence and long-term participation, both components sharing the themes concerning motivation of older persons, intervention characteristics and professional competence. As for factor differences, experience of falling was mentioned as a facilitator for uptake ([3-1]) but not adherence. Socioeconomic and linguistic barriers were mentioned only for uptake ([3-18 and 3-19]), likely because they are sufficient to discourage both uptake and adherence for the marginalised subgroups. Funding constraints impeded both uptake and adherence, though in different ways: adherence was predictably curtailed by the funding cut at the end of the pilot period ([4-17]); while uptake was impeded by deliberate policy to concentrate funding in deprived areas despite higher demand in well-off areas:

(FG3) “Now, to be honest, this [well-off] area doesn’t usually have anything. You know, I mean, all the money and the grant has been put into only deprived areas.” (Theme [3-27])

#### 2.4.2.6 Contextual factors influencing the falls prevention pathway

Table 2.3 summarises the contextual factors that influenced the pathway implementation. They could be divided into two groups: (i) intersectoral factors; and (ii) prioritising the vulnerable groups. Table A3 in Appendix A shows the direct transcript quotes.

|  |  |
| --- | --- |
| **Table 2.3** Summary of contextual factors influencing the falls prevention pathway. | |
| **Intersectoral factors [Theme #5]** | **Prioritising the vulnerable groups [Theme #6]** |
| * Health hazards in local public spaces [5-1] * Health-promoting local public spaces [5-2] * Home ownership and modification [5-3] * Communitarian approaches [5-4] | * Persons with complex comorbidities [6-1] * Persons experiencing cognitive decline [6-2] * Socially isolated persons [6-3] |

##### Intersectoral factors

Intersectoral factors concerned matters typically addressed outside the healthcare system, including the safety and health-promoting features of local public spaces, the relationship between home ownership and ability to implement home modifications, and potential communitarian approaches that mobilise the community to meet common goals. Older participants mentioned how in the past the local community would handle the challenges that lie outside the local/central government’s responsibility; the decline in communal responsibility was perceived to explain the increase in local health hazards:

(FG1) “I don’t think neighbours are neighbours anymore, either. When we were younger, I remember when snow came here, all the men of each family would come and make a path. And they don’t do that now.” (Theme [5-4])

##### Prioritising the vulnerable groups

Another set of themes concerned the need to prioritise the most vulnerable individuals at risk of a serious fall or loss of independence. Three groups were identified: persons with complex comorbidities; persons experiencing cognitive decline; and socially isolated persons. The reported experience of the diabetic participant who was below age 65 (hence below the eligibility age for the proactive pathway) illustrated how vulnerable individuals concurrently face multiple risk factors for serious falls:

(FG1) “If I had a bad day with my high sugar levels. I’ve had my bad day with blurriness. And I come down a lot of stairs and I fell X times coming down from attic and obviously coming out of my building which is a high old building. And then you’ve got to come down some more which is always full of leaves.” (Theme [6-1])

Despite this, public support for home assessment and modification was denied due to her ability to walk 100 meters without problem, and support from other care professionals was similarly lacking.

### 2.4.3 Framework (II): Potential commissioning strategies

Table 2.4 re-maps the identified themes according to the CICI-HNA framework (see also Figure A2 in Appendix A).

|  |  |  |
| --- | --- | --- |
| **Table 2.4** Themes arranged by the CICI-HNA framework to inform commissioning decisions | | |
| *Context, priority setting and need/eligibility [Theme #]1* | *Supply [Theme #]* | *Demand [Theme #]* |
| *Implementation context*   * Socioeconomic divide [3-18] * Linguistic divide/barrier [3-19] * Health hazards and opportunities in local geography [5-1, 5-2] * Legal/regulatory barriers for tenants to modify their homes [5-3] * Culture of communal responsibility that addressed key falls risk factors is no longer strong [5-4] | Provider and organisation   * Positive professional attributes: approachable [1-2]; aware of community initiatives [3-13, 3-24]; proactive and person-centred care [3-14, 4-8]; good relationship with intervention participants [4-9] * Negative professional attributes: reactive approach [1-5, 3-26]; partial attention to risk factors [1-6]; commandeering attitude [3-25] * Facility/equipment: specialist Falls Clinics [1-3]; safe and well-located venues [3-11, 3-22, 3-23, 4-15] * Positive intervention characteristics: low cost [3-7, 3-20, 4-11]; well-staffed [4-7, 4-16]; enjoyable [3-8, 4-4]; high social participation [4-5]; suitable and tailored difficulty [3-9, 4-6, 4-12, 4-13]; safe [3-10]; good timing [3-21, 4-14] | Health and fall-related motives   * Motivation to maintain health facilitates risk screening and uptake [1-4, 3-3, 3-6, 4-1] * Previous experience of fall motivates uptake [3-1] * Experience of the physical ageing process motivates uptake [3-2] * Experience of intervention reducing falls risk and improving wider health motivates adherence [4-2, 4-3] * Lack of falls risk and ageing awareness impedes risk screening and uptake [1-8, 2-3, 3-15] |
| *Priority setting challenges*   * Prioritising access for socially deprived and ethnic minority subgroups [3-18, 3-19] * Prioritising access for vulnerable groups: complex comorbidities; cognitively impaired; socially isolated [6-1, 6-2, 6-3] * Where possible, needs of marginalised groups should be met without denying services to non-marginalised groups [3-27] | Funding and policy   * Health promotion in earlier life course stages [2-1] * Use of routine data to facilitate risk identification [1-1] * Alleviating time constraints in care routine practice [1-7] * Funding to remove private intervention costs [3-7, 3-20, 4-11], sustained over the long term [4-17] * Auxiliary implementation strategies: information to informal caregivers [2-2]; community marketing [3-4, 3-6]; peer health champions [3-5] | Psychosocial motives   * Psychosocial benefits of interventions motivating uptake and adherence: enjoyability [3-8, 4-4]; social participation [4-5] * Good professional-participant relationship facilitates adherence [4-9] |
| *Need/eligibility*   * Consider needs of chronically ill, frail and with comorbidities (who may be aged <65) [4-10, 6-1] * Identify appropriate interventions for cognitively impaired [6-2] * Consider targeting those living in vulnerable circumstances such as socially isolation [6-3] | Intersectoral policy   * Improve public spaces: safer and more health-promoting [5-1, 5-2] * Change incentives for landlords to modify homes [5-3] * Make transport cheaper and more accessible [3-23, 4-15] * Support community organisations and initiatives [5-4] | External influences on demand   * Older persons are receptive to auxiliary implementation strategies, including community marketing and peer recommendations [3-4, 3-5, 3-6] * Older persons are particularly receptive to professional recommendations [3-12, 3-14] |
| **Abbreviation:** CICI: Context and Implementation of Complex Interventions (CICI) framework [181]; HNA: Health Needs Assessment framework [190]  1 See Tables 2.2 and 2.3 for themes by falls prevention pathway component and Tables A1 and A2 in Appendix A for transcript quotes. | | |

#### 2.4.3.1 Context, priority setting and need/eligibility

The first column of Table 2.4 groups together the themes on context, priority setting and need/eligibility. Not all contextual domains in the CICI framework were identified; the five identified were socioeconomic, linguistic/ethnic, setting/geographical, legal/regulatory and cultural. The commissioner and stakeholders should discuss to what extent the contextual factors are modifiable via intersectoral policies (i.e., lie within the decision space). For example, the difficulty of making safety modifications to rented properties was mentioned several times:

(FG4) “And I couldn’t [modify my house] because I live in a rented property. It’s not mine. I’m not allowed to do anything.” (Theme [5-3])

This could potentially be addressed by new housing regulations that incentivise relevant action by landlords. The culture of communal responsibility could be enhanced to some extent by supporting community organisations and civic initiatives.

Several priority setting challenges emerged from the data. The commissioner should consider prioritising intervention access for several marginalised subgroups: socially deprived; ethnic minority; with complex comorbidities; cognitively impaired; and socially isolated. Ideally, the prioritisation should not come at the expense of reduced services for non-marginalised subgroups.

The commissioner may also decide to change the eligibility criteria for falls prevention according to local priorities. Currently, CG161 recommends community-based falls risk screening for those aged 65+, followed by referral to multifactorial intervention for those at high falls risk defined by falls history and abnormal gait/balance. The screening protocol can be expanded to include those with complex comorbidities who are aged less than 65; the risk factors examined for referral can similarly be expanded to cover frailty and non-health factors such as social isolation. A separate pathway may be designed for cognitively impaired persons who require tailored support from dedicated organisations:

(INT2) “But with these walks which are organised by the Alzheimer’s Society is that there are qualified people leading the walks.” (Theme [4-7])

#### 2.4.3.2 Supply

Older participants identified a broad range of supply-side issues and solutions at provider/organisation, funding/policy and intersectoral levels as shown in the second column of Table 2.4. The commissioner should determine which solutions lie within the decision space: e.g., certain professional attributes such as commandeering attitude may not be modifiable in the short run. Significant investments – e.g., a new falls clinic, changes to GP reimbursement schedule for risk screening – would similarly take time and be constrained by the budget.

#### 2.4.3.3 Demand

The last column of Table 2.4 arranges the demand-side themes by three types: health and fall-related motives of older persons; non-health and social motives; and external influences on demand. Importantly, the external influences are modifiable by using auxiliary implementation strategies (e.g., community marketing). Older persons are also receptive of professional recommendations; hence, this influence can be maximised by improving professional attributes such as awareness of community initiatives:

(FG3) “When I was having as many as things I’ve had, I had to see Professor [name] at Hallamshire [Teaching Hospital]. So actually, I sent him details of [Dance to Health] and he wrote me to send me a very brief letter back saying ‘Thank you for this. I think I can put this to my other patients who have got a similar thing.’” (Theme [3-13])

### 2.4.4 Framework (III): Challenges for public health economic modelling

Table 2.5 summarises the methodological and evaluative challenges for falls prevention economic model identified from the qualitative data (see also Figure A2 in Appendix A).

|  |  |
| --- | --- |
| **Table 2.5** Methodological and evaluative challenges for falls prevention economic modelling. | |
| *Methodological challenges [Theme #]1* | *Evaluative challenges [Theme #]* |
| Capturing non-health outcomes and societal intervention costs   * Model should capture social benefits of falls prevention interventions [3-8, 4-4, 4-5]. * Model should capture private intervention and transport costs [3-20, 3-23, 4-11]. * Model should capture any time opportunity cost to participants and informal caregivers: e.g., due to inconvenient timing or location [3-21, 4-14, 4-15]. | Perspective, type of analysis and time horizon   * Under CUA, the generic health utility measure such as EQ-5D may not fully capture social benefits of interventions [3-8, 4-4, 4-5]; the model should consider broader wellbeing measure (e.g., ICECAP-O [104, 105]) * Societal perspective is likely necessary to capture societal intervention costs [3-20, 3-23, 4-11]. * Long time horizons are required to capture dynamic trajectories and evaluate system changes incurring large sunk costs (e.g., [1-1, 1-3]). |
| Considering dynamic complexity   * Model should incorporate dynamic trajectories of ageing and falls risk influencing older person’s demand and appropriate professional response [1-4, 1-5, 3-2, 4-1]. * Model should capture the dynamic trajectories of variables that delineate vulnerable subgroups (e.g., cognitive status, frailty) [6-1, 6-2, 6-3]. * Model should capture wider health benefits of interventions beyond falls prevention [4-3]. * Model should incorporate seasonal changes in falls risk due to environmental risk factors [5-1]. | Types of intervention scenarios evaluated   * Main intervention scenario should incorporate: local eligibility criteria tailored to changing falls risk profile; external evidence on interventions which have similar characteristics as those preferred by local older persons.2 * Intervention costing should incorporate: cost of risk identification; cost of auxiliary implementation strategies; fixed/sunk costs for major system changes; cost of additional resources to achieve full set of positive intervention characteristics; cost of professional training to obtain positive attributes; and funding to sustain intervention over sufficiently long period.3 * Additional scenarios conducting value of implementation analyses to evaluate auxiliary implementation strategies [2-2, 3-4, 3-5, 3-6]. * Additional scenarios evaluating intersectoral policies (e.g., environmental interventions [5-1, 5-2]) and earlier life-course preventive interventions [2-1]. |
| Considering theories/models of human behaviour based on psychology and sociology   * Model should incorporate the health/social motives of older persons that influence demand [1-4, 3-1, 3-2, 3-3] * Model should incorporate sociological and contextual factors that influence falls prevention: cultural factors promoting/weakening communal responsibilities for health promotion and safety [5-1, 5-2, 5-4]; regulatory barriers [5-3]. |
| Considering social determinants of health   * Model should incorporate socioeconomic and ethnic/linguistic variables and social isolation as social determinants of health [3-18, 3-19, 6-3]. | Analysis of equity and other priority setting criteria   * Model should examine equity-efficiency trade-offs in adopting strategies that reduce social inequities of health [3-18, 3-19, 3-27, 6-3] or prioritise other vulnerable groups [4-10, 6-1, 6-2]. |
| **Abbreviation:** CCA: cost-consequence analysis; CUA: cost-utility analysis: ICECAP-O: ICEpop CAPability measure for Older people; NICE CG161: National Institute for Health and Care Excellence Clinical Guideline 161 [13].  1 See Tables 2.2 and 2.3 for themes by falls prevention pathway component and Tables A1 and A2 in Appendix A for transcript quotes.  2 Local decision-maker could set the eligibility criteria for falls prevention referral, e.g., to cover those aged less than 65 who have complex comorbidities [6-1]. The intervention strategy should accommodate the changing falls risk profile that necessitates different treatments over time [1-5]. Key intervention characteristics beyond cost are: staffing level [4-7, 4-16]; enjoyability [3-8, 4-4]; social participation [4-5]; suitable and tailored difficulty [3-9, 4-6, 4-12, 4-13]; safety [3-10]; and good timing [3-21, 4-14]. External evidence (e.g., efficacy from randomised controlled trial) should be sourced from interventions with these key characteristics.  3 Cost of risk identification includes the cost of conducting risk screening in GP routine practice [1-7]. Auxiliary implementation strategies include information provision to informal caregivers [2-2], community marketing [3-4, 3-6] and promotion of peer recommendations [3-5]. Major system changes include improvements to data systems [1-1] and new Falls Clinics [1-3]. Additional resources may be required to achieve the full set of positive intervention characteristics: e.g., hiring venues that are safe [3-22] and easy to reach [3-11, 3-23, 4-15]. Investment in training may increase the level of positive professional attributes including approachability [1-2]; awareness of community initiatives [3-13, 3-24]; person-centred care [3-14, 4-8]; and relationship-building with intervention participants [4-9]. Funding should be sustained until the intervention has had enough time to generate substantial results [4-17]. | |

#### 2.4.4.1 Methodological challenges

The data identified several non-health outcomes (e.g., social benefits of group exercise) and societal intervention costs (e.g., private intervention and transport costs, costs of venues donated by local church) which were important facilitators and barriers. No older person mentioned time opportunity cost imposed on him/herself or his/her caregiver from attending interventions; but such costs may be incurred if interventions are conducted in inconvenient times and venues and should thus be incorporated in the model.

The dynamic processes of ageing and falls risk progression, starting before the age of 65, were mentioned by some participants as motivating factors for intervention uptake/adherence; yet others perceived the emerging illnesses as major barriers:

(FG4) “Well, I used to go swimming a lot every week. But then, since a long period of illness, I stopped going.” (Theme [4-10])

Either way, the model should seek to capture the dynamic trajectories of physical capacity, functional status and health perception as key determinants of intervention demand. Moreover, the dynamic progression means that persons at different stages of the falls risk progression have different intervention needs; the model can quantify the added benefits of an intervention strategy that tailors treatments to progression stages relative to a strategy that does not. An example of the latter was perceived by older participants:

(INT2) “I think [the professionals] ought to check things like stairs and back steps. And not expect the older people to report it, because they are probably so used to these things when they’ve lived in the house all the time and are not necessarily aware of how less well coordinated they are from before.” (Theme [1-5])

Participants also highlighted wider health benefits of exercise beyond falls prevention, including improved mobility and mental health:

(FG2) “Lots of my family have noticed the difference in my posture, in my walk; things like, I used to struggle bending down, picking things up from the floor. It gets you down. It affects your mental health. So yeah, my family have noticed a huge difference.” (Theme [4-3])

Hence, the model should incorporate multiple simultaneous health effects of falls prevention exercise; if this proves too complex, then at least the fall’s impact on wider health and functional outcomes (e.g., on a multivariate frailty index [47]) should be incorporated to capture the full health benefits of falls prevention.

Finally, the model should incorporate key psychological and sociological factors identified from the qualitative data (e.g., health motives influencing demand) using relevant external quantitative data. Social determinants of health identified from the data included socioeconomic and ethnic/linguistic barriers to intervention access and social isolation as a marker of vulnerable subgroup.

#### 2.4.4.2 Evaluative challenges

Given the range of non-health outcomes and societal intervention costs, the model evaluation should consider using a broader wellbeing measure and taking the societal perspective [104, 105]. The model time horizon should be sufficiently long to capture the dynamic trajectories of key variables and the full health impact of interventions; large sunk costs incurred by intervention may also be evaluated over a longer horizon.

Several intervention scenarios emerged from the data that should be evaluated under base case analysis and alternative scenario analyses. All three prevention pathways – proactive, self-referred and reactive – were mentioned in the data (see theme [1-5] for participant discussion of a reactive HAM receipt), and hence should be considered in the base case analysis. The main intervention scenario (compared to usual care under base case analysis) should incorporate interventions that have some or all of the positive characteristics listed in Table 2.4, such as allowing individually tailored difficulty. Where external studies are used as data sources (e.g., RCT for efficacy), they should evaluate interventions with similar characteristics as the model scenario.

Intervention costing should incorporate not only the cost of intervention delivery but also the cost of auxiliary implementation strategies used to generate the given uptake and adherence; for the proactive pathway, the cost of professional risk screening and referral should be included. Major system-level changes (e.g., integrated data system for risk screening) would incur fixed/sunk costs which may be incorporated as annuitized overheads. Costs would be incurred if additional professional training and resources are required to obtain positive professional attributes and intervention features, respectively.

An alternative, heuristic method to directly incorporating psychological and sociological variables in the model is to conduct value of implementation analyses as alternative intervention scenarios [199]. Additional monetary value of the health and economic gains associated with hypothetical improvements in intervention uptake/adherence can be estimated without knowing what psychological or sociological factors contributed to the improvements. The additional value is the maximum amount that can be invested in auxiliary implementation strategies that produce the given improvements. An example in the literature is a model analysis that estimated an additional return of $2.79 million for a hypothetical scheme that raised the intervention uptake from 50% to 75% in a population of size 44,000 [200]. This represents an amount that can be invested in, say, community organisations that promote the uptake.

The lower intervention access for the socioeconomically deprived and ethnic minority subgroups would mean that the intervention is less cost-effective. A strategy that prioritises access for these groups to reduce social inequities of health (e.g., concentrating funding in deprived areas [theme 3-27]) would introduce an equity-efficiency trade-off. The model should parameterise the causal mechanisms to quantify the trade-off; the strategy would be accepted if stakeholders find the trade-off to be reasonable [109]. A similar process of equity-efficiency evaluation can be applied to other vulnerable subgroups identified, i.e., those with complex comorbidities and cognitive impairment.

## 2.5 Discussion

This chapter explored older people’s views on facilitators and barriers for implementing the community-based falls prevention pathway recommended by NICE as well as broader themes on raising falls risk awareness, intersectoral initiatives and prioritisation of vulnerable groups. Participants included service users and non-users and those at high and low risks of falling. The chapter also explored how the identified themes can be mapped on to frameworks that can inform commissioning decisions via a *de novo* falls prevention economic model. It was thereby shown that the framework analysis approach [191] can flexibly accommodate diverse frameworks according to research aims.

The methods and results of this chapter contribute to the growing field of research exploring how qualitative evidence can be used to inform HTA [187]. The recent NICE Decision Support Unit (DSU) report, for example, critiques the limited consideration of qualitative evidence in the current NICE Methods Guide (PMG9) and sees the use of established, purpose-specific frameworks – including the CICI framework – as a tool for an accelerated and standardised incorporation of qualitative evidence in the HTA decision-making process [187]. This chapter showed that the CICI framework, despite its focus on supply-side conditions, can be applied to service users and eligible non-users. Previous qualitative studies have indeed shown that older people are sensitive to supply-side issues including cultural-linguistic context of intervention, professional attributes and intervention characteristics [142, 192, 201, 202], making their views highly relevant to commissioning decisions that must consider how the supply-side conditions are perceived and accepted by service users. This chapter facilitated attention on users’ perception and demand by supplementing the CICI with the HNA framework that conceptualises intervention access as an outcome of interactions between demand, supply, and normative need. Such flexible adaptation of the CICI framework is encouraged by the framework developers [181]. Moreover, both the CICI framework developers and the DSU report focus on the application of CICI to qualitative and mixed-methods systematic reviews and not to primary qualitative research [181, 187]; by applying the framework to the latter, this chapter demonstrates the wider potential reach of the framework.

This chapter also showed that the primary qualitative research on service users can identify the key methodological and evaluative challenges to public health economic evaluation and thus prospectively inform falls prevention economic modelling [1]. Retrospective application would be equally valuable to explore whether an intervention approved by national-level HTA can be implemented fully within three months by local decision-makers (recommendation 1.5.1) [154]. The local qualitative evidence can identify such barriers and anticipate any major differences in the local cost-effectiveness and population-level outcomes relative to those predicted by the HTA. The decision model(s) underlying the HTA approval can also be critiqued based on the methodological and evaluative challenges identified by the local evidence. If the model performs poorly in addressing the challenges, then a *de novo* model development is warranted, making prospective use of the qualitative data.

The holistic approach to exploring the falls prevention facilitators/barriers identified two cross-component factors: health motives of older persons; and professional competence. The role of health motives in influencing older persons’ health behaviour has been debated in the literature. One study in Scotland found that older people are unlikely to participate in exercise for health reasons but rather for the social rewards [203]; while another found that health motives (e.g., maintaining functional independence) help translate intentions into actual change in health behaviour [189]. This study found that health motives operate alongside the social rewards of interventions which corroborates the findings of a previous qualitative systematic review of older persons’ views [201]. CG161 similarly recognises both factors and recommends that care professionals provide information on the physical benefits of modifying falls risk to older persons and caregivers (recommendation 1.1.10.2), while also promoting the social values of interventions (1.1.9.2) [13].

The absolute and relative strengths of health and non-health motives impact the final combination of intervention characteristics and auxiliary implementation strategies: for example, strengthening the health motives would require well-framed health messaging [197], while addressing the non-health/social motives is a matter of better intervention design. Commissioners should note the wide diversity of motives/preferences in the older population: one survey of 134 older persons, for example, found that 46% preferred to exercise alone versus 44% in a group [204]. Importantly, the group setting may be less preferred by marginalised social groups (theme [3-18]); alternative intervention types, such as home-based digital falls prevention exercise taken up at home [205], may be considered.

The importance of the second cross-component factor, professional competence, is affirmed by CG161 which recommends that all healthcare professionals regularly dealing with older persons “develop and maintain basic professional competence in falls assessment and prevention” (1.1.10.1) [13]. Yet older participants perceived external constraints placed even on competent professionals, including time constraints. This corroborates the findings from a previous survey of English GPs which specified insufficient consultation time and lack of allied health professionals in the community as the most prominent barriers to implementing CG161 [139]. Therefore, commissioning should comprehensively account for care system bottlenecks and carefully cost the solutions for their removal. One economic model, for example, incorporated the cost of a citywide falls risk screening that was assumed to operate like a cancer screening programme [206]. Costs that are fixed/sunk would interact with uptake rate to produce worse cost-effectiveness if uptake is inadequate [207], and economies of scale if uptake is increased [206]. Hence, models should accurately portray the cost structure (fixed vs. variable) to characterise the impact of implementation quality on cost-effectiveness. Aggregate population-level health and economic impacts should also be presented by models to quantify the full impacts of implementation strategies as recommended by NICE PMG9 (recommendations 5.12.3) [154].

Less emphasised in CG161 but visible in the qualitative data (e.g., theme [4-16]) is the role of nonclinical professionals and volunteers who can substantially influence both supply and demand given their proximity to older persons in the community [208]: a pilot falls prevention scheme in Sheffield, for example, found that falls risk screening conducted at local community groups and lunch clubs significantly increased uptake [209]. It is hence critical to value the nonclinical and volunteer contributions; and value of implementation analysis offers a heuristic method to that end [199]. The monetary value of improved implementation can be combined with qualitative data on demand-side influences to devise a cost-effective implementation strategy.

The methodological approach in this chapter is highly relevant outside the falls prevention context. Geriatric public health interventions seek to implement person-centred care, handle population-level heterogeneity, achieve high integration, and devise coherent implementation strategies (Section 1.3.2). The qualitative research in this chapter charted older persons’ views on the importance of receiving holistic person-centred care (e.g., theme [1-6]), accounting for vulnerable population subgroups, integrating clinical falls prevention services with environmental and communitarian approaches, and identifying key facilitators and barriers to implementation. Therefore, the same framework analysis could inform the commissioning and economic modelling of further geriatric public health interventions. Indeed, the CICI-HNA and the public health economic modelling categories adopted by frameworks (II) and (III) and applicable to all age groups.

A key strength of the qualitative study in this chapter is the simultaneous coverage of three frameworks – i.e., cross-component factors, intervention-related causal mechanisms, and public health modelling challenges. As mentioned, qualitative research and economic evaluation are typically siloed with no interdisciplinary learning [146, 193, 194]. By contrast, this study explores how qualitative data can directly inform model-based economic evaluation.

The study nevertheless has limitations. The purposive sampling could have accounted for social categories such as area-level deprivation, particularly given the importance of social determinants of falls prevention access. The sampling was concentrated around older persons living near the Sheffield city centre, meaning that persons living in rural suburbs were under-represented. Falls prevention service users were recruited mainly from Dance to Health group exercise programme, meaning that other service types were under-represented. Only six participants (22%) reported no current/previous use of services with falls prevention properties, meaning that views of service non-users were under-represented. Moreover, the sampling did not distinguish between service non-users and those who had rejected falls prevention who would have had significantly different views. Finally, informal caregivers’ views could have been elicited given their central role in facilitating falls prevention [210].

## 2.6 Conclusion and chapter summary

A better understanding of older persons’ health motives and higher professional competence can improve the implementation of the NICE-recommended falls prevention pathway. Older persons are sensitive to implementation causal mechanisms, meaning that their views can inform contextual and supply-side changes to promote falls prevention and wider health promotion. They are also important stakeholders for the development of the falls prevention economic model, specifically for conceptualising the model structure and identifying commissioning strategies to evaluate in the final model. The wide prevalence of the same issues (e.g., the need for high service integration) in the commissioning of other public health interventions means that the methodology in this chapter should be replicated in further public health decision problems.

Yet local older persons are not the only relevant stakeholder group for falls prevention model conceptualisation. The next chapter places this qualitative research within a broader conceptualisation process involving literature reviews and consultations of local commissioners and professionals.

# Chapter 3. Understanding the Problem for Falls Prevention Economic Model Development (Conceptual Model)

## 3.1 Chapter outline

The development of a health economic decision model should commence by understanding and conceptualising the decision problem and setting the model structure [1, 211]. The conceptual model differs from the final implemented model in that it is unconstrained by data availability or technical competency of the analyst. Accordingly, the conceptual model can consider the full range of relevant causal mechanisms and set a comprehensive boundary within which the final model is parameterised. This chapter presents the conceptual model that will underpin the development and analysis of the final falls prevention model in Chapters 5 and 6. The conceptual model incorporates the results of the qualitative research presented in Chapter 2. It will also inform how previous falls prevention models are appraised in Chapter 4.

Section 3.2 outlines the conceptual modelling method that follows the phases and principles proposed by Squires and colleagues [1]. The subsequent sections address each of the development phases: Section 3.3 describes the processes of engaging local stakeholders to contextualise the decision problem. Sections 3.4 and 3.5 further clarify the nature of the decision problem. Section 3.6 conceptualises the major causal links in falls epidemiology. Section 3.7 conceptualises the current and recommended falls prevention strategies based on stakeholder inputs, guideline recommendations and wider literature, as well as alternative intervention strategies to be comparatively evaluated. Section 3.8 discusses the conceptual model and the strengths and limitations of the approach used.

## 3.2 Methods for developing the falls prevention conceptual model

Squires and colleagues lay out four phases to public health economic model development [1]:

1. Aligning the framework with the decision-making process
2. Identifying relevant stakeholders
3. Understanding the problem
4. Developing and justifying the model structure

Phase (A) sets the foundation for the modelling project, selecting the modes of stakeholder engagement, evidence searching, time/resource allocation, and documentation. For Phase (B), a relevant stakeholder is “any person who impacts on or is impacted upon in the system” (p. 5) [1]. Stakeholders together help define the model scope, make value judgements, recommend assumptions on model structure and choose interventions to be evaluated. They can be divided into three types: (i) system owners – e.g., CCG and City Council commissioners; (ii) actors in the system – e.g., falls prevention clinical experts and falls modelling experts; and (iii) customers of the interventions – e.g., older persons and their informal caregivers. Outcomes of Phases (A) and (B) are reported in Section 3.3.

Phase (C) is divided into two parts: (I) developing a conceptual model of the problem that describes the hypothesised causal relationships based on the project scope, literature and stakeholder inputs; and (II) describing the present resource pathway in the decision-making setting. Part (I) can be formulated as a series of questions and activities:

* 1. What is the problem?
  2. Why is this a problem?
  3. Identifying causal links in the disease process
  4. Identifying relevant interventions

Sections 3.4 to 3.7 address each of these questions and activities in sequence. Part (II) of Phase (C) is addressed alongside activity (4).

The methods and results for Phase (D) are reported in Chapter 5. Phase (D) also involves a review of existing models in the problem area [1]. This review is conducted and reported in Chapter 4.

For all phases, Squires and colleagues highlight the following principles: (a) systems approach to modelling – e.g., identifying elements contributing to dynamic complexity; (b) documented understanding of the problem before and alongside developing and justifying the model structure; (c) strong communication with stakeholders; and (d) systematic consideration of the determinants of health including demographic, lifestyle, socioeconomic, and environmental factors [1]. Accordingly, relevant documents for the conceptual model development are collated in Appendix B.

## 3.3 Understanding the local context for model development

This section addresses Phases (A) (aligning the framework with the decision-making process) and (B) (identifying relevant stakeholders). Because several key stakeholders were involved in the project from the outset (prior to the detailed framework alignment), the stakeholder identification under Phase (B) is described first (Section 3.3.1). The steps within Phase (A) are then described [1]: choosing the mode of stakeholder engagement (Section 3.3.2); establishing approaches to evidence searching (Section 3.3.3); and establishing resource availability and producing a protocol document (Section 3.3.4).

### 3.3.1 Identifying relevant local stakeholders

Table 3.1 lists the stakeholders who were involved in model conceptualisation. The Sheffield City Council (SCC) Public Health Principal (PHP) was involved in the project from the outset, suggesting ways in which economic modelling could assist commissioning decisions, establishing contacts with other system owners and actors, and serving as the main point of contact. Further system owners and actors were identified by snowballing from the initial group and from professional networks of the PhD researcher’s supervisors. The relevant system actors changed as the understanding of the decision problem transitioned from that of evaluating a specific multi-need integrated care scheme in Sheffield to evaluating a programme of community-based falls prevention (see Section 3.4 below).

For customers of the intervention – i.e., older users and eligible non-users of falls prevention services – a formal qualitative research was conducted as described already in Chapter 2. Table 3.1 also acknowledges the contributions of independent scientific reviewers who provided written and oral feedback on the conceptual model during the research ethics applications and confirmation review.

|  |  |  |
| --- | --- | --- |
| **Table 3.1** Stakeholder types and members for falls prevention conceptual model development. | | |
| **Stakeholder type** | **Stakeholder** | **Mode of engagement** |
| System owners | * Sheffield City Council Public Health Principal * Sheffield City Council health economist * Sheffield CCG commissioners: Chief Nurse; Commissioning director * Sheffield CCG data scientist | Face-to-face meetings and phone and email exchanges |
| Actors in the system – integrated care | * Managers of social prescribing organisations in Sheffield * Age UK Sheffield | Face-to-face meetings |
| Actors in the system – falls prevention | * Sheffield Falls Clinic falls specialist geriatrician * Sheffield Falls Clinic multidisciplinary team * PT and OT leads in Sheffield Teaching Hospitals * Dance to Health – falls prevention service provider * Age UK Sheffield – falls prevention service provider * Falls modelling expert | Face-to-face and online meetings |
| Customers of the intervention | * Older persons in Sheffield * Age UK Sheffield – representing older persons | Face-to-face focus groups, interviews and meetings |
| Independent scientific reviewers | * Two health economics modelling experts * One health services research expert | Face-to-face meetings and document feedbacks |
| **Abbreviation:** CCG: Clinical Commissioning Group; OT: occupational therapy; PT: physiotherapy | | |

Regarding the motivations for participating in the conceptualisation process, the system owners, actors and customers of falls prevention commonly sought to improve the local service quality and volume. In addition, system owners had a strategic vision for integrating complex services to achieve efficiency and quality and improving local analytic capacity (see Section 3.4.1 below).

### 3.3.2 Choosing the mode of stakeholder engagement

Table 3.1 also describes the modes of stakeholder engagement. It emerged at the early project stage (October 2018) that regular face-to-face stakeholder workshops would prove impractical for most stakeholders, particularly those engaged in full-time clinical practice. For example, the multidisciplinary team at the Sheffield Falls Clinic declined to participate in regular workshops because no guarantee could be made that the Sheffield CCG would adopt the workshop recommendations. Therefore, the mode of engagement was kept flexible to accommodate individual stakeholders’ schedule and commitment. This mainly involved one-to-one face-to-face or phone conversations. That said, several group meetings did take place at early project stages:

1. June 2018: Face-to-face meeting with managers of community organisations involved in social prescribing and SCC PHP and SCC health economist.
2. October 2018: Face-to-face Falls Planning Group meeting with the Sheffield CCG commissioners and data scientist, SCC PHP and the falls modelling expert.
3. January 2019: Face-to-face meeting with managers and care workers at Age UK Sheffield.
4. March 2019: Online meeting with managers of Dance to Health – an organisation providing dance-based falls prevention exercises for older persons in the community [195] – and an independent evaluator of Dance to Health [196].
5. April 2019: Face-to-face meeting with physiotherapy (PT) and occupational therapy (OT) leads at Sheffield Teaching Hospitals.
6. October 2019 – January 2020: Qualitative research focus groups with older persons in Sheffield.

### 3.3.3 Establishing approaches to evidence searching

The evidence searching approaches for model conceptualisation can be grouped into four: (1) stakeholder consultation; (2) systematic literature review – i.e., using explicit, systematic database search strategies; (3) general (non-systematic) literature review; and (4) primary data analysis. Table 3.2 shows how the approaches contributed to each conceptualisation phase or aspect.

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| **Table 3.2** Summary of evidence searching approaches for model conceptualisation. | | |
| **Conceptualisation phase** | **Evidence searching approach** | **Detail** |
| Economic evaluation of integrated care | Stakeholder consultation | * May-June 2018 discussions with SCC PHP on Active Support & Recovery integrated care scheme. * June 2018 meeting with social prescribing organisations to discuss the decision problem around community-based integrated care. |
| General literature review | * UK/Sheffield policy documents: e.g., [212, 213] * Scope of geriatric integrated care: e.g., [97] * Range of outcomes and study designs: e.g., [118] * Range of efficacy evidence: e.g., [214] * Potential modelling strategies: e.g., [215] * Challenges in evaluating integrated care schemes: [121] |
| Economic evaluation of falls prevention – initial scoping | Stakeholder consultation | * October 2018 Falls Planning Group meeting with CCG commissioners, PHP and falls modelling expert on relevance of Public Health England falls prevention model [216] for local decision-making * Discussion with PHP on target population, type of analysis, perspective, evaluation time horizon and CCG routine data access |
| General literature review | * UK guidelines on community-based falls prevention: [13, 129, 143, 146] * Cochrane systematic reviews of falls prevention RCTs: e.g., [124, 126] |
| Falls epidemiology | Stakeholder consultation | * October 2018 meeting with falls specialist geriatrician on major falls risk factors and health consequences |
| General literature review | * Range of falls risk factors: e.g., [43, 146, 217] * Range of health and economic consequences of falls: e.g., [30, 60, 218] * Use of routine data for falls risk analyses: e.g., [44, 47] |
| Primary data analysis | * Analysis of ELSA data on risk factors for MA and non-MA falls |
| Falls prevention strategy | Stakeholder consultation1 | * October 2018: observed multifactorial intervention at Sheffield falls clinic * January 2019 meeting with Age UK on home visit falls prevention services * April 2019 meeting with PT and OT leads of STH on current falls prevention pathways * May 2019: observed Dance to Health sessions and met with Dance to Health management |
| Systematic literature review | * July 2019 systematic review of community-based falls prevention RCTs2 (identified studies combined with those from previous systematic reviews) |
| General literature review | * Falls prevention guidelines:1 [13, 113, 130, 143, 146, 219] * Report on Sheffield Perfect Patient Pathway [209] * Previous systematic reviews of community-based falls prevention RCTs: e.g., [124-126, 220] * Literature on falls prevention facilitators and barriers: e.g., [141] * Falls prevention in broader geriatric health promotion context: e.g., [2, 93] |
| Primary data analysis | * Qualitative research with older persons in Sheffield on facilitators and barriers to implementing NICE falls prevention guideline3 |
| Modelling features | Stakeholder consultation | * October 2018 meeting with falls modelling expert on modelling challenges * November 2018 independent scientific review on preliminary conceptual model * March 2019 meeting with SCC health economist on modelling to address local decision problems * September 2019 meeting with SCC PHP and CCG data scientist on modelling with CCG routine data |
| Systematic literature review | * Systematic review of falls prevention economic models:4 how decision problem was conceptualised |
| General literature review | * Expert guideline on falls prevention economic evaluation [105] * Methodological challenges to public health economic modelling [18] * Problem conceptualisation for models incorporating capacity constraints: e.g., [221, 222] |
| Primary data analysis | * Qualitative research with older persons in Sheffield on key methodological and evaluative challenges for falls prevention economic modelling.3 |
| **Abbreviation:** CCG: clinical commissioning group; ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; NICE: National Institute for Health and Care Excellence; PHP: Public Health Principal; RCT: randomised controlled trial; SCC: Sheffield City Council; STH: Sheffield Teaching Hospitals  1 Stakeholder consultations and UK guidelines on community-based falls prevention were used to conceptualise the ‘recommended’ falls prevention strategy. Stakeholder consultations were used to understand the current ‘usual care’.  2 See Section 5.2.1.4 for methods and results.  3 See Chapter 2 for methods and results. Qualitative research with falls prevention professionals in Sheffield was also initially planned but not conducted due to the Covid-19 pandemic.  4 This systematic review was initially conducted in January 2019 in preparation for the PhD confirmation review and then updated in January 2021: see Chapter 4 for methods and results. The initial review informed the model conceptualisation while the update was conducted as part of Phase D of model development [1]. | | |

The project initially commenced with the aim of conducting an economic evaluation of a geriatric integrated care scheme in Sheffield (see Section 3.4.1). At this early stage, stakeholder consultations and general literature review were used to understand the scope of the decision problem. For example, a meeting with social prescribing organisations in Sheffield discussed how the public and voluntary sectors could coordinate referrals and whether computer models could simulate the process. Review of academic and grey literature surveyed the scope of integrated care [97], type and volume of evidence [118, 214], potential modelling strategies [215], and challenges to evaluation [121].

When the decision problem was subsequently reformulated to economic modelling of community-based falls prevention, the initial scoping of the problem similarly involved stakeholder consultations and general literature review. The Falls Planning Group meeting was the first discussion between system owners, the falls modelling expert, and the PhD researcher on the decision problem. The general literature review covered UK guidelines on community-based falls prevention, the Cochrane systematic reviews on falls prevention RCTs, and several existing falls prevention economic models [147].

Subsequent, more detailed evidence searching partitioned the focus areas into falls epidemiology, falls prevention interventions, and modelling features. Consultations with falls prevention professionals – the falls specialist geriatrician, PT and OT leads at Sheffield Teaching Hospitals, home visit professionals at Age UK, and Dance to Health managers and instructors – contributed to the understanding of both falls epidemiology and intervention. A systematic review of community-based falls prevention RCTs was conducted to understand the most up-to-date range of intervention evidence. No systematic review was conducted for falls epidemiology, and the epidemiological evidence was based mainly on existing systematic reviews (e.g., on falls risk factors [43]). Epidemiological evidence was also sourced from a primary analysis of the English Longitudinal Survey of Ageing (ELSA) data.

Challenges to model conceptualisation and operationalisation were discussed from early project stages. The Falls Planning Group meeting discussed the relevance of outputs from the Public Health England model [216] for decision-making. This was supplemented by further consultations with the falls modelling expert at ScHARR and the SCC health economist and independent scientific review by another expert modeller. Because the decision problem had initially been framed as one of capacity shortage in falls prevention, the literature on capacity modelling were also consulted [221, 222]. The systematic methodological review on relevant modelling challenges was similarly consulted [18].

### 3.3.4 Establishing time and resource availability and producing a protocol document

The protocol document was produced in September 2018 based on initial stakeholder discussions with the PHP and the literature on falls prevention and integrated care. This detailed the time and resources available for the modelling project and contained a conceptual model diagram and a logic model illustrating the preliminary understanding of the problem. It thus framed further discussions with stakeholders until June 2019.

## 3.4 What is the problem?

The nature of the decision problem changed as the project progressed; this section describes its transition from economic evaluation of a multi-need integrated care scheme (Section 3.4.1) to economic evaluation of a programme of community-based falls prevention (Section 3.4.2).

### 3.4.1 Economic evaluation of integrated care

Initial discussions with system owners in Sheffield focused on the need to evaluate a local integrated care scheme (described in Section 3.4.1.1) while also improving the local analytic capacity to evaluate commissioning decisions (Section 3.4.1.2). But the focus shifted as difficulties were encountered in defining a concrete decision problem for the integrated care evaluation (Section 3.4.1.3).

#### 3.4.1.1 Integrated care scheme in Sheffield

The main integrated care programme in Sheffield is the Better Care Fund (BCF) initiative. As noted in Section 1.3.2.3, BCF is a cross-ministry initiative that obliges and funds (£6.4 billion in 2019-20) the integration of health and social care services and budgets at the CCG and local authority level [119]. BCF thus primarily focuses on financial and administrative integration between health and social care sectors. Accordingly, Sheffield CCG and SCC have invested £362 million towards integration since 2014 (see Document 1 in Appendix B for context) and have devised component integrated care schemes, including the Active Support & Recovery (AS&R) scheme that targets the older population [212].

The aim of AS&R is “to improve the quality, efficiency and volume of care provided outside of hospital” (p. 2) [212]. The ‘Neighbourhood teams’ of GP practices, social care services and the voluntary sector would design services, mobilise relevant community assets, and address “all determinants of health such as biopsychosocial and environmental factors, not just healthcare” (p. 6) [212]. The ‘essential outcomes’ include: reduction in number of hospital (re-)admissions and length of stay; efficiency savings in service delivery; increase in the proportion of people receiving holistic, person-centred care in community; and reduction in the number of long-term care admissions (p. 3) [212]. Patient-reported outcome measures such as health utilities were not mentioned, but the last two essential outcomes indicate decision-makers’ commitment to protecting the functional independence of older persons.

#### 3.4.1.2 Improving local analytic capacity

The Sheffield system owners also wanted a proactive analysis of their routine data which had recently been created by linking the NHS health records kept by the CCG and the social care records kept by SCC for the purpose of evaluating integrated care schemes. The aims were to increase not only the local relevance of specific evaluation outputs but also: (i) the analytic capacity of local decision-makers to identify public health problems and evaluate potential solutions using readily available and comprehensive routine data; and (ii) the collaboration between academic research and local decision-making. These aims were maintained when the decision problem transitioned to falls prevention; but problems were encountered in accessing the routine data, and the aims were not subsequently pursued.

#### 3.4.1.3 Difficulties in evaluating the local integrated care scheme

The main difficulty in conceptualising the model boundary for the evaluation of Sheffield AS&R was the lack (at least in late 2018) of a clearly defined public health decision problem. Specifically, the aim of AS&R was interpreted narrowly to consist of improving service efficiency rather than in addressing one or more “determinants of health such as biopsychosocial and environmental factors, not just healthcare” (p. 6) [212]. This can be seen in Table 3.3 that lists the range of intervention components that were part of the proposed AS&R scheme in June 2018.

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| **Table 3.3** Intervention components within the prospective Sheffield Active Support & Recovery scheme in June 2018. | |
| **Commissioned by Sheffield NHS CCG** | **Commissioned by Sheffield City Council** |
| ‘Community at Night’ integrated care team | Short Term Intervention Team (STIT) – community support workers |
| Intensive home nursing service | Community reablement services |
| Community Intermediate Care Service (CICS) | Intermediate care assessment teams |
| Intermediate care beds for stroke and orthogeriatrics |  |
| Single Point of Access (SPA) – 24/7 multidisciplinary response team |  |
| Length of stay and discharge team |  |
| Falls prevention service |  |
| **Abbreviation:** CCG: Clinical Commissioning Group | |

The list contains diverse professional-led teams with no specific geriatric public health objectives (except for stroke and orthogeriatric beds and falls prevention service) but rather concerns the capacity to deliver general geriatric care in an out-of-hospital setting.[[2]](#footnote-2) Moreover, the focus is largely on post-discharge rehabilitation (e.g., CICS and STIT were both intermediate care teams) rather than on primary prevention. Therefore, the appropriate study design for AS&R appeared to be an economic evaluation alongside a short-term quasi- or non-experimental (e.g., propensity score matching) intervention study using the CCG routine data, such as the evaluation conducted using the Hospital Episode Statistics for all English BCF initiatives in 2014/15 [163]. Such design did not match the commitment in this research to studying the broad determinants of geriatric health and evaluating the long-term impact of interventions via decision modelling.

Furthermore, even if such single-vehicle evaluation were undertaken, it would face several challenges highlighted by integrated care evaluation experts [121], namely: (a) ‘problem with the [therapeutic] model’; and (b) ‘problem with evaluation’. Problem (a) concerns the lack of clear understanding on which components and mechanisms of the combined scheme contributes to the desired effect, while problem (b) concerns the often too-short time horizon of primary evaluations. For AS&R, problem (a) is particularly acute since the scheme combines several components without prior exploration of their individual effectiveness.

Therefore, a joint decision was made with system owners in July 2018 to focus on evaluating the falls prevention aspect of AS&R, while also extending the problem boundary beyond post-discharge rehabilitation to understanding the full range and trajectories of falls risk factors and other intervention strategies involving primary prevention.

### 3.4.2 Economic evaluation of community-based falls prevention

Evaluation of community-based falls prevention inherits the core objectives of AS&R, namely: reduction of public sector acute and LTC costs; provision of holistic person-centred care in out-of-hospital setting; maintaining independence of older people (e.g., preventing permanent LTC admissions); addressing wide determinants of falls risk and falls severity; and active participation of clinical and nonclinical community members in service design and implementation. The community focus excluded falls prevention initiatives in LTC and hospital inpatient settings despite these being major falls prevention arenas [223, 224]. The PHP asked for the starting age of the geriatric target population to be set as low as possible to promote primary prevention (Document 2 in Appendix B). The Sheffield commissioners oversee a geographical jurisdiction rather than a specific cohort (e.g., those aged 60+ in year 2021); the target population hence includes community-dwelling cohorts who newly enter the target age range during the analysis horizon.

The preferred evaluation framework for the CCG and SCC was ROI from the public sector perspective over a time horizon of five years [144, 216]. This was confirmed by the PHP, CCG commissioners and SCC health economist (Documents 3-5 in Appendix B). That said, the PHP confirmed that the model-based evaluation need not be confined to this organisational mandate and should track wider outcomes over a longer time horizon. This is arguably more consistent with the objectives of AS&R to provide holistic person-centred care and maintain independence of older people; various health and wellbeing outcomes should be measured to track progress towards these objectives. Hence, the primary evaluation framework for the model will be CUA over a 40-year horizon (i.e., near lifetime for the initial cohort aged 60+ at model baseline, though not for newly incoming cohorts) and societal perspective to track non-health outcomes and societal intervention costs incurred outside the public sector. The five-year ROI outcomes are presented under the secondary evaluation framework.

## 3.5 Why is this a problem?

The rationale for community-based fall prevention was outlined in Section 1.3, particularly Sections 1.3.1 and 1.3.3. This section further analyses the rationale via a conceptual model in Figure 3.1 and arranges the concepts by the following themes: (1) outcome range of falls and falls prevention (Section 3.5.1); (2) heterogeneity and dynamic complexity (Section 3.5.2); (3) behavioural factors and implementation challenges (Section 3.5.3); and (4) issues of equity (Section 3.5.4).

Diagram

Description automatically generated

**Figure 3.1** Conceptual model of the decision problem for community-based falls prevention. **Abbreviation:** PS: public sector; QALY: quality-adjusted life year.

### 3.5.1 Outcome range of falls and falls prevention

The first key rationale for falls prevention lies in the diverse adverse impacts of falls older persons, care systems and wider society. As noted in Figure 3.1, falls have acute impacts on health, wellbeing (i.e., non-health aspects of quality of life not or poorly captured by health utility measures [104]), public sector care systems and wider society. These are supplemented by the secondary effects via progression in ‘propagator’ variables. The secondary effects determine the long-term levels of QALY, wellbeing and comorbidity care costs. In Figure 1.1, frailty was illustrated as the main propagator, and the falls-frailty relationship was highlighted by stakeholders at an early project stage (Document 6 in Appendix B). Section 3.6 below considers further propagators such as fear of falling.

Particularly significant are the non-health outcomes of falls which expand the problem boundary beyond that typically overseen by the healthcare decision-makers. Prominent non-health outcomes of falls include: reduction in social wellbeing [225-227]; OOP care expenditures (around 12% of annual care costs of fallers) [75]; loss in paid and unpaid productivity [83, 91] and the related loss in older persons’ wellbeing [228]; and informal caregiver cost (around 22% of annual care costs of fallers) [85] and health-related stress [229], particularly for old/frail caregivers [81, 82, 230]. As noted in Section 1.3.2.1, how these outcomes are experienced at the individual level – e.g., number of persons enjoying some decent level of capability [231], fair innings [232], or financial protection [72] – may be more consistent with the principles of person-centred care than the population-level aggregate.

Meanwhile, falls prevention also incurs costs accrued outside the healthcare system and these must be balanced against the non-health, societal outcomes of falls. These costs include: social stigma in falls prevention participation, particularly in contexts where geriatric health promotion is uncommon [201] (but participation can also bring social benefits [233]); private co-payments and costs (e.g., for transport); and time opportunity costs for participants and accompanying caregivers [234, 235]. Falls prevention may also bring benefits that chiefly accrue to the community rather than to individuals [236-238]; for example, community-wide participation can strengthen the community’s ability to organise other health promotion initiatives. The communal benefits should be weighed against the resources invested for social mobilisation, particularly those not reimbursed by the public sector (e.g., volunteer labour). These non-health outcomes and related societal intervention costs are summarised in Table 3.4.

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| **Table 3.4** Non-health outcomes and societal intervention costs of falls and falls prevention. | | |
| **Category** | **Non-health outcome** | **Societal intervention cost** |
| (1) Older persons’ social wellbeing | Social wellbeing affected by falls and comorbidities;1 intervention process benefits on wellbeing. | Intervention process costs (e.g., stigma) |
| (2) Personal finance | Out-of-pocket care expenditure due to falls and comorbidities1 | Private co-payment for intervention (e.g., session fee, equipment, transport) |
| (3) Productivity | Productivity loss due to falls and comorbidities1 | Time opportunity cost of older participants and volunteers |
| (4) Informal caregiving | Informal caregiver burden (productivity loss, health loss) due to falls and comorbidities;1 process benefit of informal care receipt; process benefit of joint intervention attendance for participant and caregiver | Time opportunity cost of informal caregivers attending intervention |
| (5) Common good | Community empowerment through intervention and other participations. | Financial and non-financial cost of social mobilisation |
| 1 These would be reduced by falls prevention intervention; the reductions would count as positive non-health benefits. | | |

In the Sheffield context, a key objective of AS&R is to prevent permanent institutionalisation that removes the older person from his/her social network. The qualitative research participants emphasised the social benefits of falls prevention, particularly group exercise, and did not report any social stigma associated with participation (Table 2.5). They also mentioned private intervention co-payments including transport costs as barriers to uptake and adherence. Other highlighted barriers included inconvenient timing and location which likely introduce time opportunity cost to participation. A key aim of AS&R is to mobilise relevant community assets including the voluntary sector to implement prevention; hence, community empowerment via falls prevention is an important process outcome. Overall, the diverse adverse impacts of falls build a case for prevention, but the benefits of prevention should be weighed against the diverse range of costs involved.

### 3.5.2 Heterogeneity and dynamic complexity

Figure 3.1 notes the influence of diverse target population characteristics, including sociodemographic, intrinsic and environmental factors, on the multifactorial falls risk profile (see Section 3.6 for the range of key falls risk factors). This introduces significant heterogeneity in falls risk and severity and endows further complexity to the falls prevention commissioning. The latter would need to account for variations in intervention need, access, cost and efficacy across population subgroups [239, 240]. The conceptual model also notes the influence of target population characteristics on background outcome progressions. These outcomes are not affected by the primary or secondary effects of falls but nevertheless influence the final evaluation outcomes. The underlying difference in life expectancy between socioeconomic subgroups, for example, could introduce a potentially unfair difference in the volume of QALY each subgroup can derive from falls prevention that improves the health utility level – henceforth referred as the life expectancy differential (LED) problem [241].

Dynamic complexity arises from intertemporal interactions between causal mechanisms and further increases the heterogeneity between individuals and subgroups over time (p. 42) [160]. A small variation in personal or environmental determinant can yield substantial differences in long-term outcomes through feedback loops [18]. Indeed, central to the conceptual model is the cyclical ‘Falls feedback loop’ in Figure 3.1 that generates the secondary effects of falls and influences subsequent falls risk and severity and falls prevention access, cost and efficacy.

In the Sheffield context, stakeholders suggested several factors relevant to heterogeneity and dynamic complexity. Multivariate frailty was highlighted as a better indicator of falls risk heterogeneity than age and sex (Document 6 in Appendix B), as were intrinsic physical capacity variables such as gait impairment that are currently used as falls risk screening tools (Document 7). Physical activity level was highlighted as a key subgroup characteristic for planning health promotion initiatives (Document 5). The qualitative data identified several vulnerable subgroups that should be prioritised by commissioning; these were delineated by comorbidity levels (i.e., frailty), cognitive status, and social isolation (Table 2.3). Moreover, both the qualitative data and the independent scientific review (Document 8) highlighted seasonal trends in environmental falls risk (e.g., frozen pavements).

### 3.5.3 Behavioural factors and implementation challenges

The qualitative research in Sheffield highlighted health and social motives of older individuals as key behavioural determinants of intervention uptake and adherence (Table 2.2). Communal initiatives to manage environmental risk factors were also recommended (Table 2.3). Likewise, a pilot falls prevention scheme in Sheffield found that branding the exercise interventions as strength and balance improvement rather than falls prevention appealed to the health motive and reduced stigma, thereby raising uptake [209]. Accordingly, Figure 3.1 highlights demand behaviours and external influences on demand (e.g., communal responsibility, branding) as key intervention factors. These behavioural components introduce implementation challenges that influence the effectiveness and population reach/impact of falls prevention [181].

The qualitative research also identified diverse supply-side mechanisms that affected implementation. Professional competence, shaped by psychology and organisational culture, was perceived to be a key implementation facilitator (Section 2.4.2.5) [242, 243]. But other system-side constraints were likewise perceived, such as time/capacity constraints and lack of coordination with other professionals. Indeed, the professional stakeholders in Sheffield appeared to lack awareness of prevention occurring outside their immediate clinical practice (e.g., Documents 7 and 9 in Appendix B). This suggests that a coherent integration strategy is required to implement a citywide falls prevention programme [244-247]. To optimise the implementation strategy, the commissioning should distinguish between demand- and supply-side influences on the same implementation process; Table 3.5 lists the terms used in this thesis to describe the implementation processes by their demand and supply dimensions. Intervention access, for example, is shaped by demand-side uptake and supply-side adoption.

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| **Table 3.5** Implementation processes by demand and supply dimensions. | | |
| **Process** | **Demand dimension** | **Supply dimension** |
| *Access* | Uptake [248] | Adoption [249] |
| *Compliance* | Adherence [248] | Fidelity [250] |
| *Sustainability1* | Persistence [251] | Maintenance [249] |
| 1 The extent to which access and compliance are preserved over time after the initial receipt for interventions requiring ongoing receipt (e.g., exercise). | | |

### 3.5.4 Issues of equity

As highlighted by an international expert panel, healthcare decision-makers face several priority setting criteria beyond cost-effectiveness in the interest of fairness or equity [71]. These criteria include prioritising the care needs of socially deprived subgroups and those with more severe disease and past health loss among similar-age peers. These two vulnerable subgroups overlap in practice given the strong influence of social factors (e.g., income, housing) on health both over the earlier life course and contemporaneously in old age [2, 14]. In the Sheffield context, the lower super output area (LSOA) multiple deprivation variable [252] was perceived to be the main characteristic of equity relevance (Document 2 in Appendix B). The qualitative data similarly highlighted area-based social deprivation as a factor influencing intervention demand and supply; ethnic/linguistic minorities were also mentioned as being disadvantaged (Table 2.3). As for severity characteristics, the qualitative data highlighted comorbidity level (i.e., frailty), cognitive impairment and social isolation (Table 2.3).

The issues of equity widen the problem boundary for falls prevention. As noted in the shaded outcome boxes in Figure 3.1, evaluation should now consider not only outcome levels but their distribution across population subgroups. Prioritising vulnerable subgroups likely worsens the overall cost-effectiveness of the intervention given factors such as the LED problem and the ‘double jeopardy’ (DJ) problem whereby vulnerable groups derive lower efficacy (e.g., due to comorbidity-related contraindications) and/or poorer implementation quality [109, 253]. The need to handle such equity-efficiency trade-offs introduce further complexity to the decision-making.

## 3.6 Identifying causal links in the disease process

This section further explores the key causal variables within the conceptual model. Generally, the variables introduce dynamic complexity and affect not only falls risk and incidence (i.e., the disease process defined narrowly) but also wider processes and outcomes such as intervention access (which in turn reduce the falls risk) and secondary effects of falls. In Table 3.6, they are grouped into four categories: (I) sociodemographic variables (Section 3.6.1); (II) fall-related variables (Section 3.6.2); (III) frailty and intrinsic capacity variables (Section 3.6.3); and (IV) environmental variables (Section 3.6.4). Table 3.6 summarises the links between the variables and falls prevention processes and outcomes but does not describe the inter-variable links (e.g., between falls and frailty). The conceptual model in Figure 3.1 should also be referred for understanding the links.

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| **Table 3.6** Links between key causal variables and falls prevention processes and outcomes. | | | | | | |
| **Variables** | **Processes and outcomes** | | | | | |
| Falls risk and severity | Falls secondary effects1 | Background health and care cost2 | Non-health outcomes3 | Priority setting implication | Intervention access, cost and efficacy4 |
| **Sociodemographic** | | | | | | |
| Age | **×** |  | **×** | **×** |  | **×** |
| Sex | **×** |  | **×** | **×** |  | **×** |
| SES | **×** |  | **×** | **×** | **×** | **×** |
| **Fall-related** | | | | | | |
| Falls history | **×** | **×** |  | **×** |  | **×** |
| Fear of falling | **×** | **×** | **×** | **×** |  | **×** |
| **Frailty and intrinsic capacity5** | | | | | | |
| Frailty | **×** | **×** | **×** | **×** | **×** | **×** |
| Gait and balance | **×** | **×** | **×** | **×** |  | **×** |
| Cognitive status | **×** | **×** | **×** | **×** | **×** | **×** |
| PA level | **×** | **×** | **×** | **×** |  | **×** |
| Other intrinsic | **×** | **×** |  |  |  |  |
| **Environmental** | | | | | | |
| Home space | **×** |  | **×** | **×** |  | **×** |
| Public space | **×** |  | **×** | **×** |  | **×** |
| Social community | **×** | **×** | **×** | **×** | **×** | **×** |
| **Abbreviation:** PA: physical activity; SES: socioeconomic status  1 E.g., excess mortality risk and functional decline after a serious fracture.  2 Health status and associated care costs that are not associated with the acute and secondary effects of falls.  3 E.g., productivity level, out-of-pocket care expenditure, informal caregiver burden (Section 3.5.1).  4 Intervention access is determined by eligibility (defined by guidelines such as NICE CG161 [13]), supply and demand. Intervention costs include societal costs and wider health, non-health and side effects of interventions (Section 3.5.1).  5 This concerns physical, mental and cognitive capacities of the older individual as opposed to extrinsic factors in the individual’s social community and physical environment (p. 32-33) [2]. | | | | | | |

### 3.6.1 Sociodemographic variables

Age and sex are well-established independent risk factors for falls incidence, injury type and severity [42, 43, 254-256]. For example, older women are likelier than men to experience fractures after falling, while men are likelier to experience traumatic brain injuries [42]. Regarding background health status, there is evidence that age and sex impact geriatric health utilities even after controlling for frailty and socioeconomic status (SES) [257]; the evidence on healthcare costs is less strong, with proximity to death being a stronger predictor than age itself [258]. Age and sex affect diverse non-health outcomes; reducing informal caregiving burden and promoting productivity among older women are public health priorities [2]. Sheffield stakeholders did not mention age or sex as characteristics with priority setting (i.e., equity) implications; yet age- or sex-based rationing (e.g., if intervention is not cost-effective for the oldest age subgroup) would go against the principles of NHS and NICE [259, 260]. Falls prevention RCTs often use age and sex as inclusion/exclusion criteria [124]; hence, availability of evidence-based interventions may vary by age and sex. Intervention participation is typically higher among older women than men [124, 135]. Overall, age and sex affect almost all key processes and outcomes in Table 3.6 and hence are key causal variables.

There are relatively few analyses on SES as an independent falls risk factor; a systematic review of prospective falls epidemiological studies included education as the only SES-related risk factor and did not find a statistically significant association with falls risk [43]. A prospective analysis of ELSA likewise found that household wealth is not significantly associated with falls risk [255]. By contrast, primary analysis of ELSA found that subjective report of financial difficulty is significantly associated with falls risk (Document 10 in Appendix B). Regarding background health status, one study found that education, but not income, had an independent impact on older persons’ health utilities after controlling for frailty [257]. Nevertheless, improving the financial circumstances of older persons is regarded as a key strategy for promoting older persons’ health and social participation [10]; hence, reducing fall-related OOP care expenditure incurred by financially deprived subgroups should be a priority [71, 75]. As noted, Sheffield CCG recommended LSOA-level multiple deprivation as the characteristic of equity relevance. During a pilot falls prevention scheme, CCG prioritised intervention access in socially deprived areas (see Section 3.7.1.3); subsequent discontinuation of CCG funding halted intervention in socially deprived areas but not in more well-off ones which continued via self-financing. This demonstrated the area-level, SES-mediated differential in intervention access within Sheffield. Overall, SES is a key causal variable with priority setting implications and impacts on multiple falls prevention processes and outcomes.

### 3.6.2 Fall-related variables

Falls history is one of the most reliable indicators of falls risk [13, 261]. Incidence of a fall leaves the person at high risk of a recurrent fall within a year [27]. Recurrence of falls requiring medical attention (MA falls) is also frequent [200]. NICE CG161 uses recurrent, not single (unless requiring medical attention), falls history as one of the screening criteria for proactive intervention access [13]. Recurrent falls also have stronger association with physical frailty [262]; single and recurrent fallers thus likely incur heterogeneous secondary effects of their respective fall episodes. Falls of all severities, including those not incurring injuries, have secondary health effects manifesting in terms of functional decline, excess mortality and LTC admissions [33, 40, 64, 263, 264], as well as various non-health impacts (Section 3.5.1). Nevertheless, specific fall-related injuries inflict different acute and long-term health impacts; wrist fracture patients, for example, have recovered their pre-fracture health utility level within 12 months, while hip fracture patients have not recovered even after 48 months [265]. Falls of different severities also have varied risk factors (Document 10 in Appendix B). Finally, falls prevention RCTs often demarcate their target population by falls history types (e.g., see Table 3.9 below); falls history thus influences the range of available interventions.

Fear of falling encompasses multiple, potentially non-overlapping concepts: physiological – e.g., change in autonomic reactivity; behavioural – e.g., reduction in walking speed to avoid falling; and cognitive – e.g., subjective assessment of one’s ability to avoid a fall while conducting daily/important tasks (i.e., self-efficacy) [266]. Fear remains a significant falls risk factor across its different conceptual forms [43, 266, 267]; it increases falls risk directly by impairing balance and/or indirectly by causing physical deconditioning via fear-related activity curtailment [266]. It is also a consequence of falling [267, 268], and likely propagates secondary effects of falls including functional impairment, all-cause mortality, cognitive decline, and reduced social wellbeing (i.e., a non-health outcome) [269-272]. Some studies found that fear is more strongly associated with physical dependence than falls *per se* [30, 273]. It should be noted that fear is not necessarily caused by a previous fall; according to one survey, only 37% of fear cases could be attributed to a previous fall [274]. Hence, fear could affect background health and care costs without mediating the secondary effects of falls. Finally, NICE CG161 recommends interventions that reduce cases of low self-efficacy (the cognitive form of fear) and fear of falling (the physiological and behavioural forms) [13]. This is a case of falls prevention having a wider health effect beyond falls reduction and directly affecting a propagator variable: see arrow from falls prevention efficacy box to propagator progression box in Figure 3.1.

### 3.6.3 Frailty and intrinsic variables

This section discusses variables that are intrinsic to older persons (as opposed to extrinsic, environmental factors) (p. 32-33) [2] beginning with frailty. There are two main frailty models in literature: phenotypic and cumulative deficit. The phenotypic model tracks the presence of a relatively small number of symptoms that indicate vulnerability in multiple organ systems; it hence generates categorical measures [275]. The cumulative deficit model tracks a group of deficits (at least 30) and calculates a frailty index between range 0-1 as a ratio between actual and potential numbers of deficits [49, 50]. Both frailty models have independent effects on falls risk [52, 275-277] and falls severity [130, 278]; yet statistical comparisons suggest that the cumulative deficit frailty index has greater predictive power [53] (see also primary ELSA analysis in Document 10 in Appendix B). The continuous range of frailty index has a conceptual advantage in that even a minute change in frailty score contributes towards higher falls risk. The score change propagates the secondary effects of falls manifesting in terms of higher all-cause healthcare costs [279, 280], LTC admissions [47], excess mortality [47, 281], and non-health outcomes such as informal caregiver burden [282]. Frailty is an ideal tool for characterising the heterogeneity in background health utilities and care costs beyond sociodemographic factors [257, 279]. Frailty may serve as the health severity characteristic with priority setting implications [71]; it is moreover closely associated with social deprivation [48, 137] and hence provide some information on social inequities of health. It can enable targeting strategies as done recently in Sheffield [209]. Overall, continuous frailty index is a key causal variable with priority setting implications.

The second intrinsic variable of importance is gait and balance; their impairments are well-established falls risk factors highlighted by NICE CG161 [13, 42]. They are also outcomes of serious falls that establish a feedback loop between falls and falls risk [283, 284]. Slow walking speed is one of the key frailty phenotypes [275] and is associated with all-cause mortality [6], suggesting that it would affect the trajectories of background health and non-health outcomes. Abnormal gait and balance has a significant influence on intervention access; in NICE CG161, it is used as one of the screening criteria for proactive intervention access [13]. RCTs of multifactorial interventions likewise use it as an inclusion criterion to target high-risk groups [85, 285]. Individuals with the most severe impairments can be excluded from falls prevention exercise [286], suggesting that the more resource-intensive multifactorial intervention is needed to cover this vulnerable group.

Cognitive impairment is a major risk factor for falls and fall-related injuries [13, 287, 288]. Cognitive decline may also be a long-term, secondary effect of serious falls such as hip fracture, likely via physical deconditioning and activity restrictions that affect cognitive function [36]. Cognitive impairment affects broad health and non-health outcomes including all-cause mortality [289, 290], healthcare cost [291], informal caregiver burden [291, 292], and social wellbeing [293]. The qualitative research participants in Sheffield highlighted the difficulty faced by cognitively impaired persons in accessing appropriate interventions (Section 2.4.2.6). Thus, cognitive impairment is a major determinant of falls prevention intervention need and design such as whether and how informal caregivers are involved in delivery [294]. Moreover, intervention efficacy from falls prevention RCTs is less consistent for cognitively impaired persons than cognitively intact [295]. Overall, cognitive status encompasses multiple causal links and its impact on the intervention strategy is discussed further in Section 3.7.3.

Physical activity level was highlighted by SCC health economist as a key factor in designing and evaluating preventive interventions (Document 5 in Appendix B). High physical activity can significantly reduce falls risk [296, 297]. Falls may also adversely affect physical activity pattern, establishing a feedback loop [263, 298]; reduced physical activity can propagate the secondary effects of falls via physical deconditioning [266]. Physical activity is a key determinant of healthy ageing in general, reducing risks of chronic diseases and improving social wellbeing [113, 299]. Finally, higher physical activity level is a key outcome of falls prevention exercise as its wider health benefit beyond falls prevention [135]; NICE CG161 similarly recommends that falls prevention interventions promote behavioural/activity change among participants [13].

There are several further intrinsic capacity variables that have been identified as key falls risk factors in the literature: muscle weakness [300]; pain [301]; use of certain medications and polypharmacy [302, 303]; urinary incontinence [304]; visual impairment [305]; and depression [306]. Factors such as pain and depression are also consequences of falls (and closely associated with fear of falling) [266], thus propagating the secondary effects of falls. It should be noted that these variables can be incorporated as deficits in a frailty index [277]. The latter may thus serve as a parsimonious measure of the collective impact of diverse deficits to intrinsic capacity.

### 3.6.4 Environmental variables

Qualitative research participants highlighted the importance of environmental or extrinsic determinants of falls risk and health promotion (Section 2.4.2.6), as did the independent scientific reviewer (Document 8 in Appendix B). Hazards at home such as poor lighting and inappropriate indoor footwear significantly increase falls risk [217, 307] and interact closely with visual impairment [305]. Beyond falls, housing quality is a key social determinant of physical health and broader wellbeing in old age [2, 116, 308]. Homeowners are more likely to implement HAM (Section 2.4.2.6) and derive consumption benefits from the home improvement [206].

Despite the high volume of falls occurring outdoors, there are relatively few epidemiological studies on falls risk factors in the public outdoor spaces compared to those on home hazards [309]. Importantly, outdoor falls are more likely precipitated by environmental factors (e.g., uneven surfaces on sidewalks) than intrinsic capacity deficits [309]. This implies that environmental interventions should complement those addressing intrinsic risk factors. Beyond falls, establishing safe outdoor spaces is a key strategy for creating age-friendly cities [116]. Moreover, improved local environment can significantly increase physical activity levels (Section 2.4.2.6) and therefore reduce falls risk indirectly and bring wider health benefits [310, 311].

Finally, social isolation (e.g., living alone) is known to be associated with higher falls risk and worse health consequences after falling [312, 313]; the latter would propagate the secondary effects of falls. Availability of social support also reduces the link between fear of falling and consequent activity curtailment [314]. Beyond falls, older persons increasingly require social support to maintain functioning [2], and social isolation is associated with increased risks of several adverse events including cardiovascular disease, depression, and premature death [315]. Reducing social isolation is an important non-health outcome in itself; promoting the social value of falls prevention interventions is recommended by NICE CG161 as a wider intervention benefit [13]. Qualitative research participants identified socially isolated persons as a priority group for intervention access (Section 2.4.2.6).

## 3.7 Identifying relevant interventions

This section explores the appropriate sets of interventions for the decision problem. Section 3.7.1 conceptualises the current falls prevention practice in Sheffield, while Section 3.7.2 conceptualises the recommended falls prevention strategy based on the UK falls prevention guidelines. Section 3.7.3 discusses the prevention strategy for cognitively impaired persons and persons with intervention history under current and recommended practices. Section 3.7.4 conceptualises additional falls prevention strategies. Under thesis objective (3), the final model will seek to formulate commissioning recommendations amongst alternative intervention strategies, including the strategy recommended by the UK guidelines and additional ones, relative to the current practice in Sheffield.

### 3.7.1 Current falls prevention in Sheffield

Understanding the current falls prevention practice in Sheffield mainly involved discussions with local stakeholders (commissioners, professionals, and qualitative research participants) and reference to published reports of falls prevention schemes being or have been implemented in Sheffield. Table 3.7 summarises the current or previously piloted falls prevention interventions in Sheffield managed by different system owners and actors. The interventions were classified by pathway: reactive, proactive, or self-referred. The last column lists the documents in Appendix B with the stakeholder discussions.

|  |  |  |  |
| --- | --- | --- | --- |
| **Table 3.7** Current falls prevention interventions in Sheffield by system owner/actor. | | | |
| **System owner/actor** | **Falls prevention intervention** | **Pathway** | **Document in Appendix B** |
| Sheffield NHS CCG and Sheffield City Council | SCC Home assessment and modification for hospitalised fallers | Reactive | Documents 5 & 11 |
| SCC Fall alarms (self-financed) for hospitalised fallers | Reactive | Documents 5 & 11 |
| STH rehabilitation therapy for MA fallers | Reactive | Document 7 |
| CCG Fracture Liaison Service (Tai Chi) | Reactive | Documents 4 & 11 |
| CCG Integrated Community Therapy (ICT) team | Reactive; Proactive | Documents 4 & 11 |
| [Pilot scheme] CCG Dance to Health group exercise (Otago and FaME) | Self-referred | Documents 4 & 11 |
| Falls specialist geriatrician | Multidisciplinary Sheffield Falls Clinic | Reactive; Proactive | Document 9 |
| Evaluator of Sheffield PPP Falls Prevention | [Pilot scheme] QTUG and ICT team referral | Proactive | Document 12 |
| Age UK Sheffield | Independent Living Coordination programme (education, home exercise, referral to HAM) | Proactive | Document 13 |
| **Abbreviation:** FaME: Falls Management Exercise; MA faller: faller who received medical attention; OT: occupational therapy; PHP: Public Health Principal; PPP: Perfect Patient Pathway; PT: physiotherapy; QTUG: quantified timed up and go; SCC: Sheffield City Council; STH: Sheffield Teaching Hospitals | | | |

Sections 3.7.1.1 to 3.7.1.3 below discuss the current interventions by pathway. Section 3.7.1.4 subsequently discusses the client flows under current practice and associated capacity implications.

#### 3.7.1.1 Current reactive pathway

As shown in Table 3.7, reactive interventions comprised a high proportion (six out of nine) of falls prevention services in Sheffield. The proportion was even higher if temporary pilot schemes (Dance to Health and QTUG and ICT team referral) were excluded. HAM provided by SCC was part of the standard hospital discharge protocol for hospitalised fallers and constituted the main reactive component. SCC also provided a self-financed fall alarm service for discharged patients. The seven-week rehabilitation therapy provided by the Sheffield Teaching Hospitals (STH) comprised another part of the standard discharge protocol. For those who experienced a serious fracture that impaired activities of daily living, Sheffield CCG also provided the Fracture Liaison Service that offered twice-weekly group Tai Chi to around 20-30 clients.

The Sheffield Falls Clinic was based at the Assessment and Rehabilitation Centre (ARC) – an outpatient facility owned by the STH – and was operated by a multidisciplinary team of consultant geriatrician, physiotherapists, and occupational therapists for a single afternoon each week. Those referred to the Clinic received full medical, PT and OT assessments, and based on the identified falls risk factors, received tailored treatments including medical interventions and referrals (e.g., medication change, cardiac pacing, referral to ophthalmologist), up to six weeks of one-to-one PT treatments, OT home modifications, and appropriate footwear and assistive devices. The assessment results and treatment prescriptions were sent back to the GPs for further monitoring. The Clinic catered to both reactive and proactive pathways. The ICT team was another multidisciplinary unit of PT and OT professionals operating mainly under the reactive pathway.

#### 3.7.1.2 Current proactive pathway

As noted, the Falls Clinic and the ICT team took on proactive clients. Moreover, between 2016 and 2018, a proactive falls prevention scheme was piloted in Sheffield as part of the Perfect Patient Pathway (PPP) Test Bed initiative run by STH. This initiative aimed to evaluate digital health technologies that targeted diverse population groups with complex needs including older persons at the onset of physical decline and hence eligible for falls prevention [209] (Document 12 in Appendix B). The falls prevention scheme: (i) targeted cognitively intact, ‘moderately frail’ (by electronic frailty index (eFI) [47]) older persons without falls history recorded in primary care data; (ii) screened individuals for high falls risk using the quantified timed up-and-go (QTUG) test; and (iii) referred high-risk individuals to multifactorial intervention conducted by the ICT team. The scheme involved nonclinical staff from community organisations conducting falls risk screening; they in fact screened more persons than the primary and secondary care staff by using more familiar venues at community centres [209]. However, the PHP confirmed (by personal communication) in August 2020 that there were no plans to scale up the scheme to the city level. Therefore, the QTUG-based proactive pathway represents a potential option rather than the current practice. Finally, Age UK Sheffield provided its own proactive falls prevention through its Independent Living Coordination (ILC) programme (Document 13 in Appendix B). Clients were primarily referred to the programme via their GPs (i.e., proactive pathway). The ILC staff conducted home visits and falls prevention services including education, home exercise and HAM referrals. This programme would likely qualify as a multifactorial intervention [126].

#### 3.7.1.3 Current self-referred pathway

Between 2017 and 2019, CCG commissioned the Dance to Health group exercise for a two-year pilot scheme in three locations: (1) central Sheffield; (2) Fir Vale – due to its social deprivation and high ethnic minority presence; and (3) Stocksbridge – due to its rural location and large geriatric population. The commissioning hence considered the objective of reducing social inequities in health and healthcare. The programme was designed to be compatible with any pathway but linkage with other referral pathways was very limited; 10 programme attendees who participated in the qualitative research in Chapter 2 reported accessing the programme via direct community marketing and peer recommendations rather than professional referrals. Hence, the programme operated primarily within the self-referred pathway. The Dance to Health programme involved weekly two-hour sessions supervised by a professional dance and postural stability instructor (PSI). The sessions incorporated components of Otago and FaME within a dance routine to improve enjoyability and long-term participation; the routine also offered flexibility in terms of individually tailored difficulty [196]. The CCG funding was discontinued after the pilot scheme, at which point the groups at Fir Vale and Stockbridge were disbanded; the group in central Sheffield sustained itself through self-financing of PSI fee and local church donation of venue. Therefore, self-referred falls prevention exercise such as Dance to Health represents a potential option rather than a widespread current practice.

#### 3.7.1.4 Client flows and capacity implications

Current falls prevention in Sheffield thus implemented the NICE-recommended practice (see Section 3.7.2), particularly the multifactorial risk assessments and treatments within the reactive and proactive pathways, but had a highly restricted intervention reach. For example, the Falls Clinic catered to around six clients per week, amounting to 300 clients per year. Likewise, the ICT team’s workflow was highly limited, with the team reporting capacity shortages when around 150 additional clients were added over 16 months during the QTUG scheme [209]. Age UK Sheffield had a client reach restricted to Dore & Totley, a relatively well-off region within Sheffield. In all, these client flows represent a small proportion of the flow envisaged by the NICE clinical guideline. For the reactive pathway alone, the guideline recommends that all MA fallers receive multifactorial intervention [13]; according to ELSA, the annual prevalence of MA fall is 6.8%, which amounts to around 8,500 MA fallers in Sheffield being eligible for the reactive pathway each year. The falls specialist geriatrician in Sheffield reported minimal issues with capacity under current practice (Document 9 in Appendix B); but this is most likely due to a highly limited intervention eligibility rather than sufficient capacity at the NICE-envisaged level. For the self-referred pathway, the Dance to Health programme catered to around 40 regular participants during the two-year pilot scheme and the low uptake was a major, persistent issue.

### 3.7.2 Recommended falls prevention in UK guidelines

Four guidelines were chiefly referred for understanding the normative falls prevention strategy in the UK community setting:

1. 2013 NICE falls prevention clinical guideline (‘NICE CG161’) [13]
2. 2019 NICE surveillance report for the update of the 2013 clinical guideline (‘NICE SR’) [130]
3. 2017 falls and fracture consensus statement by the Public Health England and the National Falls Prevention Coordination Group (‘PHE Consensus’) [143]
4. 2019 UK Chief Medical Officers’ physical activity guidelines (‘UK CMO’) [113].

In England and Wales, NICE CG161 remains normative for clinical practice; this was confirmed by commissioning and professional stakeholders in Sheffield including the falls specialist geriatrician (Documents 5 and 9 in Appendix B). PHE Consensus mainly concurred with NICE CG161. UK CMO was not solely focused on falls prevention but was recommended by NICE SR as a reference point for exercise-based falls prevention. Figure 3.2 provides a graphical summary of the recommendations. Table B1 in Appendix B directly cites the guideline recommendations by pathway.

Diagram

Description automatically generated

**Figure 3.2** Conceptual diagram of community-based falls prevention recommended by UK guidelines. **Abbreviation:** HAM: home assessment and modification; PA: physical activity.

Multifactorial intervention is central to the recommended practice for both reactive and proactive pathways. The latter targets older persons screened during routine care contact to have experienced recurrent falls in the past year and/or have abnormal gait/balance as assessed by tools such as the TUG test. Multifactorial intervention is conducted at dedicated sites such as the Falls Clinic and incorporates multidisciplinary assessment of diverse falls risk factors including falls history, gait/balance abnormality, muscle weakness, fear of falling, visual impairment, medication use, and falls hazards at home. Clients would then receive tailored sets of treatments, including exercise, HAM, medication modification, and vision improvements [13].

Recommendations for the self-referred pathway are centred around supervised exercise and unsupervised physical activity. Exercise interventions should be individually tailored, of progressive difficulty, and comprising a minimum of 50 hours of sessions for at least two hours per week [143]. UK CMO likewise recommends evidenced-based strength and balance exercise interventions in groups or at home (e.g., embedded in everyday activities) which are professionally supervised in case of frail or cognitively impaired persons; physical activity initiatives should aim to accumulate at least 150 minutes of moderate intensity exercise per week [113]. NICE SR recommends strategies that maintain this physical activity level even after professionally supervised exercise interventions end [130].

NICE CG161 also contains several recommendations regarding implementation factors [13]. On the supply-side, professionals in regular contact with older persons in the community should have basic competence in falls risk screening and referral; attributes of commissioned interventions should be adaptable to the heterogeneous needs and preferences of older persons; the social value of group-based programmes should be promoted; and interventions should have wider effects beyond falls prevention in promoting behavioural/activity change and addressing fear of falling and low self-efficacy. Information provision in appropriate languages to both older persons and their carers is recommended as the main demand-augmenting implementation strategy.

As mentioned, the current practice in Sheffield implemented the NICE-recommended practice in several areas; hence, the main point of difference between current and recommended practices is not the intervention strategy but the intervention reach. Attention should be paid to the capacity implications of scaling the current practice to the recommended levels. For example, as estimated in Section 5.2.4.3 during model parameterisation, fully implementing the NICE-recommended reactive and proactive pathways would require around seven full-time falls clinics; this is likely beyond the feasible capacity levels in Sheffield. Even for single-component exercise interventions, capacity may be constrained if the available venues are limited; the Dance to Health Sheffield lead mentioned (by personal communication) around 100 potential venues in the city for around 20 participants each.

### 3.7.3 Cognitively impaired persons and persons with intervention history

The UK guidelines above contained limited recommendations regarding interventions for cognitively impaired older persons. NICE CG161 recognised cognitive impairment as a major falls risk factor and included cognitive assessment in the recommended multifactorial risk assessment but suggested no differentiated intervention strategy for this subgroup [13]. UK CMO simply recommended professional supervision of exercise interventions for those with moderate-severe dementia [113]. By contrast, falls prevention efficacy studies draw a sharp distinction by cognitive status when recruiting participants. For example, 89 of 159 trials included in the 2012 Cochrane review of falls prevention RCTs excluded cognitively impaired persons [124]. A systematic overview of systematic reviews of RCTs found greater inconsistencies in intervention efficacies for this subgroup [295]. These suggest that attention should be paid to the heterogeneous intervention attributes (e.g., caregiver accompaniment), costs and efficacies across cognitive status.

With regards to current practice in Sheffield, the falls specialist geriatrician mentioned (by personal communication) that access to reactive discharge interventions such as HAM and therapy rehabilitation would not make the distinction by cognitive status. Hence, the current reactive pathway is accessible to both cognitively intact and impaired persons. For the proactive pathway, the lead PT at the Falls Clinic mentioned that older persons with diagnosed cognitive impairment were referred to the specialised Memory Clinic rather than the Falls Clinic (Document 9 in Appendix B). This, together with QTUG pilot scheme’s exclusion of cognitively impaired persons, suggests that the current proactive pathway is predominantly targeted at cognitively intact persons. For the self-referred pathway, the Sheffield lead for Dance to Health mentioned (by personal communication) that the programme would accept cognitively impaired persons while involving their caregivers to ensure safety. Independent assessment of the Dance to Health affirmed the programme’s suitability for cognitively impaired persons [196]. Hence, the current self-referred pathway is accessible to both cognitively intact and impaired persons.

Another distinct subgroup in the target population comprises persons who have already received a given intervention in a previous period(s) but remain eligible in the current period (e.g., still have abnormal gait/balance and hence are eligible for proactive intervention). Given scarce resources, an option is to restrict intervention access to this subgroup. This would affect the long-term sustainability of intervention access; the issue is particularly relevant to reactive and proactive pathways where access is largely determined by clinical protocols rather than older persons’ demand. There was again limited information in the UK guidelines on risk assessment and treatment protocols for this subgroup. Nevertheless, the intervention features are unlikely to be identical for subgroups with and without intervention history; for example, persons who have already received a multifactorial intervention are unlikely to undergo the same multifactorial risk assessment given pre-recorded assessment results.

With regards to current practice in Sheffield, the falls specialist geriatrician mentioned (by personal communication) that standard reactive treatments such as rehabilitation or HAM are unlikely to be denied based on previous receipt history. Hence, reactive interventions are likely accessible to all eligible persons each year. For the proactive pathway, the falls specialist geriatrician mentioned that individuals with intervention history who remain at high falls risk would ideally be referred back to the Falls Clinic for further assessment of any significant change in the falls risk profile; but such re-referrals are infrequent in practice. For the self-referred pathway, continued participation of older persons is strongly encouraged by the Dance to Health programme [196].

### 3.7.4 Additional falls prevention strategies

Several additional intervention strategies can be conceptualised based on the major themes of the decision problem. First, each of the three distinct pathways (operational under both current and recommended practices) could be commissioned individually at their recommended level while the other two pathways are maintained at their current levels. Alternatively, two of the three pathways could be commissioned at their recommended levels.

Second, the current and recommended practices both envisage minimal engagement of community assets. This contrasts with the focus placed on community mobilisation by AS&R as well as the pilot QTUG scheme that involved community organisations in the falls risk screening. The qualitative research participants also highlighted the importance of community marketing in promoting intervention access. An alternative strategy would involve active involvement of community assets in various roles ranging from falls risk screening under the proactive pathway to intervention uptake promotion under the self-referred pathway.

Third, there are potential concerns around the capacity implications of implementing the recommended practice, as noted above. A small increase in proactive referrals under the QTUG scheme (involving three GP practices) resulted in significant waiting lists for falls prevention services [209]. Although funding would remove many of the supply-side constraints, bottlenecks may remain in several areas such as the total feasible numbers of multidisciplinary teams and group exercise venues. Alternative intervention strategies would recognise these constraints and explore the means of rationing the scarce resources, likely in the form of targeting strategies. The QTUG scheme, for example, targeted the moderately frail according to eFI scores (Document 12 in Appendix B). Another option is to target high-risk individuals according to their predicted falls risk.

Fourth, the recommended practice contains relatively little guidance around reducing environmental falls risk factors (beyond home hazards) and building health-promoting public spaces; yet both were suggested by qualitative research participants as intersectoral policies. Alternative strategies could explore the impact when environmental interventions supplement the current or recommended practices.

Finally, under the principle of high integration (Section 1.3.2.3), falls prevention is ideally a part of a larger package of further geriatric and earlier-life public health interventions. These interventions would change the underlying epidemiological characteristics of the target population. The problem boundary should incorporate situations of such epidemiological changes (if not as distinct intervention strategies) and their impact on falls prevention practice.

## 3.8 Discussion

Using a published framework for public health model development [1], this chapter developed a conceptual model for economic evaluation of community-based falls prevention in Sheffield. In the process, the chapter: identified the evaluation framework relevant to Sheffield stakeholders; highlighted the conceptual themes underlying the rationale for falls prevention; identified the key causal variables; considered the key features of current and recommended falls prevention practices; and conceptualised alternative intervention strategies.

### 3.8.1 From conceptual to methodological challenges

The conceptual model should henceforth inform Phase (D) of model development which comprises the systematic review of previous models in Chapter 4 and the model parameterisation in Chapter 5 [1]. The key themes within the conceptual model should be translated into methodological challenges addressed by the final implemented model. For example, the four conceptual themes discussed in Section 3.5 translate to the following methodological challenges: (1) capturing non-health outcomes and societal intervention costs; (2) considering heterogeneity and dynamic complexity; (3) considering theories of human behaviour and implementation; and (4) considering issues of equity. These are of course the methodological challenges used for framework analysis in Chapter 2 [18]. They form the key criteria for methodological appraisals of previous falls prevention models in Section 4.5.3 and of the newly developed model in Section 6.6.4.3.

The methodological challenges should inform the range of techniques used for model development and evaluation. For example, accounting for the secondary effects of falls and the dynamic complexity in the falls risk profile likely requires the incorporation of a multivariate frailty index and other propagators. Individual-level simulation is also likely required to capture individual-level outcomes and dynamic complexity. Various psychological and sociological factors influencing behaviour and implementation should be directly parameterised to increase the sensitivity of model outcomes to changes in these factors [160]. But even just conducting value of implementation (VoIM) analyses to explore how the model outcomes vary according to different implementation strategies and levels would generate useful, heuristic information for decision-makers [199, 316]. Finally, the issues of equity and their impact on evaluation outcomes should be quantified using an approach such as the distributional cost-effectiveness analysis (DCEA) [109].

### 3.8.2 Intersections between the key methodological challenges

In handling the methodological challenges, further attention is warranted on the likely significant interactions between them. Incorporation of non-health outcomes (challenge 1) would increase the heterogeneity and dynamic complexity in analysis (challenge 2) [2]. Wider intervention benefits and costs (challenge 1) are closely associated with implementation quality (challenge 3): for example, social benefits act as uptake facilitators [13], and co-payments as barriers [141]; see also Table 2.2. Likewise, long-term behavioural and implementation patterns (challenge 3) are dynamically complex due to feedback loops (e.g., initially successful adherence reinforces long-term persistence) (challenge 2).

The interactions between the challenges 1-3 and challenge 4 (i.e., equity issues) warrant more attention. First, capturing non-health outcomes and societal intervention costs (challenge 1) likely exacerbates the inequitable outcome differences between social- and severity-based subgroups. For example, incorporating wider consumption benefits of HAM advantages richer homeowners [206]. Incorporating productivity loss likely disadvantages the socially deprived and frail subgroups who are less likely to be in paid/unpaid employment prior to a fall. Yet excluding the wider outcomes simply masks the equity consequences (e.g., that publicly funded HAM may constitute a regressive wealth transfer towards homeowners); their inclusion is necessary to design policies that address the holistic needs of vulnerable older persons [317]. The main implication is that evaluations from the societal perspective should rigorously plan equity analyses, engaging with stakeholders to understand equity-related priorities.

Second, there is a close overlap between considerations of heterogeneous intervention need (challenge 2) and severity-based equity issues [44, 274, 318]. For example, cognitive impairment influences intervention need (as a key falls risk factor [13]) whilst also serving as a health severity indicator [113]. This should be considered by any model targeting the general community-dwelling older population since it implicitly targets a sizeable cognitively impaired subgroup; e.g., 22% of UK men aged 65-84 have mild cognitive impairment [319]. A similar consideration is warranted for multivariate frailty: tailored interventions exist that can generate positive health benefits for the frailest [320]; yet their outcomes are likely markedly worse than those of the less frail subgroups, as shown in one trial-based economic evaluation of multifactorial intervention [253]. Therefore, decision-makers aiming to implement an intervention programme benefitting the frailest should articulate their severity-based priorities beyond cost-effectiveness [71].

Third, geriatric health behaviour and intervention participation (challenge 3) are strongly influenced by social status and culture [321] and health severity [189, 202]. Complex interventions such as proactive multifactorial intervention may face greater implementation challenges (e.g., routine risk screening, multidisciplinary teamwork) but better reach vulnerable groups who are less likely to self-refer to voluntary programmes [179]. The consideration of aggregate outcomes in VoIM magnifies the priority setting challenges: vulnerable subgroups forming a minority would likely generate lower aggregate benefits from implementation improvements than the less vulnerable majority (even if the former’s ICER is more favourable). Conduct of VoIM therefore warrants equity analyses, consulting stakeholders and data on the likely subgroup-specific impacts of local implementation strategies.

### 3.8.3 Relevance to further geriatric public health challenges

The conceptualisation process in this chapter holds relevance to public health fields broader than community-based falls prevention [1, 18]. Indeed, public health issues and interventions frequently affect non-health outcomes and expend resources outside the public healthcare system [18, 71, 83, 105, 159]; these are particularly relevant to older populations who rely increasingly less on physical health to derive their overall capability [2]. The ageing process encompasses multidimensional changes in physical and psychosocial domains [2]; the resulting geriatric syndromes thus have multifactorial risk profiles and give rise to high heterogeneity and dynamic complexity [19]. Geriatric health behaviours are strongly shaped by individual psychology (e.g., motivation to prevent functional decline), social interactions and the environment [189, 238, 322]. These behaviours strongly shape the prevalence and trajectory of risk factors and the implementation quality of interventions [192, 323]. Finally, the heterogeneous exposures of geriatric subgroups to social determinants of health bring issues of equity to the forefront of any geriatric public health initiative [14, 16]. Applying the framework that can accommodate these considerations would greatly reduce the structural uncertainty of the final model.

### 3.8.4 Strengths and limitations of conceptual model

A key strength of the current conceptual model is the integration of diverse evidence sources in the conceptualisation process, including qualitative research data, stakeholder consultations, and falls prevention and broader literature. Transparency was pursued by outlining how each evidence contributed to each conceptual area (Table 3.2) and presenting the transcript quotes from qualitative research and documents collected from stakeholder consultations. The conceptual model considered a broad range of disease and intervention processes that are potentially affected by key causal variables (Figure 3.1 and Table 3.6). Local intervention features were obtained via stakeholder consultations and related reports to conceptualise the current practice, while the recommended practice and alternative strategies drew on normative UK guidelines and established principles (e.g., active community involvement).

The current methods and results of conceptualisation nonetheless have several limitations. First, there was difficulty in generating active involvement by professional stakeholders. Research ethics ruled out making reimbursements to NHS professionals for their time commitments, making consistent commitment difficult. As mentioned, professionals were reluctant to commit to a project led by a uncredentialled PhD student with no guaranteed prospect of changing commissioning and clinical practice patterns. The Covid-19 pandemic ruled out professional involvement from February 2020, although commissioners were later re-engaged to receive preliminary feedback on the implemented model results. The group meetings that did take place mostly engaged with one stakeholder group at a time and lacked inter-stakeholder interactions (e.g., between commissioners and professionals). Second, qualitative research with older persons identified relevant stakeholders (e.g., housing authority responsible for home modification legislations) who were not subsequently engaged in intersectoral discussions. Third, CCG and SCC commissioners were primarily interested in the use of their routine data to plan and evaluate their service strategies. This hampered the initial conceptualisation phase since too much attention was placed on what factors are observable in the routine data. Fourth, access to actual client flow data across falls prevention services in Sheffield would have facilitated the conceptualisation of the current practice.

Nevertheless, the conceptual model can be appraised relative to previous conceptualisation attempts in the topic area. Relatively few (seven of 46; 15.2%) previous falls prevention models identified by the systematic review in Chapter 4 attempted to validate the model structure prospectively by engaging stakeholders in the development process (see Section 4.5.4.1). In the UK setting, the model developed by Public Health England (‘PHE model’) engaged a Steering Group of national falls prevention experts to inform the model structure [216]. Yet the Steering Group input focused primarily on validating resource-use and cost inputs and there was little detailed documentation of whether and how key conceptual challenges were addressed. For example, there was no documented consideration of social determinants of falls risk, even when the systematic review preceding the model development considered social inequalities in health as a key policy concern [147]. Moreover, identifying the falls consequence types for the PHE model was primarily data-led, using the results of routine data analysis [324]. This raises the risk of neglecting several falls consequence pathways that are not easily observed in routine data (e.g., fear of falling).

A final issue to consider is the potential burden placed on the analyst from the added modelling complexity. This burden can derive from: (i) the conceptualisation process itself (e.g., identifying appropriate stakeholders); and (ii) developing the final implemented model in Phase (D) based on the conceptual one (e.g., accessing appropriate data). Concerning (i), the burden is a necessary price for improving model credibility and should be distributed rationally within a multidisciplinary modelling team. Concerning (ii), the conceptual framework acknowledges the practical issues around data, technical expertise, and other project constraints and recommends a simpler model structure if the added complexity is unlikely to affect outcomes substantially (Figure 7) [1]. The conceptual model would then serve as a reference point against which the simplifications are formulated and justified. Such critical evaluation is conducted in Chapters 6 and 7 for the model developed in Chapter 5.

## 3.9 Chapter summary

Overall, the result of this chapter likely represents the most rigorous attempt to date at conceptualising an economic model of community-based falls prevention at local health economy level. It will inform all subsequent chapters in this thesis. As mentioned, it is a case study in applying the published framework for public health model conceptualisation [1] and hence can serve as an example to future projects applying the same framework to diverse geriatric and non-geriatric public health areas.

# Chapter 4. Systematic Review of Falls Prevention Economic Models

## 4.1 Chapter outline

The aim of this chapter is to conduct a systematic review of community-based falls prevention economic models. The main objectives are to:

1. Systematically search for and identify community-based falls prevention decision models.
2. Describe and critically appraise the methods, evidence, and results of identified models.
3. Formulate methodological recommendations for model development based on the critical appraisal, focusing on features of falls epidemiology, falls prevention interventions, challenges associated with public health modelling, evaluation methods, and use of evaluation outcomes.
4. Formulate commissioning recommendations based on the results and methodological quality of models.

This systematic review can inform commissioners and other consumers of economic evidence (e.g., care professionals and patient groups), modellers producing the evidence for falls prevention and other public health areas, and systematic reviewers interested in the review methodology. In this thesis, the review results inform the model parameterisation in Chapter 5 and establish points of comparison for understanding the relative strengths and limitations of the developed model (see, e.g., Section 6.6.4).

Section 4.2 provides further background to the systematic review and Section 4.3 describes the review methods. Results of the systematic review are presented in three parts: Section 4.4 provides an overview of the identified models and checklist scores for assessing their methodological and reporting quality; Section 4.5 provides the results of narrative synthesis and critical appraisal; and Section 4.6 formulates the methodological and commissioning recommendations based on the critical appraisal and evaluation outcomes. Section 4.7 discusses the findings, and Section 4.8 concludes.

This chapter was submitted as two articles for publication: the first was published in *BMC Health Services Research* on 7th March 2022 [325]; the second in *Cost Effectiveness and Resource Allocation* on 4th July 2022 [326]. Both articles are published open access following the requirement of the Wellcome Trust who financially sponsored this work [grant reference 108903/B/15/Z]. The conditions of the open access publishing allow use of the final published PDF, original submission or accepted manuscript in this thesis (including in any electronic institutional repository or database). The content of this chapter largely overlaps with those of the published articles. See Author contributions in Appendices for co-authors’ contributions.

## 4.2 Systematic review background

As discussed, falls prevention economic evaluations can inform commissioning decisions by estimating the opportunity cost involved in investment [145]. The high number of falls prevention effectiveness studies [124-126] has been accompanied by an increasing volume of economic evidence; for example, the most recent Cochrane review of falls prevention RCTs identified 12 economic evaluations for community-based falls prevention exercise alone [125]. The rising volume of economic evaluations has been accompanied by systematic reviews of the available evidence. For a well-formulated research question, a systematic review uses systematic and explicit methods to identify relevant studies, synthesise relevant extracted data, and critically appraise their quality [327].

Two central functions of systematic reviews of economic evaluations can be: (A) to inform commissioning decisions; and (B) to summarise and evaluate the methodological features of economic evaluation in a topic area. Related to (A), the reviews can aid commissioning decisions by summarising the evaluation results most applicable to the decision-making context and/or identifying existing decision models that can be adapted and re-used [1]. The development of the NICE falls prevention guideline, for example, involved a systematic review of falls prevention economic evaluations [146].

Related to (B), systematic reviews can detail and critically appraise key methodological features of decision models [1, 145]. This can be achieved by applying a pre-established methodological and reporting quality checklist, then conducting a narrative synthesis of the modelling features including their strengths and limitations [105]. Ideally, the systematic review should perform both functions: the commissioners would benefit from the methodological appraisal that qualifies the model outcomes; the modellers basing the conceptualisation of future models on the reviewed methodological features would need to know how they affect the model results.

Prior to the systematic review in this chapter, a systematic overview of previous reviews in community-based falls prevention economic evaluations was conducted and is reported in Appendix C. This chiefly sought to appraise the methodology of previous reviews, specifically regarding how well they have performed the above functions (A) and (B). It identified seven reviews covering 21 decision models [146, 147, 328-332]. The reviews extracted a limited range of methodological features and evaluation outcomes to inform commissioning; for example, the extracted modelling features were limited to model type and brief summaries of data sources. A pilot Medline search by the PhD researcher identified 10 models of community-based falls prevention that were not included in the seven previous reviews. These findings motivate the *de novo* systematic review.

## 4.3 Systematic review methods

The systematic review protocol is registered on the Prospective Register of Systematic Reviews (CRD42021232147). It followed the PRISMA 2020 guideline [327]. The completed PRISMA checklist is reported in the published article [325]. This section outlines the methods for: data sources and study selection (Section 4.3.1); and data extraction and synthesis (Section 4.3.2).

### 4.3.1 Data sources and study selection

The systematic review shared the same search strategy as the systematic overview since the intersection between falls, older people and economic evaluation covered both falls prevention economic models and systematic reviews of models; but they applied different inclusion and exclusion criteria. The database search strategies are hence shown in Appendix C (Tables CS1.1-CS1.8 and text). References and citations of included studies were also searched.

The PhD researcher and Ms Lee independently reviewed the titles and abstracts of identified articles at the first stage and the full texts of approved article at the second stage. Those that received two second-stage approvals were included for data extraction. Prof Young arbitrated in case of disagreement.

A study was included if it: (i) targets a population of community-dwelling older persons (aged 60+) and/or individuals aged 50-59 at high falls risk; (ii) evaluates intervention(s) designed to reduce the number of falls or fall-related injuries; (iii) against any comparator(s); (iv) reports outcomes of economic evaluation [145]; (v) uses a decision model; and (vi) has English full text. Models evaluating interventions for specific disease areas (e.g., stroke) with minor falls prevention components were excluded. Interventions aiming to reduce specific falls risk factor (e.g., balance) and/or health consequences of falls (e.g., fear of falling) were excluded if the model did not explicitly incorporate falls as events. Single-vehicle evaluations were excluded but their references searched. Eligible models included in previous systematic reviews were included [146, 147, 328-332].

### 4.3.2 Data extraction and synthesis

Data extraction was primarily conducted by the PhD researcher using a pre-designed data extraction form; the extracted data fields were informed by the conceptual model in Chapter 3. Table 4.1 shows the data fields extracted from identified models, including the following categories: (A) model and evaluation overview; (B) falls epidemiology features; (C) falls prevention intervention features; (D) key challenges for public health modelling; and (E) evaluation methods and results.

|  |  |
| --- | --- |
| **Table 4.1** Data fields extracted from identified falls prevention decision models. | |
| **Category** | **Data field** |
| Reporting and methodological quality checklist | The checklist designed for falls prevention economic evaluations by a panel of falls prevention experts [105] was adapted to specifically suit decision models. There were 32 items, each scored 0 (recommendation not followed), 0.5 (partially followed), and 1 (fully followed), giving maximum score of 32. See Table D1 in Appendix D for adapted version. |
| (A) Model and evaluation overview | 1. Bibliography: author(s); publication year 2. Setting and aim: country; region; decision-maker; evaluation aim 3. Target population demographics and comorbidities (e.g., residence, age, sex, socioeconomic status, health conditions unrelated to falls risk) 4. Type of analysis: e.g., CEA; CUA; CBA; ROI 5. Perspective (e.g., public sector, societal) 6. Cost-effectiveness threshold: monetary amount and type (e.g., health opportunity cost in healthcare system, willingness to pay as consumer) 7. Model type (e.g., decision tree, Markov) 8. Model time horizon 9. Discount rates (if time horizon longer than 1 year) 10. Model cycle length (if any) |
| (B) Falls epidemiology features | 1. Characterising baseline falls risk of target population 2. Characterising multiple falls per year (recurrent falls) 3. Risk factors for falls 4. Health consequences of falls: fall/injury type; long-term health consequences (e.g., institutionalisation, excess mortality risk) 5. Health utility data: fall-related loss; comorbidity status 6. Economic consequences of falls: care resource types; unit costs; all-cause/comorbidity care costs1 |
| (C) Falls prevention intervention features | 1. Intervention characteristics: type; reach; components; access pathway; comparator(s) 2. Falls risk screening method2 3. Intervention resource use and costs: auxiliary implementation resources (e.g., marketing to improve uptake); therapeutic resources (e.g. staff labour). 4. Intervention efficacy: metric;3 fall type;4 effectiveness period5 5. Wider health effects of interventions beyond falls prevention |
| (D) Key challenges for public health modelling6 | 1. Capturing non-health outcomes and societal intervention costs 2. Considering heterogeneity and dynamic complexity: e.g., long-term progression of falls risk factors/profile 3. Considering theories of human behaviour and implementation: e.g., implementation quality (i.e., uptake and adherence rates) 4. Considering issues of equity |
| (E) Evaluation methods and results | 1. Model validity: structural/face;internal; external; cross 2. Assessing parameter uncertainty: DSA; PSA 3. Scenario analyses: to assess impact of structural assumptions on outcomes. 4. Cost-per-unit ratios (e.g., incremental cost per QALY gained) 5. Aggregate health and cost outcomes (e.g., total intervention cost, total QALY gain, total number of falls prevented) 6. Wider decisional outcomes (e.g., reduction in social inequities of health) 7. Currency: original type/year; conversion to same currency for comparison 8. Discussion by evaluation authors: generalisability; policy implementation; model strengths and limitations |
| **Abbreviation:** CBA: cost-benefit analysis; CEA: cost-effectiveness analysis; CUA: cost-utility analysis; DSA: deterministic sensitivity analysis; PSA: probabilistic sensitivity analysis; QALY: quality-adjusted life year; RCT: randomised controlled trial; ROI: return on investment  1 Expert guideline on falls prevention economic evaluation recommends that evaluations report all-cause healthcare costs in the base case and fall-related costs in sensitivity analysis [105].  2 Falls risk screening is required if: (1) model prescribes intervention to a subset of the whole target population with certain characteristics (e.g., higher falls risk) and this subset must be identified; and (2) model’s target population itself is a specific patient group (e.g., cataract patients) and this group must be identified from the general population before model baseline. Falls risk screening is distinct from falls risk assessment as part of multifactorial intervention.  3 This concerns models that import falls efficacy evidence from external intervention studies. Main falls incidence metrics are falls risk and falls rate, and their matching efficacy metrics are relative risk (RR) and rate ratio (RaR), respectively. Models should ensure that the external efficacy metric matches the internal falls incidence metric.  4 Like note 3, this concerns decision models using external efficacy evidence. The fall type (e.g., hospitalised fall, fall-induced fracture) for the efficacy data should match that for the model incidence.  5 The effectiveness period is a function of efficacy durability and implementation sustainability. Efficacy durability should not extend beyond the intervention study’s timespan unless the intervention is sustained [105]. Key determinants of sustainability are demand-side persistence and supply-side maintenance.  6 See Section 3.5 where these challenges are further described as conceptual themes. | |

#### 4.3.2.1 Checklist scores for methodological and reporting quality

A checklist specifically designed to assess the reporting and methodological quality of falls prevention economic evaluations was applied by the PhD researcher after being adapted for use on decision models, as described and presented in Appendix D, Table D1 [105].

#### 4.3.2.2 Narrative synthesis of methodological features and methodological recommendations

The extracted methodological features under categories (A) to (E) in Table 4.1 were narratively synthesised, mainly using tabular formats. Critical appraisal identified between-study variation in the methods used to characterise the features and their respective strengths and limitations (including those highlighted by the model’s authors). Methodological recommendations for future model development were subsequently formulated by this systematic review.

#### 4.3.2.3 Developing commissioning recommendations based on the review results

Commissioning recommendations are based on the model evaluation results extracted under category (E). Note that these are preliminary recommendations based on the review results alone; separate recommendations will be made in Chapter 6 based on the model analysis results and then compared to the former (i.e., cross-validation). The recommendations are based primarily on a subset of models that targeted general older populations – as opposed to specific patient groups – and conducted analyses over a lifetime horizon. Prioritising this subset addresses the information needs of decision-makers overseeing geographically defined jurisdictions (e.g., national) [164]. The evaluation over a lifetime horizon is recommended by the expert guideline on falls prevention economic evaluation [105].

The recommendations considered all available evaluation outcomes – including not only cost-per-unit ratios but also aggregate, population-level impact and wider decisional outcomes (e.g., impact on social inequities of health) – and methodological caveats potentially affecting credibility and outcomes. Monetary outcomes were converted to pound sterling (£) in 2021 using the consumer price index (CPI) in the country of study to account for inflation up to 2021 [333] and the most recent purchasing power parity (PPP) exchange ratio between £ and the original currency [334]. For CUA, an ICER less than £30,000 per QALY gained was deemed cost-effective according to the threshold recommended by the NICE Methods Guide [154].

## 4.4 Systematic review results part 1: overview

The database search results are presented (Section 4.4.1), followed by overview (Section 4.4.2) and checklist scores (Section 4.4.3) of included models.

### 4.4.1 Systematic review search results

Figure 4.1 presents the PRISMA flow diagram. In total, 15,730 titles and abstracts were screened. Ninety-two full texts were screened from which 46 decision models were identified. Six studies were identified from the grey literature and references of other studies. The main reason for exclusion at the full text screening stage was not conducting economic evaluation via decision modelling. The titles of the excluded studies are given in Table D2 in Appendix D.

Reports assessed for eligibility

(n = 77)

Reports excluded (n = 37):

Not decision model (n = 22)

No fall-related outcome (n = 2)

Not falls prevention (n = 10)

Not community-dwelling older population (n = 3)

Reports assessed for eligibility

(n = 15)

Reports excluded (n = 9):

Not decision model (n = 5)

Not full economic evaluation (n = 3)

Not falls prevention (n = 1)

Studies included in review

(n = 46)

Reports of included studies

(n = 46)

**Included**

Reports sought for retrieval

(n = 77)

Reports not retrieved

(n = 0)

Reports sought for retrieval

(n = 15)

Reports not retrieved

(n = 0)

Records screened

(n = 15,715)

Records excluded

(n = 15,638)

Records identified from (n):

Medline (4,009); Embase (2,785); PubMed (8,159); CDSR & CENTRAL (3,107); EconLit (259); CINAHL (1,552); PsycInfo (1,012); ASSIA (462); CRD (61); CEA Registry (100); PEDro (260); **Total (21,766)**

Records removed before screening:

Duplicates removed (n = 6,051)

Records identified from:

Grey literature/Websites (n = 3)

References (n = 12)

**Identification of studies via databases**

**Identification of studies via other methods**

**Identification**

**Screening**

**Figure 4.1** Preferred Reporting Items for Systematic Reviews and Meta-Analyse flow diagram for systematic review of falls prevention decision models.

### 4.4.2 Overview of included decision models

Table 4.2 provides an overview of the 46 included models. Apart from Agartioglu (2020) set in Turkey, all models were set in developed countries: 14 from the US and Canada (30.4%); 12 Australia and New Zealand (26.1%); 11 UK (23.9%); and eight Europe (17.4%). Twenty-four (52.2%) models aimed to inform decision-making at the national level, while the rest adopted more local application levels including state, city, and CCGs in the UK.

Most models (n=25; 52.2%) targeted a general population of community-dwelling adults aged 60+ or 65+; two targeted general population women only [335, 336]. Two models targeted general adult populations aged 65+ which would contain a minority of institutionalised adults [44, 337]; two incorporated institutionalisation as a non-final model state [274, 318]. Five targeted populations with falls history [200, 207, 338-340]; two populations at high falls risk without specifying cause [341, 342]. Eight targeted specific patient populations: osteoporosis or high osteoporosis risk [343, 344]; fall-risk-increasing drug (FRID) users [345-348]; and cataracts [349, 350]. Nshimyumukiza (2013) incorporated incoming cohorts, newly entering each year for 10 years.

There were three types of economic analysis, CEA, CUA, and CBA, as well as ROI. No further types (e.g., CCA) were identified. There were two costing perspectives: public sector and societal. Several models adopted multiple types of analysis and perspectives, resulting in 69 distinct analyses. Of these, CUA was most used (n=32; 46.4%), followed by ROI and CEA (each n=17; 24.6%), and then CBA (n=3; 4.3%). Around a third of analyses (n=22) adopted the societal perspective.

Exercise was the most evaluated intervention type with 17 models; eight evaluated multiple exercise forms. Multifactorial intervention was the second most evaluated type with 13 models: three evaluated multiple forms [207, 351, 352]; two combined multifactorial intervention with environmental modifications [127, 128]. Twelve evaluated multiple types of interventions: four compared multiple types directly [336, 347, 351, 352]. The most common comparator scenario was not receiving the modelled intervention(s). Eight models described the ‘usual care’ (without falls prevention properties) received in the comparator scenario, e.g., non-expedited cataract surgery compared to expedited [349]; but others (24 of 32 with non-receipt scenario) were vague in the description or used ‘no intervention’ and ‘usual care’ interchangeably [146, 167, 216, 340, 353].

There were four model type categories: (1) binary decision (n=14); (2) static (n=9); (3) cohort-level Markov (n=19); and (4) patient- or individual-level Markov (n=4). Binary decision models compared the state of the world with and without the intervention and did not incorporate probability trees (i.e., excluding decision tree models) or time progression (i.e., excluding Markov-type models). Beard (2006), for example, modelled the wider societal outcomes of an intervention evaluated in a quasi-experimental study [127]. Static models excluded within-simulation time progression (e.g., time cycles in Markov models). All static models except Smith (2016) were decision trees; Smith (2016) compared several falls risk cut-off levels (i.e., non-binary) without time progression. Model time horizon varied between one year and lifetime. Seventeen of 23 Markov models adopted lifetime horizons. A significant number of studies cited short time horizon as a limitation of their analyses [127, 167, 200, 207, 216, 335, 338, 345, 353-356]. Hektoen (2009), for example, noted that the short horizon would prioritise secondary over primary prevention since recurrent falls are more frequent in the short run.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 4.2** Overview and quality score of included falls prevention decision models. | | | | | | | | | |
| **#** | **Reference** | **Setting** | **Target population** | **Type of analysis** | **Perspective** | **Intervention type [comparator]** | **Model type** | **Time horizon** | **Checklist quality score1** |
| 1 | Agartioglu (2020) [357] | Turkey, Izmir | CD adults aged 65+ | CEA | Public sector | HAM [UC] | DT | 1 year | 22 |
| 2 | Albert (2016) [354] | US, Pennsylvania | CD adults aged 50+ (mean age 75.5) | CUA | Public sector | MF int. [UC] | DT | 1 year | 20.5 |
| 3 | Alhambra-Borras (2019) [341] | Spain, Valencia, hospital level | CD adults aged 65+ at high falls risk or frail with no severe physical or cognitive limitation | CUA | Public sector | Exercise [UC] | Markov cohort | Lifetime | 16 |
| 4 | Beard (2006) [127] | Australia, NSW | CD adults aged 60+ | CBA; ROI | Public sector; Societal | MC (intersectoral) int.2 [UC] | Binary decision3 | 5 years | 21 |
| 5 | Boyd (2020) [337] | New Zealand | Adults aged 65+ | CUA | Public sector | Cataract surgery (expedited, routine) [NR] | Markov cohort | Lifetime | 23 |
| 6 | Carande-Kulis (2015) [358] | US, private insurers | CD adults aged 65+ | ROI | US health insurance payer | Exercise (2 forms); MC int. (Stepping On) [NR] | Binary decision | 1 year | 18.5 |
| 7 | CSP (2016) [359] | UK, varying regions | CD adults aged 65+ | ROI | Public sector | FRS + Exercise (physiotherapy) [NR] | DT | 1 year | 17.5 |
| 8 | Church (2011) [360] | Australia, NSW | CD adults aged 65+ (separate model for residential care) | CEA; CUA | Public sector | Exercise (3 forms); MC int.; MF int.; MRA; Exp. cataract surgery; Med. modification; Cardiac pacing [NR] | Markov cohort | 10 years | 15.5 |
| 9 | Church (2012) [351] | Australia, NSW | CD adults aged 65+ | CEA; CUA | Public sector | Exercise (4 forms); MC int.; MF int. (2 forms); MRA; HAM; Exp. cataract surgery; Cardiac pacing; Med. modification [NR; Cross-comparison] | Markov cohort | Lifetime | 17.5 |
| 10 | Comans (2009) [207] | Australia, Brisbane | CD adults aged 65+, falls history in past 6 months or gait/functional decline and cognitively intact | ROI | Societal | MF int. (2 forms) [NR] | Binary decision | 1 year | 20.5 |
| 11 | Day (2009) [167] | Australia, varying regions | CD adults aged 50+ (age and characteristics differ by intervention type)4 | CEA | Public sector; Societal | Exercise (2 forms); HAM; MF int.; Med. modification; Cardiac pacing [NR] | DT | 1 year | 20.5 |
| 12 | Day (2010) [353] | Australia | CD adults aged 70+ | CEA | Public sector; Societal | Exercise (Tai Chi) [NR] | DT | 1 year | 18 |
| 13 | Deverall (2018) [361] | New Zealand | CD adults aged 65+ | CUA | Public sector; Societal | Exercise (3 forms) [NR] | Markov cohort | 25 years | 24 |
| 14 | Eldridge (2005) [274] | UK, primary care trust | Adults aged 65+ in community or nursing home | CUA | Public sector | FRS + MF int. or Exercise [UC] | DT + Markov cohort | Lifetime | 17.5 |
| 15 | Farag (2015) [362] | Australia | CD adults aged 65+ without falls history | CUA | Public sector | Non-specific intervention [NR] | Markov cohort | Lifetime | 17 |
| 16 | Franklin (2019) [363] | UK, city level | CD adults aged 65+ | CUA | Public sector (2 types) | FRS + Exercise (3 forms) or HAM [NR; Cross-comparison] | DT + Markov cohort | 2 years | 22.5 |
| 17 | Frick (2010) [352] | US | CD adults aged 65+ | CUA | US healthcare payer5 | Exercise (2 forms); HAM; MF int. (2 forms); Vit. D; Med. modification [Cross-comparison] | Binary decision | 1 year6 | 21 |
| 18 | Hektoen (2009) [335] | Norway | CD women aged 80+ | CEA | Societal | Exercise [NR] | Binary decision | 1 year | 23.5 |
| 19 | Hiligsmann (2014) [343] | Belgium | Adults aged 60+ with osteoporosis | CUA | Societal | Vit. D and calcium [NR] | Markov patient | Lifetime | 24 |
| 20 | Hirst (2016) [345] | UK | Women aged 75+ on chronic pain medication | CUA | Public sector | Med. modification (Transdermal Buprenorphine) [Tramadol] | DT7 | 1 year | 26 |
| 21 | Honkanen (2006) [318] | US, Medicare/aid | Adults aged 65+ living in community at baseline | CUA; ROI | Societal | Hip protectors [NR] | Markov cohort | Lifetime | 23.5 |
| 22 | Howland (2015) [200] | US, Massachusetts | CD adults aged 65+ admitted to A&E due to fall | ROI | US healthcare payer5 | MC int. (MoB/VLL) [NR] | Binary decision | 1 year | 20 |
| 23 | Ippoliti (2018) [364] | Italy, Piedmont | CD adults aged 65+ living in mountainous areas | ROI | Public sector | MF int. [NR] | Binary decision | 3 years | 18.5 |
| 24 | Johansson (2008) [128] | Sweden, Stockholm | CD adults aged 65+ | CUA | Societal | MC (intersectoral) int.8 [UC] | Markov cohort | Lifetime | 26.5 |
| 25 | Lee (2013) [365] | US, Medicare/aid | CD adults aged 65-80 without falls history | CBA | Public sector | Vit. D (targeted, universal) [NR] | DT + Markov cohort | 3 years | 20.5 |
| 26 | Ling (2008) [338] | US, Hawaii | CD adults aged 65+ with falls history or other risk factors | ROI | US healthcare payer5 | HAM [NR] | Binary decision | 1 year | 13.5 |
| 27 | McLean (2015) [355] | Australia, Melbourne | CD adults aged 70+ | CEA; CUA | Public sector | Exercise [UC] | DT | 18 months | 26 |
| 28 | Miller (2011) [342] | US, Texas | CD adults aged 50+ at high falls risk | ROI | US healthcare;5 Societal | MC int. (MoB/VLL) [NR] | Binary decision | 2 years | 16 |
| 29 | Mori (2017) [344] | US | CD women aged 65+ at osteoporosis risk without previous fracture | CUA | Societal | Exercise and bisphosphonate combined [Cross-comparison: single or no intervention] | DT + Markov patient | Lifetime | 25.5 |
| 30 | Moriarty (2019) [346] | Ireland | CD adults aged 65, no current/previous adverse events for benzodiazepine/PPI | CUA | Public sector | Med. modification (Benzodiazepine, PPI) [Inappropriate prescribing] | DT + Markov patient | 35 years | 23 |
| 31 | Nshimyu-mukiza (2013) [336] | Canada | Women aged 40+ (with subgroup aged 65+) | CEA; CUA | Public sector | Fracture risk screening + Physical activity, Vit. D and calcium, and/or Osteoporosis screen & treat [NR; Cross-comparison] | DT + Markov patient | Lifetime | 27 |
| 32 | OMAS (2008) [366] | Canada, Ontario | CD adults aged 65+ | CEA; ROI | Public sector | Exercise; HAM; Vit. D and calcium; Med. modification; gait-stabilizer [NR] | Markov cohort | Lifetime | 22.5 |
| 33 | Pega (2016) [241] | New Zealand | CD adults aged 65+ | CUA | Public sector | HAM [NR] | Markov cohort | Lifetime | 23.5 |
| 34 | Poole (2014) [367] | UK | Adults aged 65+ | ROI | Public sector | Vit. D [NR] | Binary decision | 1 year | 23.5 |
| 35 | Poole (2015) [356] | UK | CD adults aged 60+ | CUA; ROI | Public sector | Vit. D [NR] | Markov cohort | 5 years | 20.5 |
| 36 | PHE (2018) [216] | England, varying regions | CD adults aged 65+ | CUA; ROI | Public sector | Exercise (3 forms); HAM [NR] | DT | 2 years | 26.5 |
| 37 | RCN (2005) [146] | England & Wales | CD adults aged 60+ | CUA | Public sector | Exercise; MF int. [NR] | Markov cohort | Lifetime | 18 |
| 38 | Sach (2007) [349] | UK | Women aged 70+ with bilateral cataracts | CEA; CUA | Public sector; Societal | Exp. cataract surgery (first eye) [UC: Routine surgery] | Binary decision | Lifetime extrapol.9 | 20 |
| 39 | Sach (2010) [350] | UK | Women aged 70+ with second operable cataract | CUA | Public sector; Societal | Exp. cataract surgery (second eye) [UC: No surgery] | Binary decision | Lifetime extrapol.9 | 20 |
| 40 | Smith (2016) [44] | UK, NW London | Adults aged 65+ covered by GP practice and hospital | ROI | Public sector | FRS + MF int. [Cross-comparison] | Risk prediction | 1 year | 18 |
| 41 | Tannenbaum (2015) [347] | US, Medicare/aid | CD adults aged 65+ with insomnia | CUA | Public sector | Med. modification; CBT [NR; Cross-comparison] | Markov cohort | 1 year | 23.5 |
| 42 | Turner (2020) [348] | Canada, Quebec | CD adults aged 65+ who are chronic users of sedatives for insomnia | CUA | Public sector | Med. modification [NR] | DT + Markov cohort | 1 year | 22 |
| 43 | Velde (2008) [339] | Netherlands | CD geriatric outpatient population with falls history (mean age 78) | CEA | Public sector | Med. modification [NR] | Binary decision | 1 year6 | 18 |
| 44 | Wilson (2017) [206] | New Zealand, Manukau | CD adults aged 65+ | CUA | Public sector | HAM [NR] | Markov cohort | Lifetime | 23.5 |
| 45 | Wu (2010) [340] | US, Medicare/aid | CD Medicare beneficiaries aged 65+ with falls history | CEA; ROI | Public sector; Societal | MF int. [NR] | Binary decision | 1 year | 22 |
| 46 | Zarca (2014) [368] | France | Adults aged 65+ without previous hip fracture | CEA; CUA | Public sector | Vit. D (targeted (2), universal) [NR; Cross-comparison] | DT + Markov patient | Lifetime | 25.5 |
| **Abbreviation:** CBA: cost-benefit analysis; CBT: cognitive behavioural therapy; CD: community-dwelling; CEA: cost-effectiveness analysis; CSP: Chartered Society of Physiotherapy; CUA: cost-utility analysis; DT: decision tree; Exp.: expedited; Extrapol.: extrapolated; FRS: falls risk screening; HAM: home assessment and modification; Int.: intervention; MC: multiple-component; Med.: medication; MF: multifactorial; MoB/VLL: Matter of Balance Lay-Led Version; MRA: multifactorial risk assessment only; NR: non-receipt of modelled intervention(s); NSW: New South Wales; OMAS: Ontario Medical Advisory Secretariat; PHE: Public Health England; PPI: proton pump inhibitor; RCN: Royal College of Nursing; ROI: return on investment analysis; UC: usual care  1 This applies the adapted reporting/methodological quality checklist designed specifically for falls prevention economic evaluations [105]. The maximum score is 32. See Tables D1 and D3 in Appendix D for checklist content and item-specific scores for each study.  2 Intervention included individually tailored education, HAM and exercise and public space safety improvement.  3 Binary decision models include two scenarios, with or without intervention, and no time-based cycles or probability trees.  4 Cardiac pacing targeted population aged 50+ due to their high falls risk. Other interventions targeted populations aged 65+.  5 This would include Medicare/aid, private health insurance and patients.  6 One-year horizon with lifetime costs and health effects of falls.  7 Authors described the model as microsimulation; but there was only a single one-year cycle. Hence, the model is classified as a decision tree.  8 Intervention included individually tailored education, group balance exercises, Tai Chi, other physical activities and HAM, neighbourhood hazard removal and housing reconstruction.  9 One-year trial outcomes are extrapolated over lifetime horizon. | | | | | | | | | |

### 4.4.3 Checklist scores for methodological and reporting quality

Table 4.2 shows the checklist scores for models which ranged between 13.5 and 27 of maximum 32 with mean of 21.2. Thus, around a third of checklist items were not met, suggesting a general shortfall in methodological and/or reporting quality of models, at least relative to the expert recommendations on falls prevention economic evaluation [105]. Table D3 in Appendix D shows the item-specific scores. The lowest scored item across models was item 15, which recommends reporting total/all-cause health resource utilisation costs under base case analysis and fall-related costs under sensitivity analysis. For this, only four models (all using primary collection of cost data) incorporated all-cause healthcare costs as the main economic outcome [341, 349, 350, 354]; six incorporated comorbidity care costs, which together with fall-related costs constitute all-cause costs [128, 206, 241, 318, 337, 361]. The second lowest scored item was item 21, which recommends: (i) reporting intervention costs and all-cause/fall-related healthcare costs separately; and (ii) reporting both aggregate and mean costs. For this, eight followed both recommendations [128, 200, 207, 216, 335, 340, 345, 364], five followed (i) only [338, 355, 356, 359, 367], and four followed (ii) only [336, 362, 366, 368]. The third lowest scored item was item 8 for clearly stating and justifying the comparator which, as discussed above, was done by less than half (n=22) of studies.

## 4.5 Systematic review results part 2: narrative synthesis and appraisal

The results for narrative synthesis and appraisal are presented by the following categories: falls epidemiology features (Section 4.5.1); falls prevention intervention features (Section 4.5.2); key challenges for public health economic modelling (Section 4.5.3); evaluation methods (Section 4.5.4); and evaluation outcomes (Section 4.5.5).

### 4.5.1 Falls epidemiology features

As detailed in Table 4.1, falls epidemiology features are synthesised based on: (1) characterising baseline falls risk (Section 4.5.1.1); (2) characterising recurrent falls (Section 4.5.1.2); (3) range of falls risk factors (Section 4.5.1.3); (4) range of falls health consequences (Section 4.5.1.4); (5) health utilities for CUA (Section 4.5.1.5); and (6) range of fall-related economic consequences (Section 4.5.1.6).

#### 4.5.1.1 Baseline falls risk

Table 4.3 shows four main approaches for characterising the baseline falls risk/rate: (1) analysis of individual-level epidemiological data; (2) use of published epidemiological data or expert/author opinion; (3) use of internal intervention study; and (4) use of falls risk/rate from RCT control group.

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| **Table 4.3** Evidence sources for baseline falls risk/rate used by falls prevention decision models. | | |
| **Data source** | **N** | **Study label1** |
| (1) Individual-level epidemiological data | 8 | BODE3 models – Boyd (2020), Deverall (2018), Pega (2016), Wilson (2017); Eldridge (2005); Ippoliti (2018); OMAS (2008); Smith (2016) |
| (2) Published epidemiological data or expert/author opinion | 25 | Agartioglu (2020); Carande-Kulis (2015); CSP (2016); Church (2011); Church (2012); Farag (2015); Franklin (2019); Frick (2010); Hiligsmann (2014); Hirst (2016); Honkanen (2006); Howland (2015); Lee (2013); Ling (2008); Miller (2011); Mori (2017); Moriarty (2019); Nshimyumukiza (2013); Poole (2014); Poole (2015); RCN (2005); Tannenbaum (2015); Turner (2020); Wu (2010); Zarca (2014) |
| (3) Internal intervention study2 evidence | 9 | Albert (2016); Alhambra-Borras (2019); Beard (2006); Comans (2009); Johansson (2008); McLean (2015); Sach (2007); Sach (2010); Velde (2008) |
| (4) Risk/rate from external RCT control group | 4 | Day (2009); Day (2010); Hektoen (2009); PHE (2018) |
| **Abbreviation:** BODE3: Burden of Disease Epidemiology, Equity and Cost-Effectiveness; CSP: Chartered Society of Physiotherapy; OMAS: Ontario Medical Advisory Secretariat; PHE: Public Health England; RCN: Royal College of Nursing; RCT: randomised controlled trial  1 See Table 4.2 for study references.  2 This may be randomised or non-randomised. | | |

Eight models employing (1) estimated the baseline falls risk/rate by analysing individual-level data relevant to the decision-making context. One used a local survey [274], but the other seven analysed administrative healthcare (routine) datasets. For example, the four BODE3 models developed by the same research group analysed the insurance claims data at national and state levels to estimate the incidence rates of MA falls. A key strength of routine data is that falls incidence is linked to consequent care utilisation and cost; the latter can then be stratified by individual-level risk factors. The routine data should contain individual identifiers to distinguish between number of fallers and falls per faller. The BODE3 models did not make this distinction, counting multiple falls per person as multiple fallers and overestimating the baseline falls risk.

Twenty-five models used published epidemiological evidence (n=22) or expert opinion (n=3) [342, 351, 360]. Compared to approach (1), the use of published evidence restricted the range of falls risk factors and relevant population subgroups (see Section 4.5.1.3). Nevertheless, published evidence allowed parameterisation of fall-related events that are not well-observed in routine data (e.g., non-MA falls).

Nine models sourced the baseline falls risk/rate and intervention effectiveness from the same internal intervention study. For example, Albert (2016) developed a decision tree model using the baseline risk, effectiveness, and costs evidence from a quasi-experimental evaluation of multifactorial intervention. The reliance on a single intervention study makes these models similar to non-modelling SVEs. Nevertheless, the nine models: explicitly developed models using internal data [341, 354, 355]; extrapolated results over a longer time horizon [128, 349, 350]; extrapolated results to national population [339]; and extrapolated results to a wider societal perspective [127]. These models assumed that the internal intervention sample is representative of the target population; this assumption would not hold if there were sampling biases.

Four models used the falls risk/rate from the control group of an external RCT (or pool of RCTs). For example, Day (2010) used the falls rate pooled from two Tai Chi RCTs to characterise the baseline rate, then applied the Tai Chi efficacy from a separate meta-analysis. Analysts can draw on diverse external RCTs to characterise the baseline risk; heterogeneous risks across subpopulations can be modelled by drawing on multiple sources simultaneously. However, this approach generally restricts the model time horizon to that of an external RCT and cannot model the long-term falls risk progression without being supplemented by longer-term observational data.

#### 4.5.1.2 Recurrent falls

Table 4.4 lists the models by model type category and their features relevant to characterising recurrent falls. The first feature is the ‘transition entity’, i.e., the type of entity that experiences the modelled events or faces the probabilities for them. In the study context, the entity is either a fall event (facing risks of different severities and economic consequences) or an individual (facing falls risks and transitioning to different model states such as the ‘post-fall’ one). The individual-transitioning models, particularly those with cycle length of one year or longer, should ensure that recurrent falls could occur to individuals during each cycle. A qualifying factor is the type of main fall-related event: if the event is unlikely to recur within a year (e.g., hip fracture), then the need to model recurrent falls is reduced.

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| **Table 4.4** Modelling methods for characterising recurrent falls. | | | | |
| **Study label1** | Transition entity2 | Cycle length | Main fall-related event | Possible to model recurrent falls |
| **Binary decision model** | | | | |
| Beard (2006) | Fall event | N/A3 | MA fall | Yes |
| Carande-Kulis (2015) | Individual | N/A | MA fall | No |
| Comans (2009) | Individual | N/A | Any fall | Yes |
| Frick (2010) | Individual | N/A | Hip fracture | No |
| Hektoen (2009) | Fall event | N/A | Any fall | Yes |
| Howland (2015) | Individual | N/A | MA fall | Yes: targeted recurrent fall |
| Ippoliti (2018) | Fall event | N/A | Hip fracture | Yes |
| Ling (2008) | Individual | N/A | Any fall | No |
| Miller (2011) | Individual | N/A | MA fall | No |
| Poole (2014) | Fall event | N/A | Hip fracture | Yes |
| Sach (2007); (2010) | Fall event | N/A | Any fall | Yes |
| Velde (2008) | Fall event | N/A | Any fall | Yes |
| Wu (2010) | Individual | N/A | Any fall | Yes: targeted recurrent fall |
| **Static model**4 | | | | |
| Agartioglu (2020) | Individual | N/A | Any fall | No |
| Albert (2016) | Individual | N/A | Any fall | Yes |
| CSP (2016) | Individual | N/A | MA fall | Yes |
| Day (2009); (2010) | Fall event | N/A | Any fall | Yes |
| Hirst (2016) | Individual | N/A | Fractures | No |
| McLean (2015) | Individual | N/A | Any fall | Yes: Adjusted risk |
| PHE (2018) | Fall event | N/A | Any fall | Yes |
| Smith et al (2016) | Individual | N/A | MA fall | No |
| **Cohort-level Markov model** | | | | |
| Alhambra-Borras (2019) | Individual | 1 year | Composite5 | Yes: Composite5 |
| BODE3 models | Individual | 1 year | MA fall | No |
| Church (2011); (2012) | Individual | 1 year | Any fall | No |
| Eldridge (2005) | Individual | 1 year | Any fall | No |
| Farag (2015) | Individual | 1 year | Any fall | No |
| Franklin (2019) | Individual | 1 year | Any fall | Yes |
| Honkanen (2006) | Individual | 1 year | Hip fracture | No |
| Johansson (2008) | Individual | 1 year | Hip fracture | No |
| Lee (2013) | Individual | 1 month | Any fall | Yes |
| Moriarty (2019) | Individual | 1 year | MA fall/Hip fracture | No |
| OMAS (2008) | Individual | 1 year | MA fall | No |
| Poole (2015) | Individual | 1 year | MA fall | No |
| RCN (2005) | Individual | 1 year | MA fall | No |
| Tannenbaum (2015) | Individual | 6 months | Any fall | Yes |
| Turner (2020) | Individual | 1 month | MA fall/Hip fracture | Yes |
| **Individual-level Markov model (microsimulation)** | | | | |
| Hiligsmann (2014) | Individual | 6 months | Fractures | Yes |
| Mori (2017) | Individual | 1 year | Fractures | No |
| Nshimyumukiza (2013) | Individual | 1 year | Fractures | No |
| Zarca (2014) | Individual | 3 months | Hip fracture | Yes |
| **Abbreviation:** BODE3: Burden of Disease Epidemiology, Equity and Cost-Effectiveness Programme studies, including Boyd (2020), Deverall (2018), Pega (2016) and Wilson (2017); CSP: Chartered Society of Physiotherapy; Int.: intervention; MA fall: fall requiring medical attention; N/A: not applicable; OMAS: Ontario Medical Advisory Secretariat; PHE: Public Health England; RCN: Royal College of Nursing.  1 See Table 4.2 for study references.  2 All Markov models conceive *individuals* (or proportion of individuals within cohort) transitioning between model states. Some binary decision and static models have fall events transitioning through health and economic sequelae.  3 Cycle length was not relevant or applicable to non-cycle-based models such as the decision tree.  4 All studies under this category, except Smith (2016), used a decision tree model.  5 This model used a composite measure of health consequences including recurrent falls, fear of falling and mobility and balance problems. Hence, recurrent falls were captured within the composite measure. | | | | |

There were 23 models incapable of characterising recurrent falls. Seven of the 23 had fracture as the main event which are less likely to recur within a year [128, 318, 336, 344-346, 352]; whilst 16 models with falls as the main event were incapable of characterising recurrent MA or non-MA falls. Of 13 individual-transitioning models that *were* capable of characterising recurrent falls, three methods were mainly used: (1) modelling separate health states for recurrent fallers; (2) assigning average number of falls per faller; and (3) incorporating cycle lengths shorter than one year. Three models used (1) [341, 354, 359]: e.g., CSP (2016) incorporated age- and gender-specific risks of experiencing recurrent falls conditional on having fallen. Three used (2) [207, 359, 363]: e.g., Franklin (2019) assigned 2.8 falls as the average number of falls experienced per faller. Five used (3), incorporating the following cycle lengths: one month [348, 365]; three months [368]; and six months [343, 347]. Hiligsmann (2014) and Zarca (2014) had fractures as the main event yet incorporated short cycles. Tannenbaum (2015) modelled higher falls risk in the second of the two six-month cycles for those who experienced a fall in the first. Other methods included: applying a negative binomial regression on individual-level data to adjust the falls risk for the number of falls per faller [355]; and targeting those who have experienced a fall immediately prior to the model baseline (‘targeted recurrent fall’ in Table 4.4) [200, 340]. No study employed model types incorporating time-to-event data (e.g., discrete event simulation) to overcome the limitation of set cycle lengths.

#### 4.5.1.3 Falls risk factors

Table 4.5 summarises the range of risk factors for falls and fall-related events incorporated by models that conducted primary analysis of individual-level data or used published epidemiological evidence (i.e., the first two approaches for characterising baseline risk in Table 4.3). For the eight models that conducted primary analysis, the individual-level granularity offered greater scope for incorporating a wide range of risk factors. For example, the four BODE3 models incorporated age, sex, ethnicity, and MA falls history as risk factors for MA fall, hospitalised fall, and fatal fall. Smith (2016) constructed a MA falls risk prediction tool using diverse variables in primary and secondary care routine data including history of fall/fracture, chronic disease diagnoses, and history of all-cause secondary care use.

Twenty-five models that used published evidence were more restricted in their incorporation of risk factors. Ten incorporated a single baseline risk or included age and/or sex as the only non-exogenous (i.e., not set at baseline) risk factors [146, 200, 340, 342, 343, 352, 356-358, 367]. Only four incorporated non-injurious or non-MA falls as a risk factor for further falls within model simulation [338, 351, 360, 362]. No model incorporated fear of falling as a risk factor. Only three incorporated chronic diseases: osteoporosis [336, 344]; and depression and cognitive impairment [338]. Physical impairments as risk factors included: vitamin D deficiency [365, 368]; low bone mass density [336]; impaired gait/balance, leg weakness and functional impairment [338]; and functional dependency [318].

Models using internal intervention study evidence or external RCT data to characterise the baseline falls risk/rate (i.e., the last two approaches in Table 4.3) took the risk factors as given from the internal or external studies. For example, Day (2009) used the inclusion criteria of external RCTs to define the risk profiles of six model subgroups receiving different interventions. A representative population survey was then used to estimate the subgroup sizes.

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| **Table 4.5** Risk factors for fall-related events in models conducting primary analysis of epidemiological data or using published epidemiological evidence. | | | | | | | | | | | | | |
|  |  | **Falls risk factors** | | | | | | | | | | | |
| **Study label1** | **Fall-related event** | Age | Sex | Ethnicity | Region/ Residence | Non-inj./MA falls history | Inj./MA falls history | Fear of falling | Chronic disease | Medication | Physical capacity | Service use history | Risk identification tool |
| ***Primary analysis of epidemiological data*** | | | | | | | | | | | | | |
| BODE3 models | MA fall; Hospitalised fall; Fatal fall | ˟ | ˟ | ˟ |  |  | ˟ |  |  |  |  |  |  |
| Cataract surgery benefit in Boyd (2020) |  |  |  |  |  |  |  | ˟ |  |  |  |  |
| Eldridge (2005) | Any fall | ˟ |  |  |  | ˟ | ˟ |  | ˟ | ˟ | ˟ |  | FRAT |
| Fear of falling | ˟ |  |  | *LTC* | ˟ | ˟ |  | ˟ | ˟ | ˟ |  | FRAT |
| Fracture | ˟ |  |  | *LTC* |  |  | ˟ |  |  |  |  |  |
| Ippoliti (2018) | Hip fracture |  |  |  | *Region* |  |  |  |  |  |  |  |  |
| OMAS (2008) | MA fall; Fracture; Hip fracture; Fatal fall; LTC fall; Hospitalised fall | ˟ | ˟ |  |  |  | ˟ |  |  |  |  |  |  |
| Smith (2016) | MA fall | ˟ | ˟ |  |  |  | ˟ |  | ˟ | ˟ |  | ˟ | Internal tool |
| ***Use of published epidemiological evidence or expert opinion*** | | | | | | | | | | | | | |
| Agartioglu (2020) | Any fall; MA fall; Hospitalised fall; Different injuries | *Single risk* | | | | | | | | | | | |
| Carande-Kulis (2015) | Any fall; Falls healthcare cost | ˟ |  |  |  |  |  |  |  |  |  |  |  |
| CSP (2016) | Any fall; Recurrent fall | ˟ | ˟ |  |  |  |  |  |  |  |  |  |  |
| Any fall |  |  |  |  |  |  |  |  |  |  |  | TUG |
| MA fall | *Single risk* | | | | | | | | | | | |
| No. of recurrent falls |  | ˟ |  |  |  |  |  |  |  |  |  |  |
| Care events | ˟ |  |  |  |  |  |  |  |  |  |  |  |
| Church (2011); (2012) | Any fall | ˟ |  |  |  | ˟ | ˟ |  |  |  |  |  |  |
| Fatal fall; Care events; LTC fall | ˟ |  |  |  |  |  |  |  |  |  |  |  |
| Farag (2015) | Any fall | ˟ |  |  |  | ˟ | ˟ |  |  |  |  |  |  |
| MA fall; Care events; LTC fall | ˟ |  |  |  |  |  |  |  |  |  |  |  |
| Franklin (2019) | Any fall; MA fall; Fatal fall; LTC fall; Care events | ˟ |  |  |  |  |  |  |  |  |  |  |  |
| Any fall |  |  |  |  |  |  |  |  |  |  |  | TUG & QTUG |
| Frick (2010) | Any fall; Hip fracture | *Single risk* | | | | | | | | | | | |
| Hiligsmann (2014) | Hip fracture; Vertebral fracture; Wrist fracture; Other fracture | ˟ | ˟ |  |  |  |  |  | *Exo* |  |  |  |  |
| Hirst (2016) | Hip fracture; Humerus fracture; Wrist fracture; Other fracture | ˟ | *Exo* |  |  |  |  |  |  | ˟ |  |  |  |
| Honkanen (2006) | Hip fracture; LTC hip fracture | ˟ | ˟ |  |  |  | ˟ |  |  |  | Funct. dep. |  |  |
| Functional dependency | ˟ | ˟ |  |  |  | ˟ |  |  |  |  |  |  |
| Howland (2015) | MA fall; Care events |  |  |  |  |  | *Exo* |  |  |  |  |  |  |
| Lee (2013) | Any fall; MA fall | ˟ | ˟ | *Exo* |  |  | *Exo* |  |  |  | Vit. D def. |  | Vit. D level |
| Ling (2008) | Any fall | ˟ |  |  |  | ˟ | ˟ |  | ˟ | ˟ | ˟ |  |  |
| Miller (2011) | Hospitalised fall | ˟ |  |  |  |  |  |  |  |  |  |  |  |
| Mori (2017) | Hip fracture; Humerus fracture; Wrist fracture; Other fracture | ˟ | *Exo* | *Exo* |  |  | ˟ |  | ˟ |  |  |  |  |
| Moriarty (2019) | Hip fracture; Other MA falls | ˟ |  |  |  |  | ˟ |  |  | ˟ |  |  |  |
| Nshimyu-mukiza (2013) | Hip fracture; Vertebral fracture; Wrist fracture | ˟ | *Exo* |  |  |  | ˟ |  | ˟ |  | BMD |  | Fracture risk tool |
| Fatal hip/vertebral fracture | ˟ |  |  |  |  |  |  |  |  |  |  |  |
| Poole (2014) | Hip fracture; Fatal hip fracture | ˟ | ˟ |  |  |  |  |  |  |  |  |  |  |
| Poole (2015) | MA fall; Hospitalised fall; LTC fall; Fatal fall | ˟ |  |  |  |  |  |  |  |  |  |  |  |
| RCN (2005) | MA fall; Severity of MA fall | ˟ |  |  |  |  |  |  |  |  |  |  |  |
| Tannenbaum (2015) | Any fall |  |  |  |  |  | ˟ |  | *Exo* | ˟ |  |  |  |
| Turner (2020) | Non-fracture MA fall; Hospitalised hip & non-hip fractures; Fatal hip fracture |  |  |  |  |  |  |  | *Exo* | ˟ |  |  |  |
| Wu (2010) | Recurrent MA fall | ˟ |  |  |  |  | *Exo* |  |  |  |  |  |  |
| Zarca (2014) | Hip fracture | ˟ | ˟ |  |  |  | ˟ |  |  |  | Vit. D level |  | Vit. D level |
| Post-hip fracture excess mortality |  | ˟ |  |  |  |  |  |  |  |  |  |  |
| **Abbreviation:** BMD: bone mass density; BODE3: Burden of Disease Epidemiology, Equity and Cost-Effectiveness Programme studies, including Boyd (2020), Deverall (2018), Pega (2016) and Wilson (2017); CSP: Chartered Society of Physiotherapy; Funct. dep.: functional dependency; FRAT: fall risk assessment tool; LTC fall: fall requiring long-term care; MA fall: fall requiring medical attention; OMAS: Ontario Medical Advisory Secretariat; QTUG: quantitative timed up and go test; RCN: Royal College of Nursing; TUG: timed up and go test; Vit. D def.: vitamin D deficiency  **Note:** ‘*Exo*’ denotes the case where a risk factor is exogenous to the model evaluation. ‘*Single Risk*’ denotes the case where the model incorporates a single event risk/rate.  1 See Table 4.2 for study references. | | | | | | | | | | | | | |

#### 4.5.1.4 Fall-related health consequences

Table 4.6 summarises the health consequences of falls explicitly incorporated by models: i.e., where studies included separate model states and probabilities for the consequence.

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| **Table 4.6** Summary of health consequences of falls included in decision models.1 | | | | | | | |
| **Study label2** | Non-MA or non-injurious fall | MA or injurious fall | Fracture | Fatal fall | Fear of falling | Fall-induced LTC admission | Excess mortality |
| Agartioglu (2020) | ˟ | Injury | Mix3 |  |  |  |  |
| Albert (2016) | ˟ | MA |  |  |  |  |  |
| Alhambra-Borras (2019) | Com4 | Com |  |  | Com |  |  |
| Beard (2006) |  | MA |  |  |  |  |  |
| BODE3 models |  | MA |  | ˟ |  |  |  |
| Carande-Kulis (2015) |  | MA |  | ˟ |  |  |  |
| CSP (2016) | ˟ | MA |  |  |  | ˟ |  |
| Church (2011); (2012) | ˟ | MA | Mix | ˟ | ˟ | ˟ |  |
| Comans (2009) | ˟ | MA |  |  |  |  |  |
| Day (2009); (2010) | ˟ | MA |  |  |  |  |  |
| Eldridge (2005) | ˟ | MA | Hip | ˟ | ˟ | ˟ | ˟ |
| Farag (2015) | ˟ | MA |  | ˟ |  | ˟ |  |
| Franklin (2019) | ˟ | MA |  | ˟ |  | ˟ | ˟ |
| Frick (2010) |  |  | Hip | ˟ |  |  | ˟ |
| Hektoen (2009) | ˟ | Injury | Mix |  |  |  |  |
| Hiligsmann (2014) |  |  | Mix |  |  |  | ˟ |
| Hirst (2016) |  |  | Mix |  |  | ˟ |  |
| Honkanen (2006) |  |  | Hip |  |  | ˟ | ˟ |
| Howland (2015) |  | MA |  |  |  |  |  |
| Ippoliti (2018) |  |  | Hip |  |  |  |  |
| Johansson (2008) |  |  | Hip |  |  |  | ˟ |
| Lee (2013) | ˟ | MA |  |  | ˟ |  |  |
| Ling (2008) | ˟ | MA |  |  |  | ˟ |  |
| McLean (2015) | ˟ | Injury | Mix |  |  |  |  |
| Miller (2011) | ˟ | MA |  |  |  |  |  |
| Mori (2017) |  |  | Mix |  |  | ˟ | ˟ |
| Moriarty (2019) |  | MA | Hip |  |  | ˟ | ˟ |
| Nshimyumukiza (2013) |  |  | Mix |  |  | ˟ | ˟ |
| OMAS (2008) |  | MA | Mix | ˟ |  | ˟ |  |
| Poole (2014) |  |  | Hip |  |  |  | ˟ |
| Poole (2015) |  | MA |  | ˟ |  | ˟ |  |
| PHE (2018) | ˟ | MA | Mix | ˟ | ˟ | ˟ |  |
| RCN (2005) |  | MA | Hip |  |  |  |  |
| Sach (2007); (2010) | ˟ | MA |  |  |  |  |  |
| Smith (2016) |  | MA | Mix |  |  |  |  |
| Tannenbaum (2015) | ˟ | MA | Mix | ˟ | ˟ |  | ˟ |
| Turner (2020) |  | MA | Mix | ˟ |  |  |  |
| Velde (2008) | ˟ | MA |  |  |  |  |  |
| Wu (2010) | ˟ | MA |  |  |  |  |  |
| Zarca (2014) |  |  | Hip |  |  |  | ˟ |
| **Abbreviation:** BODE3: Burden of Disease Epidemiology, Equity and Cost-Effectiveness Programme studies, including Boyd (2020), Deverall (2018), Pega (2016) and Wilson (2017); Com: composite; LTC: long-term care; MA fall: fall requiring medical attention.  1 Only the health consequences that are explicitly incorporated by models are catalogued: i.e., where studies included separate model states and probabilities for each consequence.  2 See Table 4.2 for study references.  3 The model incorporated multiple specified fracture types (e.g., hip, vertebral, wrist) or a general category of fracture without specifying the component fracture types.  4 A composite measure of health consequences including recurrent falls, fear of falling and mobility and balance problems. Thus, columns for fall types and fear of falling are marked as ‘Composite’ (Com). The model also included a multivariate frailty index capturing physical, psychological and social aspects of vulnerability. | | | | | | | |

There was a noticeable between-study variation in the range of health consequences: 21 (45.7%) models included non-injurious or non-MA falls; 10 (21.7%) considered only fractures, of which six considered only hip fracture; 16 (34.8%) included fatal falls; and six (13.0%) fear of falling. In Church (2011) and (2012), and Tannenbaum (2015), fear of falling was associated with non-MA and MA fall incidence; in Lee (2013) and PHE (2018) only with MA fall; in Eldridge (2005) fear could occur independently of falls. Fifteen (32.6%) incorporated fall-induced LTC admission; 12 (26.1%) incorporated excess mortality associated with major injuries.

Since a narrower range of health consequences would underestimate the cost-effectiveness of falls prevention, several models highlighted the exclusion of specific health consequences as a limitation: fear of falling [206, 241, 361]; fatal falls [355]; and non-fracture injuries [128, 344, 368]. Yet others advocated a narrower range to focus on falls with discernible health consequences [44] and generate conservative results [359]. Regardless, the between-study variation impairs outcome comparisons.

#### 4.5.1.5 Health utilities

Table D4 in Appendix D summarises the health utilities data used for CUA, the health states to which they are applied, and their sources. Twenty-nine models incorporated health utilities; 25 sourced them from external literature. EQ-5D was the most widely used instrument by 17 models; other instruments included HUI2, HUI3, and SF-6D. Four models concurrently used multiple instruments [318, 346-348]; two used values directly elicited from TTO exercises [274, 318].

The effect of an adverse event on health utility was depicted in three main approaches: (i) assigning an absolute decrement/loss to pre-event utility level; (ii) assigning proportional (i.e., multiplier) decrement to pre-event level; and (iii) assigning a specific health utility level to post-event state. An example of each are: EQ-5D loss of 0.200 for hip fracture in the 1st year, followed by loss of 0.060 for subsequent years [352]; multiplier 0.79 for hip fracture to pre-fracture level for 1st year, followed by multiplier 0.90 for subsequent years [368]; utility level of 0.050 for bad hip fracture requiring LTC admission [274]. These illustrate the significant between-model variation in the applied utility data that reduces the comparability of CUA results.

#### 4.5.1.6 Fall-related economic consequences

Table 4.7 summarises the economic consequences of falls from the health and social care perspective. The economic consequences were marked even if only their costs were considered without separate model states (unlike health consequences in Table 4.6). Care consequences directly attributed to falls are divided into six categories: (i) ambulatory care excluding emergency department (ED), e.g., GP visit and ambulance call-out; (ii) ED visit/admission; (iii) hospitalisation; (iv) rehabilitation, e.g., outpatient; (v) short-term social care, e.g., meal-on-wheels; and (vi) LTC. The cost of LTC admission was incorporated by 26 (56.5%) models. Studies noted the technical difficulty in costing LTC admission, particularly in identifying admissions directly attributable to falls and in stratifying costs by age and life expectancy at admission [207, 359, 361].

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| **Table 4.7** Summary of economic consequences of falls from the health and social care perspective included in decision models.1 | | | | | | | |
| **Study label2** | Ambulatory care | ED | Hospital-isation | Rehabili-tation | Short-term social care | LTC admission | Comorbidity care cost |
| Agartioglu (2020) | ˟ | ˟ | ˟ |  |  |  |  |
| Albert (2016) |  | AC | AC |  |  |  |  |
| Alhambra-Borras (2019) | AC |  | AC |  |  |  |  |
| Beard (2006) | ˟ | NS | ˟ | ˟ | NS | ˟ |  |
| BODE3 models | ˟ |  | ˟ | ˟ |  |  | ˟ |
| Carande-Kulis (2015) | NS | NS | NS | NS |  |  |  |
| CSP (2016) | ˟ | ˟ | ˟ | ˟ |  | ˟ |  |
| Church (2011); (2012) | NS | ˟ | ˟ | ˟ |  | ˟ |  |
| Comans (2009) | ˟ | ˟ | ˟ | ˟ | ˟ | ˟ |  |
| Day (2009); (2010) |  |  | No cost3 |  |  |  |  |
| Eldridge (2005) | NS | NS | NS | ˟ |  | ˟ |  |
| Farag (2015) | NS | ˟ | ˟ | NS |  | ˟ |  |
| Franklin (2019) | ˟ | ˟ | ˟ | ˟ |  | ˟ |  |
| Frick (2010) | NS | NS | NS | NS | NS | NS |  |
| Hektoen (2009) | ˟ | ˟ | ˟ | ˟ | ˟ | ˟ |  |
| Hiligsmann (2014) | NS | NS | NS | NS |  | ˟ |  |
| Hirst (2016) | NS | NS | NS | NS |  | ˟ |  |
| Honkanen (2006) | ˟ | NS | ˟ | ˟ |  | ˟ | ˟ |
| Howland (2015) |  | ˟ | ˟ |  |  |  |  |
| Ippoliti (2018) |  |  | ˟ | ˟ |  |  |  |
| Johansson (2008) | ˟ | NS | ˟ | ˟ | ˟ | ˟ | ˟ |
| Lee (2013) | ˟ | NS | ˟ |  |  |  |  |
| Ling (2008) | NS | NS | NS | NS |  | ˟ |  |
| McLean (2015) | ˟ | ˟ | ˟ | ˟ |  |  |  |
| Miller (2011) | ˟ | ˟ | ˟ | ˟ |  |  |  |
| Mori (2017) | NS | NS | NS | NS |  | ˟ |  |
| Moriarty (2019) | ˟ | ˟ | ˟ | ˟ |  | ˟ |  |
| Nshimyumukiza (2013) |  | ˟ | ˟ | ˟ |  | ˟ |  |
| OMAS (2008) |  | ˟ | ˟ | ˟ |  | ˟ |  |
| Poole (2014); (2015) | ˟ | ˟ | ˟ | ˟ |  | ˟ |  |
| PHE (2018) | ˟ | ˟ | ˟ | ˟ |  | ˟ |  |
| RCN (2005) | ˟ | ˟ | ˟ | ˟ |  | ˟ |  |
| Sach (2007); (2010) | AC | AC | AC | AC | AC | AC |  |
| Smith (2016) | ˟ |  | ˟ |  |  |  |  |
| Tannenbaum (2015) |  | ˟ | ˟ |  |  |  |  |
| Turner (2020) | ˟ | ˟ | ˟ | ˟ |  |  |  |
| Velde (2008) |  | ˟ | ˟ | ˟ | ˟ | ˟ |  |
| Wu (2010) |  | ˟ | ˟ | ˟ |  |  |  |
| Zarca (2014) |  |  | ˟ |  |  |  |  |
| **Abbreviation:** AC: all-cause; BODE3: Burden of Disease Epidemiology, Equity and Cost-Effectiveness Programme studies, including Boyd (2020), Deverall (2018), Pega (2016) and Wilson (2017); CSP: Chartered Society of Physiotherapy; ED: emergency department; Int. cost only: intervention cost only; LTC: long-term care; NS: not (precisely) specified; OMAS: Ontario Medical Advisory Secretariat; PHE: Public Health England; RCN: Royal College of Nursing.  1 Economic consequences are marked even if only their costs are incorporated without separate model states or probabilities.  2 See Table 4.2 for study references.  3 The models estimated the intervention impact on hospital admission rate but not cost and used only intervention costs in conducting cost-effectiveness analysis. | | | | | | | |

Four models incorporated all-cause (‘AC’), rather than fall-specific, care consequences using primary data from intervention studies [341, 349, 350, 354]. Six models incorporated comorbidity care costs [128, 206, 241, 318, 337, 361]. The four BODE3 models incorporated annual (all-cause) healthcare cost and cost of dying that varied by age and sex; falls prevention indirectly affected these costs by changing the life expectancy and age at death via fatal fall prevention. Johansson (2008) incorporated age-stratified societal costs of added life-years measured in net consumption (production value minus consumption and care costs) but not cost of dying. In Honkanen (2006), the annual healthcare cost and cost of dying were stratified by functional dependency and residence (community vs. nursing home); fracture prevention indirectly affected these by lowering the risks of functional dependency and nursing home admission. Comorbidity care costs were hence relevant to models that incorporated fatal falls and injuries that contribute to increased frailty, care dependency, and excess mortality. Yet these costs were included in only six (listed above) of 24 models that incorporated fatal falls and/or excess mortality.

### 4.5.2 Falls prevention intervention features

As detailed in Table 4.1, falls prevention intervention features are synthesised based on: (1) intervention access pathways (Section 4.5.2.1); (2) falls risk identification methods (Section 4.5.2.2); (3) intervention resource-use and cost (Section 4.5.2.3); (4) intervention efficacy (Section 4.5.2.4); and (5) wider health effects of interventions beyond falls prevention (Section 4.5.2.5). Table D5 in Appendix D provides additional detail on intervention components by study.

#### 4.5.2.1 Intervention access pathway

Table 4.8 categorises all model-evaluated interventions by access pathway – reactive, proactive, self-referred or unclear – and intervention type. Of 101 interventions in total – counting multiple forms per study separately – nearly half (49) had unclear pathway descriptions. The most common pathway was proactive with 29 interventions, followed by self-referred (16) and reactive (7).

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| **Table 4.8** Intervention access pathways by intervention type [number of intervention forms].1 | | | | | | | | |
| **Intervention type (total N)** | **Reactive** | **N** | **Proactive** | **N** | **Self-referred** | **N** | **Unclear** | **N** |
| Exercise (33) |  | 0 | Alhambra-Borras (2019); CSP (2016); Day (2009); Eldridge (2005); Franklin (2019) [3]; Nshimyumukiza (2013); RCN (2005) | 9 | Carande-Kulis (2015) [2]; Day (2009); Day (2010); Deverall (2018) [3]; Eldridge (2005); Hektoen (2009); McLean (2015) | 10 | Church (2011) [3]; Church (2012) [4]; Frick (2010) [2]; Mori (2017); OMAS (2008); PHE (2018) [3] | 14 |
| HAM (11) | Day (2009);2 PHE (2018) | 2 | Franklin (2019); Wilson (2017)3 | 2 | Wilson (2017) | 1 | Agartioglu (2020); Church (2012); Ling (2008); OMAS (2008); Pega (2016); Frick (2010) | 6 |
| Medication review and modification (10) |  | 0 | Day (2009); Tannenbaum (2015); Turner (2020); Velde (2008) | 4 |  | 0 | Church (2011); Church (2012); Frick (2010); Hirst (2016); Moriarty (2019); OMAS (2008) | 6 |
| Cataract surgery (5) |  | 0 | Sach (2007); Sach (2010) | 2 |  | 0 | Boyd (2020); Church (2011); Church (2012) | 3 |
| Vitamin D supplement (11) | Nshimyumukiza (2013) | 1 | Hiligsmann (2014); Lee (2013) [2]; Nshimyumukiza (2013); Zarca (2014) [3] | 7 |  | 0 | Poole (2014); Poole (2015); Frick (2010); OMAS (2008) | 4 |
| Other single-component (6) | Day (2009) – cardiac pacing | 1 |  | 0 | Farag (2015) – non-specific intervention | 1 | Church (2011) – cardiac pacing; Church (2012) – cardiac pacing; Honkanen (2006) – hip protector; OMAS (2008) – gait stabiliser | 4 |
| MF int. and MF FRA (17) | Day (2009); Eldridge (2005) | 2 | Eldridge (2005); Ippoliti (2018); RCN (2005); Smith (2016); Wu (2010) | 5 | Albert (2016) | 1 | Church (2011) [2]; Church (2012) [3]; Comans (2009) [2]; Frick (2010) [2] | 9 |
| MC int. (7) | Howland (2015) | 1 |  | 0 | Beard (2006); Carande-Kulis (2015); Johansson (2008) | 3 | Church (2011); Church (2012); Miller (2011) | 3 |
| **Total (101)** |  | 7 |  | 29 |  | 16 |  | 49 |
| **Abbreviation:** CSP: Chartered Society of Physiotherapy; FRA: falls risk assessment; HAM: home assessment and modification; MC int.: multiple-component intervention; MF int.: multifactorial intervention; OMAS: Ontario Medical Advisory Secretariat; PHE: Public Health England; RCN: Royal College of Nursing  1 See Table 4.2 for study references. Number of intervention form is one unless specified.  2 For all-cause, not fall-related, hospital inpatients.  3 In alternative intervention scenario. | | | | | | | | |

Models with unclear access pathways frequently failed to mention how specific groups eligible for intervention were identified and recruited. For example, Church (2012) evaluated group exercise, HAM, and multifactorial intervention given to the high falls risk subgroup within the target population but did not mention how this subgroup would be identified; it also failed to mention how specific patient groups for cataract surgery, psychotropic medication withdrawal, and cardiac pacing would be identified.

Three models considered multiple pathways for the same intervention. Eldridge (2005) evaluated a falls risk screening and referral programme that encompassed all three pathways operating in tandem: falls patients at A&E and hospital would be screened by the falls risk assessment tool (FRAT) and referred to a multidisciplinary falls clinic (reactive pathway); primary care professionals would screen and refer high-risk individuals to the falls clinic or bi-disciplinary treatment (proactive); the low-risk individuals not referred could still self-refer to the bi-disciplinary treatment (self-referred). In Nshimyumukiza (2013), vitamin D and calcium supplementation could be initiated proactively after fracture risk screening or reactively after fracture incidence. Wilson (2017) evaluated a self-referred HAM in the base case and a proactive HAM (targeted at those with MA falls history) as an alternative scenario.

#### 4.5.2.2 Falls risk screening

Falls risk screening is required to identify subgroups within target population eligible for intervention or specific risk/patient groups serving as the target population itself. Four methods were used to model the screening process: (i) using primary data to assign individual-level distribution of falls risk factors; (ii) using external data to assign cohort-level distribution of falls risk factors; (iii) using external data on screening efficacy (i.e., sensitivity and specificity) without assigning distributions; and (iv) incorporating screening cost only. Two models used (i): Eldridge (2005) used primary survey data to estimate falls risk according to FRAT; Smith (2016) used routine data to predict falls risk. Three used (ii): Lee (2013) assigned age- and sex-stratified prevalence of vitamin D insufficiency; Zarca (2014) a lognormal distribution of vitamin D level; and Nshimyumukiza (2013) a distribution of BMD level. Screening detected (with perfect precision) vitamin D or BMD insufficiency for intervention referrals.

Two used (iii): CSP (2016) assumed that the sensitivity and specificity of the TUG test were both 87% regardless of the underlying distribution of gait/balance impairment; following screening, the 11% highest risk individuals from each five-year age group were referred to physiotherapy. The latter assumption is problematic given that older age groups likely have higher proportions of high-risk individuals (unless the test cut-off levels varied across age groups). Franklin (2019) similarly incorporated fixed efficacies for TUG and quantitative TUG (QTUG) without modelling the underlying gait/balance distribution. A disadvantage of this approach is that subgroup variation in the joint distributions of diverse falls risk factors would introduce subgroup differences in the screening efficacy not explored by Franklin (2019). Seven used (iv) [146, 167, 343, 347-350]: e.g., RCN (2005) included the cost of identifying eligible high-risk individuals.

#### 4.5.2.3 Intervention resource-use and cost

Table 4.9 summarises the intervention resource-use and cost from the public sector perspective (see Section 4.5.3.1 for societal intervention costs). The resources are divided into auxiliary resources facilitating implementation and resources generating therapeutic effects. Exercise and multiple-component interventions were most likely to incorporate these auxiliary resources: e.g., marketing to assist exercise uptake [358]. Regarding auxiliary resources for falls risk screening, two models failed to cost their screening tools [44, 359]. Three models included set-up costs [274, 342, 363]. There were noticeable between-study variations in resource incorporation for each intervention type.

Therapeutic resources included labour, training, transport, venue and overheads, and health technology and equipment. Labour was the most widely costed resource, including labour performed by nonprofessional volunteers and reimbursed by the public sector [200, 342, 354, 361]. Models evaluating technology-based interventions such as hip protector and gait stabiliser tended to neglect the cost of contributory labour [318, 336, 345, 347, 356, 365-367]. Training costs were concentrated in exercise interventions; only three non-exercise evaluations incorporated them [342, 354, 358]. Staff transport costs were concentrated in models evaluating exercise, HAM, and multifactorial intervention. Venue costs and overheads were generally included as simple supplements to per-participant labour cost: e.g., Frick (2010) increased the labour cost by 50% to account for overheads; Velde (2008) by 72%. All intervention types required some technology and equipment; yet not all models detailed or costed them. For example, Frick (2010) costed the labour but not the equipment for HAM.

In costing the interventions, preserving the distinction between fixed and variable (i.e., per-participant) costs had a significant impact on results. For example, Eldridge (2005) incorporated the fixed cost in running the falls clinic which, under a low uptake rate (6.5% of eligible population), increased the per-participant cost and reduced the cost-effectiveness. Likewise, Comans (2009) included annual fixed cost of multifactorial intervention, which determined the uptake rate required to break-even financially. Despite this, 36 (78.3%) models only incorporated per-participant costs, some deliberately translating fixed costs into per-participant rates [167, 206, 342, 353].

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| **Table 4.9** Intervention resource-use and cost from the public sector perspective in included decision models. | | | | | | | | | | | |
|  |  | **Auxiliary implementation resources1** | | | | **Therapeutic resources1** | | | | | **Cost** |
| **Study label2** | **Intervention** | Initial access | Compliance & sustain. | Falls risk screening | Set-up; other | Staff labour | Training | Staff transport | Venue & Overhead | Health tech. & equipment | Summary |
| ***Exercise*** | | | | | | | | | | | |
| Alhambra-Borras (2019) | Group exercise |  |  |  |  | ˟ |  |  |  |  | PP |
| Carande-Kulis (2015) | Home exercise | ˟ |  |  |  | ˟ | ˟ | ˟ |  |  | PP |
| Tai Chi (group) | ˟ |  |  |  | ˟ | ˟ |  |  |  | PP |
| CSP (2016) | FRS and physiotherapy (group or home) |  |  | Not costed |  | ˟ |  |  |  |  | Per staff; Total |
| Day (2009) | Home exercise3 | ˟ |  | ˟ |  | ˟ | ˟ | ˟ |  | ˟ | PP |
| Day (2009); (2010) | Tai Chi (group) | ˟ | ˟ |  |  | ˟ |  |  | VN | ˟ | PP |
| Deverall (2018) | Home exercise | ˟ |  |  |  | ˟ |  |  | OH | ˟ | PP |
| Group exercise (peer-led) |  |  |  |  | ˟ | ˟ | ˟ |  |  | PP |
| Franklin (2019) | FRS and home exercise |  |  | ˟ | Set-up; Eval. cost | ˟ | ˟ | ˟ |  | ˟ | Fixed & PP |
| FRS and group exercise (FaME) |  |  | ˟ | Set-up; Eval. cost | ˟ | ˟ | ˟ | VN&OH | ˟ | Fixed & PP |
| FRS and Tai Chi (group or home) |  |  | ˟ | Set-up; Eval. cost | ˟ | ˟ | ˟ | VN&OH | ˟ | Fixed & PP |
| Frick (2010) | Muscle & balance training |  |  |  |  | ˟ |  | ˟ | OH |  | PP |
| Tai Chi |  |  |  |  | ˟ |  | ˟ | OH |  | PP |
| Hektoen (2009) | Home exercise | ˟ |  |  |  | ˟ |  |  |  | ˟ | PP |
| McLean (2015) | Group + home exercise | ˟ |  |  |  | ˟ |  |  | VN&OH | ˟ | PP |
| Mori (2017) | Home exercise | ˟ |  |  |  | ˟ | ˟ | ˟ |  |  | PP |
| OMAS (2008) | Group exercise |  |  |  |  | ˟ |  |  |  |  | PP |
| PHE (2018) | Home exercise |  |  |  | Eval. cost | ˟ | ˟ | ˟ |  | ˟ | PP |
| Group exercise (FaME) |  |  |  | Eval. cost | ˟ | ˟ | ˟ | VN&OH | ˟ | PP |
| Tai Chi (group or home) |  |  |  | Eval. cost | ˟ | ˟ | ˟ | VN&OH | ˟ | PP |
| Nshimyumukiza (2013) | BMD screening and physical activity | ˟ |  | BMD |  |  |  |  |  |  | PP |
| RCN (2005) | FRS and exercise (unspecified) |  |  | ˟ |  | Not specified | | | | | PP |
| ***Home assessment and modification (HAM)*** | | | | | | | | | | | |
| Agartioglu (2020) | HAM |  |  |  | ˟ | ˟ |  | ˟ |  | ˟ | PP |
| Day (2009) | HAM (reactive)3 |  |  | Not costed |  | ˟ |  | ˟ |  | ˟ | PP |
| PHE (2018) | HAM (reactive) |  |  |  | Eval. cost | ˟ |  |  | OH | ˟ | PP |
| Franklin (2019) | FRS and HAM |  |  | ˟ | Set-up; Eval. cost | ˟ |  |  | OH | ˟ | Fixed & PP |
| Frick (2010) | HAM |  |  |  |  | ˟ |  | ˟ | OH |  | PP |
| Ling (2008) | HAM |  |  |  |  | ˟ |  |  |  | ˟ | PP |
| OMAS (2008) | HAM |  |  |  |  | ˟ |  |  |  | ˟ | PP |
| Pega (2016) | HAM |  |  |  |  | ˟ |  |  |  | ˟ | PP |
| Wilson (2017) | HAM | ˟ |  | ˟ |  | ˟ |  |  |  | ˟ | PP |
| ***Medication review and change*** | | | | | | | | | | | |
| Day (2009) | FRS and psychotropic withdrawal3 |  |  | ˟ |  | ˟ |  |  |  | ˟ | PP |
| Frick (2010) | Psychotropic withdrawal |  |  |  |  | ˟ |  |  | OH | Not specified | PP |
| Hirst (2016) | Pain medication change |  |  |  |  |  |  |  |  | ˟ | PP |
| Moriarty (2019) | Change in PIP benzodiazepine and PPI |  |  |  |  | ˟ |  |  |  | ˟ | PP |
| OMAS (2008) | Psychotropic withdrawal |  |  |  |  | ˟ |  |  |  | Not specified | PP |
| Tannenbaum (2015) | FRS and insomnia drug vs. CBT |  |  | ˟ |  |  |  |  |  | ˟ | PP |
| Turner (2020) | Sedatives withdrawal |  |  | ˟ |  | ˟ |  |  |  | ˟ | PP |
| Velde (2008) | FRID withdrawal |  |  |  |  | ˟ |  |  | OH | ˟ | PP |
| ***Expedited cataract surgery*** | | | | | | | | | | | |
| Boyd (2020) | Expedited and routine surgeries |  |  |  |  | ˟ |  |  |  | ˟ | PP |
| Church (2011); (2012) | Expedited surgery |  |  |  |  | ˟ |  |  |  | ˟ | PP |
| Sach (2007); (2010) | Expedited surgery |  |  | ˟ |  | ˟ |  |  |  | ˟ | Total |
| ***Vitamin D supplementation*** | | | | | | | | | | | |
| Lee (2013) | Vit. D screening and supplementation |  |  | Vit. D |  |  |  |  |  | ˟ | Unit cost |
| Zarca (2014) | Vit. D screening and supplementation |  |  | Vit. D |  | ˟ |  |  |  | ˟ | Unit cost |
| Frick (2010) | Vit. D |  |  |  |  | ˟ |  |  | OH | Not specified | PP |
| Hiligsmann (2014) | Vit. D screening and Vit. D + calcium |  |  | BMD |  | ˟ |  |  |  | ˟ | PP |
| Nshimyumukiza (2013) | Vit. D screening and Vit. D + calcium |  |  | BMD |  |  |  |  |  | ˟ | PP |
| OMAS (2008) | Vit. D + calcium |  |  |  |  |  |  |  |  | ˟ | PP |
| Poole (2014); (2015) | Vit. D |  |  |  |  |  |  |  |  | ˟ | PP |
| ***Other single-component interventions*** | | | | | | | | | | | |
| Day (2009) | Cardiac pacing3 |  |  | ˟ |  | ˟ |  |  |  | ˟ | PP |
| Honkanen (2006) | Hip protector |  |  |  |  |  |  |  |  | ˟ | PP |
| OMAS (2008) | Gait stabiliser |  |  |  |  |  |  |  |  | ˟ | PP |
| ***Multifactorial intervention and risk assessment*** | | | | | | | | | | | |
| Albert (2016) | MF int. |  | ˟ |  |  | ˟ | ˟ |  |  |  | PP |
| Comans (2009) | MF int. |  |  |  |  | ˟ |  | ˟ |  | ˟ | Fixed & PP |
| Day (2009) | FRS and MF int.3 | ˟ |  | ˟ |  | ˟ |  |  | OH | ˟ | PP |
| Eldridge (2005) | FRS and falls clinic MF int. or balance and gait treatment | ˟ | ˟ | ˟ | Set-up | ˟ |  |  | VN&OH | ˟ | Fixed & PP |
| Frick (2010) | MF int. |  |  |  |  | ˟ |  | ˟ | OH |  | PP |
| MF int. for high risk |  |  |  |  | ˟ |  | ˟ | OH |  | PP |
| Ippoliti (2018) | MF int. |  |  |  |  | ˟ |  | ˟ |  |  | Total |
| RCN (2005) | FRS and MF int. |  |  | ˟ |  | Not specified | | | | | PP |
| Smith (2016) | FRS and MF int. |  |  | Not costed |  | Not specified | | | | | PP |
| Wu (2010) | MF int. |  |  |  |  | Not specified | | | | | PP |
| Church (2011); (2012) | MF risk assessment |  |  |  |  | ˟ |  |  |  |  | PP |
| ***Multiple-component intervention*** | | | | | | | | | | | |
| Beard (2006) | MC (intersectoral) int.4 | ˟ |  |  |  | ˟ |  |  | OH |  | Annual total |
| Carande-Kulis (2015) | Stepping On5 | ˟ | ˟ |  |  | ˟ | ˟ |  | VN |  | PP |
| Howland (2015) | MoB (lay-led) | Not costed |  |  |  | Not specified | | | | | PP |
| Johansson (2008) | MC (intersectoral) int.6 | ˟ | ˟ |  |  | ˟ |  |  | VN&OH | ˟ | Total |
| Miller (2011) | MoB (lay-led) |  | ˟ |  | Set-up | ˟ | ˟ |  |  | ˟ | PP |
| **Abbreviation:** BMD: bone mineral density; CBT: cognitive behavioural therapy; Compliance & sustain.: compliance and sustainability; CSP: Chartered Society of Physiotherapy; FaME: Falls Management Exercise programme; FRID: fall-risk increasing drug; FRS: falls risk screening; Health tech.: health technology; Int.: intervention; MC: multiple-component; MF: multifactorial; MoB: Matter of Balance; OH: overhead; OMAS: Ontario Medical Advisory Secretariat; PHE: Public Health England; PIP: potential inappropriately prescribed; PP: per participant; PPI: proton pump inhibitor; PT: physiotherapy; RCN: Royal College of Nursing; VN: venue  1 ‘Not costed’ refers to cases where resource use is mentioned but not costed. ‘Not specified’ refers to cases where summary cost is reported but component resources are not, requiring inference on the likely components.  2 See Table 4.2 for study references.  3 Same intervention resource use and cost data were used by Church (2011) and (2012).  4 Intervention included individually tailored education, HAM and exercise and public space safety improvement.  5 Church (2011) and (2012) cite the same RCT as the source of intervention resource use and cost; but the final PPY mean costs differ.  6 Intervention included individually tailored education, group balance exercises, Tai Chi, other physical activities and HAM, neighbourhood hazard removal and housing reconstruction. | | | | | | | | | | | |

#### 4.5.2.4 Intervention efficacy

Table 4.10 specifies the fall-related event used for the intervention efficacy and, in parenthesis, the main fall-related event used to characterise falls risk/rate. Twelve (26.1%) models did not incorporate matching events (highlighted in bold). Thirty-six (78.3%) sourced efficacy data from internal or external RCTs and meta-analyses, while three used observational studies [336, 345, 347]. On using external RCT data, several models questioned whether it can be generalised to routine practice [167, 200, 216, 340, 353, 358, 367]; Mori (2017) down-adjusted the RCT-based efficacy by 40% for generalisation. The fifth column details the efficacy and, in parenthesis, incidence metrics. The metrics did not match in 12 (26.1%) models: e.g., Deverall (2018) applied rate ratio (RaR; i.e., reduction in number of falls, not fallers) on individual falls risk (determining number of fallers).

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| **Table 4.10** Summary of intervention efficacy data used by decision models. | | | | | |
| **Study label1** | Intervention type | Efficacy (main model) fall-related event | Data source type | Efficacy (incidence) metric | Effectiveness period2 (model time horizon) |
| Agartioglu (2020) | HAM | Any fall  (any fall) | External meta-an. and internal RCT | RR (risk) | 1 year (1 year) |
| Albert (2016) | Multifactorial int. | Any fall  (any fall) | Internal non-randomised | RR (risk) | 1 year (1 year) |
| Alhambra-Borras (2019) | Group exercise | Composite3 (composite) | Internal quasi-experiment | RR (risk) | 1 year (lifetime) |
| Beard (2006) | Multifactorial int. | Hospital fall (hospital fall) | Internal quasi-experiment | RaR (rate) | 5-year sustainability (5 years) |
| Boyd (2020) | Expedited cataract surgery | Any fall  (**MA fall**) | External RCT | RR (risk) | 1 year4 (lifetime) |
| Carande-Kulis (2015) | Multiple types | Any fall  (**MA fall**) | External RCTs | RR or RaR (**risk**) | 1 year (1 year) |
| CSP (2016) | Physiotherapy | Any fall  (**MA fall**) | External meta-an. | RaR (**risk**) | 1 year (1 year) |
| Church (2011) | Multiple types | Any fall  (any fall) | External meta-an. | RaR (**risk**) | Efficacy durability differ by int. type (10 years) |
| Church (2012) | Multiple types | Any fall  (any fall) | External meta-an. | RaR (**risk**) | Efficacy durability differ by int. type (lifetime) |
| Comans (2009) | Multifactorial int. | Any fall  (any fall) | External RCT | RaR (**risk & rate**) | 1 year (1 year) |
| Day (2009) | Multiple types | Any fall  (any fall) | External RCTs | RaR (rate) | Efficacy durability same as model time (1, 2 or 5 years) |
| Day (2010) | Tai Chi | Any fall  (any fall) | External meta-an. | RaR (rate) | 1 year (1 year) |
| Deverall (2018) | Multiple exercise types | Any fall  (**MA fall**) | External meta-an. | RaR (**risk**) | Varying persistence  (25 years) |
| Eldridge (2005) | FRAT; balance and gait int. | Any fall  (any fall) | External meta-an. | RR (risk) | Not specified (lifetime) |
| Farag (2015) | Unspecified | Any fall  (any fall) | Assumption | RR (risk) | Not specified  (lifetime) |
| Franklin (2019) | Multiple types | Any fall  (any fall) | External meta-an. and RCTs | RR and RaR (risk & rate) | 1 year (2 years) |
| Frick (2010) | Multiple types | Any fall  (**hip fracture**) | External meta-an. | RR (risk) | 1 year  (1 year5) |
| Hektoen (2009) | Home exercise | Any fall  (any fall) | External RCT | RaR (rate) | 1 year (1 year) |
| Hiligsmann (2014) | Vit. D + calcium supplement | Mix fracture; (mix fracture) | External meta-an. | RR (risk) | 6 years6 (lifetime) |
| Hirst (2016) | Buprenorphine vs. Tramadol | Mix fracture  (mix fracture) | External surveys | OR (risk) | 1 year (1 year) |
| Honkanen (2006) | Hip protector | Hip fracture  (hip fracture) | External RCT | RR (risk) | Varying persistence  (20 years) |
| Howland (2015) | Matter of Balance lay-led | MA fall  (MA fall) | External RCT | RR (risk) | 1 year (1 year) |
| Ippoliti (2018) | Multifactorial int. | Hip fracture  (hip fracture) | Policy variable | RaR (rate) | 3 years (3 years) |
| Johansson (2008) | Multifactorial int. | Hip fracture  (hip fracture) | Internal quasi-experiment | RaR (**risk**) | 1 year (lifetime) |
| Lee (2013) | Vit. D screening & supplement | Any fall  (any fall) | External meta-an. | RR (risk) | 2.5 years (3 years) |
| Ling (2008) | HAM | Any fall  (any fall) | External RCT | RR (risk) | 1 year (1 year) |
| McLean (2015) | Exercise | Any fall  (any fall) | Internal RCT | RR (risk) | 1.5 years (1.5 years) |
| Miller (2011) | Matter of Balance lay-led | Any fall  (any fall) | Policy variable | RR (risk) | 2 years (2 years) |
| Mori (2017) | Exercise & bisphosphonate | Mix fracture  (mix fracture) | External meta-analyses | RR or RaR (**risk**) | 1/2 year maintenance (lifetime) |
| Moriarty (2019) | Withdrawal of PIP mediations | MA fall/Hip fracture (MA fall/hip fracture) | External RCTs | RR (risk) | Lifetime persistence (35 years) |
| Nshimyumukiza (2013) | Exercise, Vit. D + calcium & osteoporosis int. | Mix fracture (mix fracture) | External meta-an. & surveys | RR (risk) | Lifetime sustainability  (lifetime) |
| OMAS (2008) | Multiple types | Any fall  (**MA fall**) | Internal meta-an. | RR (risk) | Lifetime persistence for 1st year adherers (lifetime) |
| Pega (2016); Wilson (2017) | HAM | Any fall  (**MA fall**) | External meta-an. | RaR (**risk**) | Lifetime or 10-year efficacy (lifetime) |
| Poole (2014) | Vit. D supplement | Hip fracture  (hip fracture) | External meta-an. | HR (rate) | 1 year (1 year) |
| Poole (2015) | Vit. D supplement | Any fall  (**MA fall**) | External meta-an. | RR (risk) | 5 years maintenance  (5 years) |
| PHE (2018) | Multiple types | Any fall  (any fall) | External meta-an. and RCTs | RaR (rate) | 2 years (2 years) |
| RCN (2005) | Multiple types | Any fall  (**MA fall**) | External meta-an. | RR (risk) | Not specified  (lifetime) |
| Sach (2007); (2010) | Expedited cataract surgery | Any fall  (any fall) | Internal RCT | RaR (rate) | Lifetime efficacy durability (lifetime) |
| Smith (2016) | Risk prediction; Multifactorial int. | Any fall  (**MA fall**) | External meta-an. | RaR (**risk**) | 1 year (1 year) |
| Tannenbaum (2015) | Insomnia treatments | Any fall  (any fall) | External surveys | OR (risk) | Not specified  (1 or 5 years) |
| Turner (2020) | Sedative withdrawal | Hip/non-hip fracture (**MA fall, hip/non-hip fracture**) | External RCT | RaR (**risk**) | 1 year (1 year) |
| Velde (2008) | FRID withdrawal | Any fall  (any fall) | Internal non-randomised | RaR (rate) | 1 year (1 year5) |
| Wu (2010) | Multifactorial int. | Any fall  (any fall) | External meta-an. | RR (risk) | 1 year (1 year) |
| Zarca (2014) | Vit. D screening & supplement | Vit. D level  (vit. D level) | External meta-an. and RCT | Other7 | Varying persistence (lifetime) |
| **Abbreviation:** CSP: Chartered Society of Physiotherapy; FRID: fall-risk-increasing drug; HAM: home assessment and modification; MA fall: fall requiring medical attention; Met-An.: meta-analysis; OMAS: Ontario Medical Advisory Secretariat; OR: odds ratio; PHE: Public Health England; PIP: potential inappropriately prescribed; RaR: rate ratio; RCN: Royal College of Nursing; RCT: randomised controlled trial; RR: relative risk; Vit. D: vitamin D  1 See Table 4.2 for study references.  2 The effectiveness period is a function of efficacy durability and implementation sustainability. Key determinants of sustainability are demand-side *persistence* and supply-side *maintenance*; not all studies made this distinction.  3 This model used a composite outcome including fall-related consequences – recurrent falls, fear of falling and mobility and balance problems – and multivariate frailty index – physical, psychological and social aspects of vulnerability.  4 Also includes benefit of cataract surgery on vision: permanent increase of 0.0565 quality-adjusted life year per person.  5 The study contained a single one-year cycle but included lifetime healthcare costs and effects of hip fracture.  6 After three years of vitamin D and calcium supplementation, the efficacy would remain for further three years, though declining linearly over that period.  7 Supplementation increased the vitamin D level which in turn reduced hip fracture risk. | | | | | |

Table 4.10 also compares the model horizon with the ‘effectiveness period’, i.e., a function of efficacy durability and implementation sustainability. Several studies contained significant disparities between the model horizon and the effectiveness period. For example, Mori (2017) restricted the effectiveness period to one year within a lifetime horizon to produce conservative outcomes. Several lifetime models incorporated long-term effectiveness for individuals who persisted in intervention uptake [318, 346, 361, 366, 368]. Models made diverse assumptions on post-implementation efficacy often without justification [216, 342, 343, 351, 360]. For example, Church (2011) and (2012) incorporated lifetime efficacy for expedited cataract surgery and cardiac pacing but one-year efficacy for other interventions; unsurprisingly, the latter were significantly less cost-effective. Some deliberately curtailed the model horizon to reduce the discrepancy with the effectiveness period [167, 216, 353, 356]. See Section 4.5.3.3 for further discussion on modelled implementation sustainability.

#### 4.5.2.5 Wider health effects of interventions

Few models incorporated wider health effects of interventions beyond falls prevention. Hiligsmann (2014) evaluated a scenario where vitamin D and calcium supplementation reduced the background mortality risk. Alhambra-Borras (2019) incorporated the effect of falls prevention exercise on frailty reduction. Boyd (2020) allowed cataract surgery to generate QALY gain through vision improvement. Models that incorporated all-cause care costs captured wider health effects without specifying the mechanism [349, 350, 354]. Other models mentioned their non-incorporation as a limitation [128, 167, 200, 336, 342, 344, 353, 358, 359, 361, 368]. Deverall (2018), for example, stated that the non-incorporation of exercise benefit on cardiovascular disease (CVD) risk reduction potentially biased the evaluation against the ethnic Maori subgroup who have greater CVD risk.

Two models incorporated *adverse* health effects and process costs of interventions. Hirst (2016) considered the side-effect of transdermal buprenorphine as a replacement for (more fall-risk-inducing) tramadol in chronic pain management. Honkanen (2006) expressed the process/social cost of hip protector use through a health utility decrement of 0.010 for each year of use. Due to the decrement, younger groups aged 65 and 70 experienced overall QALY *loss* from hip protector use despite fractures being prevented.

### 4.5.3 Key challenges for public health economic modelling

The modelling methodological features are synthesised by the four key challenges: (1) capturing non-health outcomes and societal intervention costs (Section 4.5.3.1); (2) considering heterogeneity and dynamic complexity (Section 4.5.3.2); considering theories of human behaviour and implementation (Section 4.5.3.3); and considering issues of equity (Section 4.5.3.4).

#### 4.5.3.1 Capturing non-health outcomes and societal intervention costs

Eighteen models operationalised analyses from the societal perspective (Table 4.2). Of these, 15 described the non-health outcomes and/or societal intervention costs incorporated in the analyses, as shown in Table 4.11. The three models not included in Table 4.11 conducted evaluations from the US healthcare perspective (broader than Medicare/Medicaid) including private healthcare costs but did not specify the cost type or proportion by sector [200, 338, 352]. Further studies specified non-inclusion of non-health outcomes or societal intervention costs as limitations [207, 336, 347, 355, 358, 365, 367]

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| **Table 4.11** Non-health outcomes and societal intervention costs included in decision models. | | | | | | | |
| **Study label1** | **Non-health outcomes** | | | | **Societal intervention costs** | | |
| Social wellbeing | Out-of-pocket expenditure | Productivity | Informal caregiver burden | Social cost | Private co-payment | Time opportunity cost2 |
| Beard (2006) |  |  |  |  |  | ˟ | Not costed |
| Carande-Kulis (2015) |  |  |  |  |  |  | ˟ |
| Comans (2009) |  |  |  |  |  | ˟ |  |
| Day (2009); (2010) |  |  |  |  |  | ˟ |  |
| Deverall (2018) |  |  |  |  |  | ˟ | Not costed |
| Hektoen (2009) |  | ˟ |  |  |  |  |  |
| Hiligsmann (2014) |  | ˟ |  |  |  |  |  |
| Honkanen (2006) | ˟ |  |  |  | ˟ |  |  |
| Johansson (2008) |  |  | ˟ | ˟ |  | ˟ | ˟ |
| Miller (2011) |  |  |  |  |  | ˟ | ˟ |
| Mori (2017) |  |  |  |  |  |  | ˟ |
| Sach (2007); (2010) |  | ˟ |  | ˟ |  |  |  |
| Wu (2010) |  | Private insurance |  |  |  |  |  |
| 1 See Table 4.2 for study references.  2 Time opportunity cost of older participants and volunteers corresponding to productivity. No study incorporated time opportunity cost of informal caregivers attending intervention corresponding to informal caregiver burden; there is hence no dedicated column. | | | | | | | |

Only Honkanen (2006) incorporated the social wellbeing loss of fracture-induced residence change from community to nursing home, expressed within a health utility decrement. Other models similarly assigned utility decrements for LTC admission, but it was unclear whether these were specifically associated with residence change or with severity of admission-related fall [351, 360, 362, 363]. The use of health utilities to express social wellbeing is noteworthy given their narrow health dimensions. Studies frequently mentioned the exclusion of non-health benefits of exercise interventions, particularly regarding social participation [344, 353, 361] and broader wellbeing (e.g., self-confidence) gains [358, 359]. On the intervention cost side, Honkanen (2006) expressed the social cost of hip protector use (discomfort, embarrassment) again within a health utility decrement; the impact was significant, producing an overall QALY *loss* from intervention for younger subgroups.

Five models incorporated OOP care expenditure: transport costs for fallers [335]; home care [349, 350]; non-specific care [343]; and cost of private insurance [340]. Of these, none incorporated private co-payments as an intervention cost. Seven incorporated intervention co-payments borne by individuals or organisations (but not OOP care expenditure): exercise enrolment [127, 167, 353]; transport cost for participants [207]; venue hire [342, 361]; and local stakeholder involvement [128].

Only Johansson (2008) included productivity as outcome. Specifically, the productivity value (net consumption) was assigned by age group; hip fractures would then reduce net productivity by shortening life-years. On the intervention cost side, Johansson (2008) included the time opportunity costs of unpaid volunteering and older persons’ participation. Three further models incorporated time opportunity costs of volunteers/participants but not productivity outcomes [342, 344, 358]. Two models mentioned volunteer time commitments but did not apply monetary values [127, 361].

Three models incorporated informal caregiver burden as productivity loss [128, 349, 350]; none incorporated the health impact on caregivers. Likewise, none incorporated the informal caregivers’ time opportunity cost in accompanying intervention participants.

Two models – both evaluating a combined programme of environmental modifications and multifactorial intervention – discussed the intervention impact on community empowerment but did not quantify it [127, 128]. Both also perceived community involvement – community healthcare staff raising falls risk awareness [127] and local stakeholders designing and delivering interventions [128] – solely as intervention costs rather than as empowerment.

Where outcomes are generated and costs incurred outside the public healthcare system, their valuation methods should change accordingly [145]. Yet only Beard (2006) used the value of a statistical life to estimate the *consumption* value of disability-adjusted life year (DALY) burden of falls under CBA. There may also be differences in productive efficiencies between the healthcare sector and wider society, leading to intersectoral variations in cost-effectiveness thresholds [161]. Yet Beard (2006) did not account for the threshold differential under CBA. Incorporating such differential may have changed the final decision in further models [349, 350, 361].

Overall, comprehensive incorporation of non-health outcomes and societal intervention costs is infrequent among models operationalising analyses from the societal perspective. A pressing issue is the balanced incorporation of non-health outcomes and societal intervention costs to prevent models over-estimating (if intervention costs are excluded) or under-estimating (if outcomes excluded) the cost-effectiveness of interventions.

#### 4.5.3.2 Considering heterogeneity and dynamic complexity

##### Heterogeneity

Overall, 27 (58.7%) models conducted at least one analysis related to heterogeneity. Table 4.12 categorises these analyses into subgroup analysis (SA), targeting analysis (TA), and analysis of heterogeneous intervention needs (IN) and specifies the relevant subgroup delineating variables. The table excludes studies that targeted specific patient groups from the outset, e.g., cataract patients [349].

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| **Table 4.12** Methods for assessing heterogeneity in decision models. | | | | | | | |
| **Study label1** | **Subgroup delineating variables** | | | | | | |
| Age | Sex | Social | Falls history | Falls risk2 | Chronic disease & Med. use | Physical capacity |
| Alhambra-Borras (2019) | SA | SA |  |  |  |  |  |
| Boyd (2020) | SA | SA | SA: ethnic. | SA |  |  |  |
| Carande-Kulis (2015) | TA |  |  | TA |  |  |  |
| CSP (2016) |  |  |  |  |  |  |  |
| Day (2009) | IN |  |  | IN |  | IN | IN |
| Deverall (2018) | TA | SA | SA: ethnic. |  |  |  |  |
| Eldridge (2005) |  |  |  | IN | IN |  |  |
| Franklin (2019) | TA |  |  |  |  |  |  |
| Hiligsmann (2014) | TA | TA |  |  |  |  |  |
| Hirst (2016) | TA |  |  |  |  |  |  |
| Honkanen (2006) | TA | TA |  |  |  |  | SA |
| Ippoliti (2018) |  |  | SA: region |  |  |  |  |
| Johansson (2008) | SA | SA |  |  |  |  |  |
| Lee (2013) | SA | SA |  |  |  |  | TA |
| McLean (2015) |  | SA |  |  |  |  |  |
| Mori (2017) | TA |  |  |  |  | TA |  |
| Moriarty (2019) |  |  |  |  |  | Separate models3 |  |
| Nshimyumukiza (2013) | TA |  |  |  |  | IN |  |
| OMAS (2008) |  | SA; IN |  |  | IN | IN | IN |
| Pega (2016) | TA | SA | SA: ethnic. | TA |  |  |  |
| Poole (2014) | SA; TA | SA |  |  |  |  |  |
| Poole (2015) | SA; TA |  |  |  |  |  |  |
| PHE (2018) |  |  |  | IN |  |  |  |
| Smith (2016) |  |  |  |  | TA |  |  |
| Wilson (2017) | TA | SA | SA: ethnic. | TA |  |  |  |
| Wu (2010) | SA |  |  |  |  |  |  |
| Zarca (2014) | TA | SA |  |  |  |  | TA |
| **Abbreviation:** CSP: Chartered Society of Physiotherapy; ethnic.: ethnicity; Exo: exogenous; Int.: intervention; IN: intervention need; Med.: medication; OMAS: Ontario Medical Advisory Secretariat; PHE: Public Health England; RCN: Royal College of Nursing; SA: subgroup analysis; TA: targeting analysis  1 See Table 4.2 for study references.  2 Models which evaluated a falls risk screening process and targeted intervention at high fall risk individuals in base case analysis but did not explore alternative non-targeted or differently targeted scenario(s) (e.g., CSP (2016) and Franklin (2019)) were not marked as having performed TA.  3 The study constructed separate models for non-steroidal anti-inflammatory drug, benzodiazepine and proton pump inhibitor users. The latter could be interpreted as intervention subgroups within the same target population. | | | | | | | |

Age and sex were the most common delineating characteristics, used in 24 models. The use of social characteristics was infrequent: four models from the same BODE3 research group used ethnicity [206, 241, 337, 361], while one used health authority region [364]. Smith (2016) compared different cut-off levels (i.e., targeting scenarios) based on multivariate falls risk estimated from routine data. Osteoporosis and carotid sinus hypersensitivity were the only chronic disease factors [167, 336, 344]; psychotropic medication use delineated intervention need in two models [167, 366]. Physical capacity factors included mobility, functional status and vitamin D level. Five models incorporated heterogeneous intervention subgroups [167, 216, 274, 336, 366]; of these, two incorporated non-mutually exclusive interventions [274, 336].

Pega (2016) was unique in characterising heterogeneity in efficacy for the same intervention across recipient subgroups: in one scenario analysis, the falls rate ratio of HAM compared to usual care was set to be 0.62 for those at high falls risk and 0.94 for low risk. Studies generally favoured the use of pooled efficacy estimates from meta-analyses: 23 of 35 models using external efficacy sourced meta-analysis estimates (Table 4.10); however, pooled estimates can mask heterogeneity in efficacy. With some exceptions [207, 216, 241, 363], there was little effort to discern whether a single or pooled estimate would better reflect the heterogeneity in efficacy**.** Likewise, heterogeneity in intervention cost was poorly modelled: only Honkanen (2006) allowed the hip protector cost to vary by recipients’ functional status and residence.

An issue in several models concerned how evaluation outcomes were compared across heterogeneously sized target subgroups. Specifically, there was a need to compare both incremental cost-per-unit ratios (e.g., ICER) and aggregate outcomes (e.g., total INMB). An intervention tailored to a specific subgroup may generate a very favourable cost-per-unit ratio but a low aggregate benefit due to the small subgroup size. Accordingly, Day (2009) compared both the ICER and total falls prevented across six heterogeneously sized subgroups with different intervention needs; here, Otago exercise had the least favourable ICER (although still cost-effective) but the most favourable aggregate impact in terms of the number of hospitalised falls prevented. By contrast, Moriarty (2019) estimated the most favourable ICER for modification of inappropriate non-steroidal anti-inflammatory drug (NSAID) relative to benzodiazepine and proton pump inhibitor (PPI) modifications (all three dominated no modification as comparator); however, the prevalence of inappropriate NSAID use was 4.1% compared to 23.6% for PPI. Hence, if aggregate benefits are considered, PPI modification likely becomes the policy priority, not NSAID as concluded by the study. Likewise, PHE (2018) estimated that HAM had the most favourable ROI and ICER (with ‘no intervention’ as comparator) relative to three exercise interventions; but HAM targeted a subgroup 17 times smaller than the latter, thus generating the smallest INMB.

##### Dynamic complexity

Table 4.13 shows the time-variant falls risk factors and determinants of background health (expressed in health utility values) and comorbidity care costs incorporated in 17 models (13 cohort- and four individual-level Markov models) with time horizons longer than five years.

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| **Table 4.13** Time-variant falls risk factors and determinants of background health utility and care cost progressions in non-binary models with horizons longer than five years. | | | | | |
|  | **Time-variant falls risk factors** | | | **Background2 health/cost determinants** | |
| **Study label1** | **Age** | **Falls incidence** | **Other** | **Health utility** | **Comorbidity care cost** |
| **Cohort-level Markov models3** | | | | | |
| Boyd (2020) | Tunnel state?4 | MA fall |  | Age5 | Age5 |
| Church (2011); (2012) | Tunnel state? | Any fall |  | Age6 |  |
| Deverall (2018) | Tunnel state? | MA fall |  | Age5 | Age5 |
| Eldridge (2005) | Tunnel state? | Fracture | FoF | Unclear6 | Post-fracture7 |
| Farag (2015) | Tunnel state? | Any fall |  | Age6 |  |
| Honkanen (2006) | Tunnel state? | Hip fracture | FS | Age;5 FS; LTC; Post-hip fracture | FS; LTC |
| Johansson (2008) | Tunnel state? | Hip fracture |  | Age5,6 | Age |
| Moriarty (2019) | Tunnel state? | MA fall, Hip fracture |  | Age6 |  |
| OMAS (2008) | Tunnel state? | MA fall |  | CEA |  |
| Pega (2016) | Tunnel state? | MA fall |  | Age5 | Age5 |
| RCN (2005) | Tunnel state? |  |  | Age |  |
| Wilson (2017) | Tunnel state? | MA fall |  | Age5 | Age5 |
| **Individual-level Markov models** | | | | | |
| Hiligsmann (2014) | ˟ |  |  | Post-hip and vertebral fractures | Post-hip fracture7 |
| Mori (2017) | ˟ | Fracture | Osteoporosis | Age; Post-hip and vertebral fractures | Post-hip fracture7 |
| Nshimyumukiza (2013) | ˟ | Fracture | BMD | Post-hip and vertebral fractures |  |
| Zarca (2014) | ˟ | Hip fracture | Vitamin D | Age; Post-hip fracture |  |
| **Abbreviation:** BMD: bone mass density; CEA: cost-effectiveness analysis; FoF: fear of falling; FS: functional status; LTC: long-term care; MA fall: fall requiring medical attention; OMAS: Ontario Medical Advisory Secretariat; RCN: Royal College of Nursing.  1 See Table 4.2 for study references.  2 Not directed related to but indirectly influenced by falls/fractures: e.g., fatal fall influences lifetime comorbidity care costs.  3 Alhambra-Borras (2019) was excluded due to unclear description of the dynamic model states following intervention.  4 Age-based risk progression would require tunnel states, but this was not mentioned or graphed, hence the question mark.  5 Stratified by further time-invariant factors including sex and ethnicity.  6 Unclear whether events such as fracture and LTC admission incurred a one-off or permanent health utility loss.  7 Incorporated ongoing care costs for serious fractures, which are not technically comorbidity care costs since they are directly associated with fall/fracture in model; but they can be interpreted as such given their permanent nature. | | | | | |

The time-variant risk factors were grouped into three categories: ‘age’, ‘falls incidence’, and ‘other’ (e.g., fear of falling). For the four individual-level Markov models, fracture risks were updated for individuals by age progression in each cycle. For the 13 cohort-level models, accounting for the age-based risk progression would have required tunnel states for each model state, but this was not mentioned or graphed. Tunnel states exist within each pre-specified Markov model state and have differing transition probabilities to other states to reflect the changes in risk that would occur over the time spent in the given model state [369]; the proportion of the Markov cohort who do not transition to another model state would instead transition to the tunnel states. Lack of tunnel states would bias the results against those who are younger at baseline: the falls risk kept low despite ageing would reduce the absolute number of falls prevented by the intervention and hence its cost-effectiveness.

Fifteen incorporated fall/fracture incidence within modelled time as a risk factor, establishing a feedback loop. Only five models incorporated progression of other risk factors. Eldridge (2005) modelled individuals transitioning in and out of the state of fear of falling which increased the risks of hip fracture, LTC admission, and mortality. Honkanen (2006) modelled transitions to functional dependence which increased the risks of hip fracture, LTC admission, and mortality. Therefore, Eldridge (2005) and Honkanen (2006) captured the natural trajectory of geriatric health (using binary indicators) that interacted with fracture incidence and risk.

Only two models incorporated dynamic changes to intervention need: Honkanen (2006) allowed the type of hip protector to change according to functional status; Nshimyumukiza (2013) shifted individuals to a reactive fracture prevention pathway when a fracture occurred. It was unclear in Nshimyumukiza (2013) whether fracture risk screening was repeated each cycle to change the proactive intervention components. Eldridge (2005) did not model the progressions of factors included in FRAT (e.g., mobility, chronic diseases, medication use) that determined the proactive components nor incorporate repeated risk screening after the baseline year. Deverall (2018) was unique in allowing the cost of group exercise to vary dynamically from NZ$480 per person in the 1st year to NZ$62 in subsequent years for those who persist.

All models in Table 4.13 except OMAS (2008) performed CUA. Of these, Honkanen (2006) was most thorough in characterising the trajectory of health utility values which progressed by age, functional status, residence, and hip fracture incidence. The four individual-level models did not incorporate such geriatric health/frailty progression but allowed severe fractures to have permanent impacts on utilities. Nine allowed utility progression by age alone, which precluded capturing the heterogeneous health progression within the same age group. Honkanen (2006) was again most thorough in characterising the trajectory of comorbidity care costs.

Table D6 in Appendix D describes the entry and exit patterns for the above non-binary models. Nshimyumukiza (2013) was unique in incorporating incoming cohorts each year for the first 10 years. Other models mentioned the non-incorporation of incoming cohorts as a limitation that underestimated the total intervention costs and benefits [167, 241, 353]. Pega (2016) and Wilson (2017) incorporated annual probabilities of households moving in/out of modified housing which altered the need for HAM. Concerning model exit via mortality, four used fall-related and other-cause mortality rates [206, 241, 337, 361], while the rest used fall-related and all-cause rates, which double-counts the former. Seven faced a similar issue in double-counting fall-related LTC admission [274, 318, 346, 351, 360, 362, 366].

Overall, the assessment of heterogeneity was limited, confined primarily to comparisons delineated by demographic factors and binary disease or physical capacity status (e.g., mobile vs. non-mobile); the latter neglects the nature of geriatric health best characterised as a position on a continuous spectrum [2]. Likewise, the dynamic progressions in falls risk profile, intervention need, health utilities and care costs were poorly captured.

#### 4.5.3.3 Considering theories of human behaviour and implementation

No model directly parameterised psychological and social causal mechanisms based on individual and social behavioural theories. Nevertheless, 31 (67.4%) models reported at least one implementation level, as shown in Table 4.14. See also Table 3.5 above for references concerning the terms used to describe the implementation processes.

A notable feature was the frequent reliance on modeller assumptions to parameterise the implementation levels, which was widely acknowledged as a limitation by authors [167, 336, 342, 347, 358, 359]. Of the 18 models that reported access levels, five relied on assumptions [200, 216, 362-364]. Only Turner (2020) distinguished between adoption and uptake: in the main intervention scenario, professionals’ adoption of sedative de-prescribing is imperfect, and only in an alternative scenario does it become 100%; meanwhile, older persons’ uptake remains at 53% in both scenarios. Nine models reported compliance levels, four relying on assumptions [200, 342, 346, 368]. Honkanen (2006) uniquely applied per-protocol rather than ITT efficacy from RCT; the adherence rate then determined the intervention effectiveness. In other models that used ITT evidence *and* applied compliance rates, there was a risk of confounding. For example, OMAS (2008) specified the adherence rates for their interventions and seemingly applied the ITT efficacies to both adherers and non-adherers, which would underestimate the efficacy for adherers and overestimate for non-adherers. Of the 19 models that reported sustainability durations, 13 used assumptions [128, 206, 216, 241, 336, 342-344, 351, 360, 363, 366, 368]. Under long model horizons, rudimentary assumptions on intervention sustainability would produce misleading results. For example, Church (2012) did not allow for sustained access to ongoing interventions such as exercise, while one-off procedures such as expedited cataract surgery were assumed to generate permanent efficacy, thus significantly advantaging the latter.

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| **Table 4.14** Summary of base case implementation levels, evidence source and outcomes in associated sensitivity analyses. | | | | | | |
|  |  | **Base case implementation levels2** | | | | **Sensitivity analysis outcome** |
| **Study label1** | **Intervention** | **Initial access** | **Compliance** | **Sustainability (model time horizon)** | **Evidence source** |
| Albert (2016) | MF int. |  | Adherence: 78.6%  Fidelity: 84.1% |  | Internal non-randomised | *No analysis* |
| Alhambra-Borras (2019) | Exercise | Uptake: 39.6% |  |  | Internal quasi-experimental | *No analysis* |
| Beard (2006) | MC (intersectoral) int. |  |  | Maint.: 5 years (of 5) | Internal quasi-experimental | *No analysis* |
| Church (2011) | Multiple types |  |  | Maint.: 1 year (of 10) | Assumption | *No analysis* |
| Church (2012) | Multiple types |  |  | Maint.: 1 year (of lifetime) | Assumption | *No analysis* |
| Comans (2009) | MF int. (2 forms) | Uptake: as scenario |  |  | Assumption | ROI break-even |
| Day (2009); (2010) | Multiple types3 | Uptake: 1.9% Tai Chi; 39.4% Home exercise; 55.4% HAM; 55.4% MF int.; 18.9% Psychotropic med. withdrawal; 80.0% Cardiac pacing |  | Persistence: 61% Home exercise  Maint.: 1 year (of 2) Home exercise; 1 year (of 5) Cardiac pacing | External RCT | Falls and hospitalised falls averted; ICER (CEA) |
| Deverall (2018) | Group (commercial) exercise | Uptake: 52% |  |  | External RCT | Inc. cost; Inc. QALY; ICER (CUA) |
|  |  | Persistence: 80.5% uptake in year 2; 10% in year 10 | External RCTs & Assumption | *Same as Uptake* |
|  |  | Maint.: permanent | External RCT | *No analysis* |
| Home exercise | Uptake: 52% |  |  | External RCT | Inc. cost; Inc. QALY; ICER (CUA) |
|  |  | Persistence: 76.3% uptake in year 2; 10% in year 5 | External RCTs & Assumption | *Same as Uptake* |
|  |  | Maint.: permanent | External RCT | *No analysis* |
| Eldridge (2005) | FRS + MF int. or Exercise (prescribed or self-referred) | Uptake: 6.5% FRS; 50%/10% self-referred Exercise for high-/low-risk persons |  |  | Internal survey | Proportion of total falls averted |
| Farag (2015) | Non-specific intervention | Uptake: 50% |  |  | Assumption | ICER (CUA) |
| Franklin (2019) | FRS + Exercise (3 forms) or HAM | Uptake: 100% for those referred from FRS |  |  | Assumption | ICER (CUA) |
|  |  | Maint.: 1 year (of 2) | Assumption | *No analysis* |
| Hiligsmann (2014) | Vit D & calcium supplement |  |  | Maint.: 3 years (of lifetime) | Assumption | ICER (CUA) |
| Hirst (2016) | Med. modification |  | Adherence: 29.4% of eligible days |  | External survey | Inc. cost; Inc. QALY; ICER (CUA) |
| Honkanen (2006) | Hip protector |  | Adherence: 36% of daily hours |  | External survey | ICER (CUA) |
|  |  | Persistence: 50% discontinue after 1st year; discontinuation rate declines exponentially | External survey | ICER (CUA) |
| Howland (2015) | MC int. (lay-led) | Uptake: 50% |  |  | Assumption | Aggregate efficiency (ROI: net cost saving) |
|  | Fidelity: 100% refer |  | Assumption | *No analysis* |
| Ippoliti (2018) | MF int. | Uptake: 80% |  |  | Assumption | *No analysis* |
| Johansson (2008) | MF int. |  |  | Maint.: 5 years (of lifetime) | Internal quasi-experiment | *No analysis* |
| Lee (2013) | Vit D screening & supplement |  | Adherence: 80% |  | External RCT | *No analysis* |
| Miller (2011) | MC int. (lay-led) |  | Adherence: 71.4% | Maint.: 1 year (of 2) | Assumption | *No analysis* |
| Mori (2017) | Home exercise | Uptake: 42% |  |  | External RCTs | *No analysis* |
|  |  | Maint.: 1 year (of lifetime) | Assumption | Inc. cost; Inc. QALY; ICER (CUA) |
| Moriarty (2019) | Med. modification (Benzodiazepine, PPI) |  | Adherence: 100% |  | Assumption | Inc. cost; Inc. QALY |
| Nshimyumukiza (2013) | Fracture risk screening + Physical activity, Vit D & calcium, and/or Osteoporosis screen & treatment | Uptake: 53% |  |  | External survey | ICER (CEA, CUA) |
|  |  | Maint.: permanent | Assumption | *No analysis* |
| OMAS (2008) | Multiple types | Uptake: 57.0% Exercise; 27.0% Psychotropic med.; Not specified for HAM, Vit D, Gait stabiliser | Adherence: 79.0% Exercise; 75.7% HAM; 81.8% Vit D; 53.0% Psychotropic med.; 80.0% Gait stabiliser |  | External RCTs and survey | *No analysis* |
|  |  | Persistence: same as adherence | Assumption | *No analysis* |
| Pega (2016); Wilson (2017) | HAM | Uptake: 89.0% |  |  | External RCT | Inc. cost; Inc. QALY; ICER (CUA) |
|  |  | Maint.: one-off, no renewal | Assumption | *No analysis* |
| Poole (2015) | Vit D supplement |  |  | Maint.: 5 years (of 5) | External RCTs | *No analysis* |
| PHE (2018) | Exercise (3 forms); HAM | Uptake: 20% |  | Maint.: 1 year (of 2) | Assumption | *No analysis* |
| Turner (2020) | Med. modification | Adoption: 66% of GPs received pharmacist advice; 79% met older persons for deprescribing |  |  | Unclear4 | Inc. cost; Inc. QALY; ICER (CUA) |
| Uptake: 53% |  |  | External RCT | *No analysis* |
| Wu (2010) | MF int. | Uptake: 50% |  |  | External RCT and surveys | Aggregate efficiency (ROI: net cost saving); ICER (CEA) |
| Zarca (2014) | Vit D screening & supplement |  | Adherence: 50%; 100% after fracture |  | External survey and assumption | ICER (CUA) |
|  |  | Maint.: permanent | Assumption | *No analysis* |
| **Abbreviation:** CBT: cognitive behavioural therapy; CEA: cost-effectiveness analysis; CSP: Chartered Society of Physiotherapy; CUA: cost-utility analysis; FRID: fall risk increasing drug; FRS: falls risk screening; HAM: home assessment and modification; ICER: incremental cost-effectiveness ratio; Inc.: incremental; Int.: intervention; Maint.: maintenance; MC: multiple-component; MF: multifactorial; OMAS: Ontario Medical Advisory Secretariat; PHE: Public Health England; PPI: proton pump inhibitor; QALY: quality-adjusted life year; RCT: randomised controlled trial; ROI: return on investment.  1 See Table 4.2 for study references.  2 Supply and demand dimensions to implementation levels are distinguished: uptake (demand) and adoption (supply) for initial access; adherence and fidelity for compliance; and persistence and maintenance for sustainability. See Table 3.5 in Chapter 3 for the references concerning the terms used.  3 The configuration is the same for Tai Chi in Day (2010)  4 Cites the model Moriarty (2019) which does not report the parameter estimates directly. | | | | | | |

Table 4.14 also lists the outcomes used for one-way sensitivity or scenario analysis that involved changes in implementation levels. Twelve of 31 (38.7%) models did not assess varying implementation levels, and several acknowledged this as a limitation [343, 363, 364]. Cost-per-unit ratios were the most common outcomes used (by 15 models). A key disadvantage of ratios is that their association with implementation levels depends strongly on the cost summary method, specifically whether fixed/sunk intervention costs are incorporated. If fixed costs are translated to per-participant rates, higher implementation level would raise the net intervention cost and health benefit at the constant rates such that the cost-per-unit ratio remains constant. Accordingly, models without fixed costs found that varying implementation had minimal impacts on cost-per-unit ratio [167, 206, 241, 318, 340, 344, 353, 361, 362]. Ratios should thus be interpreted alongside aggregate outcomes to enable holistic evaluations. For example, Zarca (2014) found that adherence rate of 30% was sufficient to generate a favourable ICER and ruled out further information campaigns to improve adherence; but this neglects the aggregate benefits foregone by low adherence.

Twelve models evaluated the effect of varying implementation on aggregate outcomes: total number of falls prevented [167, 274, 353]; incremental costs and QALYs in CUA [206, 241, 344-346, 348, 361]; and aggregate net economic saving in ROI [200, 340]. Of the latter, Howland (2015) estimated that increasing the uptake of multiple-component interventions from a base case rate of 50% to 75% would generate savings of $2.79 million for a population of 44,000. This represents the maximum amount the decision-maker could spend on auxiliary implementation strategies to achieve the bespoke uptake increase. Yet, models seldom discussed *how* the variations in implementation levels were generated, often assessing the variations under deterministic sensitivity analysis (i.e., to assess parameter uncertainty) rather than under scenario analysis as distinct intervention strategies (e.g., [206, 241, 361]).

An issue related to implementation is the presence of capacity or budget constraint which defines the feasible levels of implementation [240]; no model incorporated such constraints. PHE (2018), for example, assumed that in a typical English local health authority area, around 5,000 older persons would receive group exercise at any time. With 20 participants per group, this would require 250 venues per week, which is likely beyond the venue capacity of most local health authorities. For decision-makers overseeing a specific geographical region, the sizes of the newly incoming cohorts (e.g., newly turned age 60 or 65) would affect the capacity use over time; yet, as noted, only Nshimyumukiza (2013) incorporated incoming cohorts and only for the first 10 years.

Overall, the most pressing methodological issue regarding behaviour and implementation concerns parameterising the long-term intervention sustainability using appropriate evidence rather than using modeller assumptions. Moreover, there is greater scope for conducting VoIM analyses and incorporating capacity constraints to improve model credibility [199, 240].

#### 4.5.3.4 Considering issues of equity

Only seven (15.2%) models, shown in Table 4.15, incorporated vulnerable subgroups based on social deprivation or health severity. Two potential causes of reduced capacity to benefit for these subgroups (relative to non-vulnerable peers) could be discerned from the models: (i) the double jeopardy (DJ) problem; and (ii) life expectancy differential (LED) problem.

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| **Table 4.15** Social and severity subgroups in models and cause(s) of reduced capacity to benefit. | | | |
| **Study label1** | **Subgroup delineating characteristic2** | **Cause of reduced capacity to benefit** | **Note** |
| Four BODE3 models3 | Social: ethnicity (Maori vs. non-Maori) | Life expectancy differential | Also explores outcome differences across sex subgroups. Difficult to explore the double jeopardy problem due to homogenous intervention efficacy, cost and implementation level across subgroups. |
| Eldridge (2005) | Severity: fear of falling | Life expectancy differential | Fear of falling experienced by fallers and non-fallers and hence can be interpreted as frailty. Does not report subgroup results. |
| Honkanen (2006) | Severity: functional dependence | Double jeopardy; Life expectancy differential |  |
| Smith (2016) | Severity: multivariate falls risk/frailty4 profile | No reduced capacity | Multivariate falls risk/frailty profile contained age, sex, all-cause secondary care use, fall and fracture history, chronic diseases and polypharmacy; all persons had same intervention efficacy, cost and implementation level. |
| **Abbreviation:** BODE3: Burden of Disease Epidemiology, Equity & Cost-Effectiveness; HAM: home assessment and modification  1 See Table 4.2 for study references.  2 In identifying health severity subgroups, age, sex and individual fall/fracture risk factors (e.g., falls history, mobility impairment, bone mass density, vitamin D level, psychotropic medication use) were not interpreted as delineating characteristics. Studies that targeted specific patient groups within general older populations were excluded.  3 Boyd (2020), Deverall (2018), Pega (2016) and Wilson (2017) which were developed by the Burden of Disease Epidemiology, Equity and Cost-Effectiveness (BODE3) research group in New Zealand.  4 The falls risk prediction tool included several indicators of generalised frailty (e.g., recurrent secondary care utilisations). | | | |

Only the four models from the BODE3 research group incorporated social subgroups delineated by ethnicity (Maori vs. non-Maori) [206, 241, 337, 361]. All four reported lower QALY gains and higher ICERs for the Maori group. Except Boyd (2020), they also investigated the cause of reduced capacity to benefit: under a hypothetical scenario of equal life expectancy, the Maori group experienced *higher* per-capita QALY gain than the non-Maori group. Hence, the LED problem was identified as the main cause of reduced capacity. But homogenous parameters across ethnic subgroups for intervention cost, efficacy and implementation precluded analysis of the DJ problem. The latter was only narratively discussed, with reference to non-ethnic social characteristics. For example, Wilson (2017) mentioned that HAM uptake is likely lower for low-income populations who are likelier to rent; Pega (2016) mentioned that public campaign to promote do-it-yourself HAM would disproportionately benefit homeowners.

Three models incorporated severity subgroups delineated by variables other than age, sex and individual falls risk factors (e.g., falls history). Eldridge (2005) incorporated a severity subgroup of individuals with fear of falling as indicator of generalised frailty. Fear did not influence the intervention type, efficacy, cost or uptake; hence, the DJ problem was precluded. Instead, the higher mortality risk faced by those with fear means that the LED problem was present. Another key feature is the model’s incorporation of health utility *levels* for health states: those with and without fear had utilities of 0.67 and 1, respectively, prior to fracture, and the same utility 0.31 after fracture; the respective utility decrements are hence 0.36 and 0.69. This improves the cost-effectiveness of fracture prevention for those *without* fear. Nevertheless, the model did not report any subgroup results.

Honkanen (2006) incorporated a severity subgroup of functionally dependent individuals who generated less favourable cost-effectiveness result than the whole population. Specifically, hip protector use no longer dominated no intervention for functionally dependent women aged 80 and 85 unlike the whole population. This could partly be attributed to the DJ problem because the dependent subgroup incurred a higher intervention cost to achieve the same efficacy as the independent. Interestingly, fracture cost was *lower* for the dependent, meaning that fracture prevention is *less* cost-effective for them. The LED likely also contributed via the higher mortality risk faced by the dependent.

Smith (2016) operationalised a multivariate falls risk prediction tool that included several indicators of frailty. The one-year horizon precluded any LED problem. The model applied homogenous intervention efficacy, cost and implementation level for all frailty/risk level, removing any DJ problem. This generated potentially misleading outcomes: for example, the model estimated that only the 1.8% highest risk individuals should be referred to the intervention to achieve positive financial returns; but these individuals likely have significantly reduced capacity to benefit due to their comorbidities. The model hence likely overestimated the cost-effectiveness of targeting the most vulnerable.

No model conducted analyses that quantified the equity-efficiency trade-off. The BODE3 models only explored the hypothetical scenario of equal life expectancy across subgroups and did not evaluate intervention strategies prioritising intervention access/outcomes for the Maori subgroup. They nevertheless discussed several such equity-oriented intervention strategies: Pega (2016) and Wilson (2017) suggested HAM targeting low-income renters; Boyd (2020) discussed how public sector provision of cataract surgery should counteract worsening health inequity under private sector provision. They did not discuss any methodological aspects of equity analysis such as estimating the relative importance of equity and efficiency gains. For severity-based equity issues, only Honkanen (2006) reported the subgroup results but did not evaluate any strategy prioritising the severity subgroup. Overall, equity consideration and analysis were highly limited within existing models.

### 4.5.4 Evaluation methods

The model evaluation methods are synthesised under the following fields: (1) model validation methods and results (Section 4.5.4.1); (2) methods for assessing parameter uncertainty (Section 4.5.4.2); and (3) alternative scenarios evaluated (Section 4.5.4.3). Methods for assessing heterogeneity and for considering equity issues have been already discussed in Sections 4.5.3.2 and 4.5.3.4, respectively.

#### 4.5.4.1 Model validity

Four validity types influence the credibility of model results: structural/face; internal; external; and cross [173]. Seven models involved experts and stakeholders in model development to achieve structural validity prospectively [167, 200, 216, 336, 346, 348, 368]. For example, PHE (2018) engaged two groups of stakeholders: a Steering Group of national falls prevention experts informing the model structure, and a User Group of local commissioners advising on model usability. Hirst (2016) explicitly stated the purpose of alternative scenario analyses as retrospectively validating the model structure.

Six studies reported efforts to assess external validity [128, 336, 343, 344, 367, 368]. For example, Nshimyumukiza (2013) compared the predicted fracture incidence and age-based mortality rates to published data and found less than 5% divergence. Only four studies reported conducting verification steps or sensitivity analyses to ensure internal validity [128, 343, 346, 368]. Cross validity assessment by comparing the model results with those of previous models was the most common form of validation; yet 13 (28.3%) did not report having conducted it [167, 216, 274, 342, 345, 353, 358-360, 363, 364, 366, 367]. Only Zarca (2014) conducted all four validations; four conducted three [128, 336, 343, 346]. Overall, conducting and reporting model validation is not yet a common practice in this field.

#### 4.5.4.2 Assessing parameter uncertainty

Table D7 in Appendix D summarises the parameters that were unilaterally varied in DSA to assess their impact on outcomes. It also summarises the methods used to conduct PSA assessing the impact of joint parameter uncertainty. The DSA parameters are divided into falls epidemiology and falls prevention intervention parameters. A distinction was made between parameter variations to assess parameter uncertainty and those depicting alternative scenarios based on studies’ descriptions of the said variations.

Twelve (26.1%) models conducted no assessment of parameter uncertainty. Of 21 models that conducted DSA, there was a wide between-study variation in the number of parameters assessed, ranging from two to 12. Twenty-eight (60.9%) conducted PSA. The cost-effectiveness acceptability curve (CEAC) which plots the probability of each intervention being the most cost-effective option at each cost-effectiveness threshold was the most frequently used presentation method (n=18). Only Agartioglu (2020) plotted the cost-effectiveness acceptability frontier (CEAF) which marks the threshold at which an intervention produces the highest expected value relative to alternatives across simulated runs. Only Albert (2016) conducted value of information analysis, estimating that the cost-effectiveness of multifactorial intervention would improve under simulation runs that excluded uncertainty over health utility decrement parameters.

#### 4.5.4.3 Scenario analyses

Table D8 in Appendix D summarises the scenarios that were evaluated, categorised into areas of falls epidemiology, falls prevention intervention and evaluation framework. Most (n=38; 82.6%) models evaluated at least one alternative scenario. Of these, there was a wide variation in the number of scenarios, ranging from one to 10. With some exceptions [128, 336, 340], there was a lack of clarity on how the scenarios were chosen among the range of possible options.

### 4.5.5 Evaluation outcomes leading to commissioning recommendations

This section formulates commissioning recommendations based on the evaluation outcomes extracted from 12 general population, lifetime models summarised in Table 4.16. See Table D9 in Appendix D for outcome summaries of non-general population and/or non-lifetime models. As noted, the recommendations in this section are based on the review results alone. Chapter 6 will make separate recommendations based on the results of the developed model and a wider set of decision criteria (e.g., equity). The two sets of recommendations will then be compared for cross-validation.

All models except OMAS (2008) conducted CUA; hence their ICERs (converted to 2021 £) are compared to the NICE cost-effectiveness threshold of £30,000 per QALY. All models targeted those aged 65+ except RCN (2005) which targeted 60+. Models incorporated diverse fall-related health and economic consequences (Tables 4.6 and 4.7) which hamper between-study comparison. All models except Nshimyumukiza (2013) and Zarca (2014) were Markov cohort models but mentioned no tunnel states for age-related progression in falls risk. Only three studies reported validation efforts (other than cross-validation): Johansson (2008) internally and externally; Nshimyumukiza (2013) structurally and externally; and Zarca (2014) structurally, externally, and internally. The last column of Table 4.16 notes the main methodological caveats for each model that are relevant for commissioning. The methodological quality checklist scores in Table 4.2 should also be noted.

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| **Table 4.16** Features and evaluation outcomes of general population, lifetime horizon decision models. | | | | |
| **Study label1** | **Target population; Analysis; Perspective** | **Intervention [Comparator]** | **Evaluation outcomes2** | **Methodological caveats** |
| Church (2012) | CD adults aged 65+; CUA/CEA; Public sector | (a) General population – Group exercise; Home exercise; Tai Chi; Multi-component int.; Multifactorial int.; Multifactorial risk assessment; (b) High-risk population – Group exercise; HAM; Multifactorial int. [NR; Cross comparisons] | ***Ratio*:** (a) General – Tai Chi ICER £27,734 per QALY vs. NR; other interventions dominated; (b) High-risk – Group exercise ICER £31,957 per QALY vs. NR; HAM ICER £36,298 per QALY vs. NR; Multifactorial int. dominated.  ***Aggregate*:** Reports incremental cost, no. of falls avoided and QALY gain per intervention, but all interventions have same reach3 (including those targeting high-risk and specific subgroups), and hence cannot compare aggregate impacts.  ***Parameter uncertainty*:** DSA – int. cost and efficacy had largest impact on group exercise ICER. PSA – CEAC.  ***Scenarios*:** No fear of falling had the largest impact on group exercise ICER among parameter changes. | Recurrent falls not characterised; Unclear falls risk progression;4 Unclear intervention reach;5 Unclear how high-risk subgroup identified; Mismatch between falls incidence and efficacy metrics |
| Deverall (2018) | CD adults aged 65+; CUA; Public sector, Societal | Exercise – (i) Peer-led group exercise; (ii) Home exercise; (iii) Commercial exercise [NR] | ***Ratio*:** (i) Peer-led group exercise ICER £4,527 per QALY vs. NR; (ii) Home exercise ICER £3,928 per QALY vs. NR; (iii) Commercial exercise ICER £33,461 per QALY vs. NR.  ***Aggregate*:** For base case, home exercise generated 47,100 additional QALYs at incremental cost of £161m relative to NR; this compares to 42,000 and 42,300 QALYs for group exercise and commercial exercise at £305m and £1,110m incremental cost relative to NR, respectively. Hence, home exercise dominated group and commercial exercises.  ***Parameter uncertainty***: DSA – efficacy and utility decrement had largest impact on ICER. PSA – 95% UI; CEAC.  ***Scenarios***: Subgroup analyses showed higher ICERs for Maori and men; equity analyses showed higher ICERs can be mainly attributed to their shorter life expectancies.5 | Routine data lacks individual identifiers;6 Recurrent falls not characterised; Unclear falls risk progression;4 No background transition in health utilities;7 Includes comorbidity care costs; Mismatch between falls incidence and efficacy metrics; No tiered threshold for evaluating societal outcomes;8 No scenario estimating equity-efficiency trade-off.5 |
| Eldridge (2005) | Adults aged 65+ in community or nursing home; CUA; Public sector | Falls risk screening + multifactorial int. or exercise [UC] | ***Ratio***: Not reported.  ***Aggregate***: Intervention reduced the number of fallers by 2.8% over one year under base case (6.5% uptake of screening).  ***Parameter uncertainty***: PSA – 40% probability intervention is cost-effective at £30,000 per QALY threshold.  ***Scenarios***: 100% screening uptake would reduce number of fallers by 11.3% over one year; 100% screening uptake and 100% self-referred exercise uptake would reduce number of fallers by 15.0%; impact of uptake increase on ICER not reported. | Recurrent falls not characterised; Unclear falls risk progression;4 No background transition in health utilities;7 Incorporated fixed intervention costs |
| Farag (2015) | CD adults aged 65+ without prior fall; CUA; Public sector | Non-specific falls prevention int. with relative risk of 0.75 and per-participant cost of £420 [NR] | ***Ratio*:** ICER of £17,320 per QALY vs. NR  ***Aggregate*:** Incremental cost and QALY gain outcomes per person can be scaled up but unclear to what extent.  ***Parameter uncertainty*:** DSA – falls risk and LTC cost had largest impact on ICER. PSA – CEAC; 57% probability of being cost-effective at AUS$50,000 (£29,935) threshold.  ***Scenarios*:** e.g., variation in uptake rate had little impact on ICER | Recurrent falls not characterised; Unclear falls risk progression;4 No discounting |
| Honkanen (2006) | Adults aged 65+ living in community at baseline; CUA/ROI; Public sector | Hip protector [NR] | ***Ratio***: Women, baseline age 65 – intervention dominated by NR; Women, age 70 – intervention dominated by NR; Women, age 75 – ICER of £19,336 per QALY; Women, age 80 – intervention dominates NR; Women, age 85 – intervention dominates NR; Men, age 65 – intervention dominated by NR; Men, age 70 – intervention dominated by NR; Men, age 75 – intervention dominated by NR; Men, age 80 – ICER of £132,180 per QALY; Men, age 85 – intervention dominates NR.  ***Aggregate***: Prevented fractures, incremental cost and QALY gain outcomes per person can be scaled up but unclear to what extent.  ***Parameter uncertainty***: DSA – base case results robust. PSA – 68% probability of being cost-effective at $50,000 (£50,839) threshold for women age 75; 61% for men age 85.  ***Scenarios***: Intervention is less cost-effective for functionally dependent subgroup – e.g., intervention cost-effective for women aged 80 and 85 at £50,839 threshold (point estimates not reported) but intervention no longer dominates NR | Unclear falls risk progression;4 Includes comorbidity care costs. |
| Johansson (2008) | CD adults aged 65+ (n=5,500); CUA; Societal | Multifactorial and environmental int.9 [UC] | ***Ratio*:** Intervention dominates comparator  ***Aggregate*:** Total int. cost of £640,918; total costs savings of £647,970; total QALY gain of 35.16  ***Parameter uncertainty*:** No DSA. PSA – scatter plot  ***Scenarios*:** Scenarios that made intervention no longer dominant – doubled fracture risk; lower fracture cost; inclusion of net consumption care cost;10 higher discount rate; no health/cost consequences of fracture beyond 1st year; 25% rise in int. cost | Unclear falls risk progression;4 Includes comorbidity care costs (net consumption); Quasi-experimental study for effectiveness evidence; No tiered threshold for evaluating societal outcomes;8 Internal and external validities assessed |
| Nshimyu-mukiza (2013) | Women aged 65+ (subgroup within women aged 40+); CUA/CEA; Public sector | Fracture risk screening + Physical activity (PA), Vitamin D & calcium and/or Osteoporosis screening & treatment [NR; Cross comparisons] | ***Ratio***: No screening + PA dominates NR; BMD/CAROC screening + PA + Vit D & calcium produces ICER of £41,012 relative to No screening + PA and dominates all other strategies.  ***Aggregate***: Incremental cost and QALY gain per person can be scaled up (total population reported).  ***Parameter uncertainty***: No DSA. PSA – CEAC; 75% probability that BMD/CAROC +PA +Vit D & calcium is cost-effective to No screening + PA under threshold of CAD$50,000 (£37,081).  ***Scenarios***: Rankings of strategies under CUA and CEA robust under variations in single or multiple parameters. | Incorporates incoming cohorts; No background transition in health utilities;7 Structural and external validities assessed |
| OMAS (2008) | CD adults aged 65+; CEA/ROI; Public sector | (i) Exercise; (ii) HAM; (iii) Vit D & calcium; (iv) Gait stabiliser; (v) Psychotropics withdrawal.11 [NR] | ***Ratio*:** All interventions dominate NR for men and women  ***Aggregate*:** Reports net cost saving per person which can be scaled up to total for each intervention subgroup at regional level  ***Parameter uncertainty*:** No analysis  ***Scenarios*:** No analysis | Recurrent falls not characterised; Unclear falls risk progression;4 Mismatch between intervention need and falls risk;11 Parameter uncertainty not assessed |
| Pega (2016) | CD adults aged 65+; CUA; Public sector | HAM [NR] | ***Ratio*:** HAM produces ICER of £5,123 per QALY vs. NR.  ***Aggregate*:** For base case, total int. cost was £82.5m, total net cost vs. NR £62.6m and total QALY gain 34,000.  ***Parameter uncertainty*:** DSA – impact on ICER not assessed, fatal falls risk and falls risk most impactful for incremental cost and QALY, respectively. PSA – 95% UI for base case ICER between below zero to £11,385 per QALY.  ***Scenarios*:** For secondary prevention scenario,12 ICER was £1,139 per QALY, total int. cost £10.2m, total net cost vs. NR, £3.5m, and total QALY gain 20,100. Subgroup analyses showed higher ICERs for Maori and men; equity analyses showed higher ICERs can be mainly attributed to their shorter life expectancies.5 | Routine data lacks individual identifier;6 Recurrent falls not characterised; Unclear falls risk progression;4 No background transition in health utilities;7 Includes comorbidity care costs; Mismatch between falls incidence and efficacy metrics; Unrealistic efficacy duration; Joint parameter uncertainty not assessed; No scenario estimating equity-efficiency trade-off.5 |
| RCN (2005) | CD adults aged 60+; CUA; Public sector | Exercise; Multifactorial intervention [NR] | ***Ratio***: Multifactorial intervention for high-risk group dominates NR; Exercise for high-risk group produces ICER of £13,912 per QALY relative to NR.  ***Aggregate***: Not reported.  ***Parameter uncertainty***: No DSA. PSA – scatter plot  ***Scenarios***: No analysis | Recurrent falls not characterised; Unclear falls risk progression;4 Unclear intervention reach.3 |
| Wilson (2017) | CD adults aged 65+; CUA; Public sector | HAM [NR] | ***Ratio***: HAM produces ICER of £3,120 per QALY vs. NR.  ***Aggregate***: For base case, total int. cost was £5.5m, total net cost vs. NR £4.8m and total QALY gain 2,800.  ***Parameter uncertainty***: DSA – efficacy had largest impact on base case ICER. PSA – 95% UI for base case ICER between below zero to £8,710 per QALY.  ***Scenarios***: For secondary prevention scenario,12 ICER was £399 per QALY, total int. cost £492,000, total net cost vs. NR, £52,000, and total QALY gain 1,420. For primary prevention scenario,13 ICER was £5,465 per QALY, total int. cost £5.0m, total net cost £4.7m and total QALY gain 1,520. Subgroup analyses showed higher ICER for Maori; equity analyses showed higher ICER can be mainly attributed to Maori’s shorter life expectancy.5 | Routine data lacks individual identifiers;6 Recurrent falls not characterised; Unclear falls risk progression;4 No background transition in health utilities;7 Includes comorbidity care costs; Unclear intervention reach;3 Mismatch between falls incidence and efficacy metrics; Unrealistic efficacy duration; Joint parameter uncertainty not assessed; No scenario estimating equity-efficiency trade-off.5 |
| Zarca (2014) | Adults aged 65+ without previous hip fracture; CUA/CEA; Public sector | Vitamin D – (i) Universal supplementation; (ii) Supplement then screen for calibration; (iii) Screen then supplement [NR; Cross comparisons] | ***Ratio***: Universal supplementation was dominated by other strategies; Supplement then screen strategy produces ICER of £5,555 per QALY vs. NR; Screen then supplement strategy produces ICER of £5,232 per QALY vs. Supplement then screen and £5,445 per QALY vs. NR.  ***Aggregate***: Difficult to compare strategies without data on intervention reach.3 Possible that Screen then supplement strategy has smallest reach. Estimating total cost of Screen then supplement to be £80m for 800,000 persons.  ***Parameter uncertainty***: DSA – int. cost had largest impact on ICER of Screen then supplement vs. NR. PSA – 100% probability of Screen then supplement being most cost-effective strategy at threshold of €20,000 (£21,286).  ***Scenarios***: Results robust to discount rates rising from 3% to 6%. | Hospitalisation cost only; Unclear intervention reach;3 Structural, external and internal validities assessed |
| **Abbreviation:** CEA: cost-effectiveness analysis; CEAC: cost-effectiveness acceptability curve; CD: community-dwelling; CUA: cost-utility analysis; DSA: deterministic sensitivity analysis; ED: emergency department; HAM: home assessment and modification; ICER: incremental cost-effectiveness ratio; int.: intervention; LTC: long-term care admission; MA fall: fall requiring medical attention; NR: non-receipt of modelled intervention(s); OMAS: Ontario Medical Advisory Secretariat; pharma.: pharmaceuticals; PSA: probabilistic sensitivity analysis; QALY: quality-adjusted life year; rehab.: rehabilitation; RCN: Royal College of Nursing; ROI: return on investment; UC: usual care; UI: uncertainty interval  1 See Table 4.2 for study references.  2 All monetary units are converted to £ in year 2021 using the average consumer price index (CPI) between the original year of reported currency to 2019 (most recent year for CPI data) [333] in the country of study and purchasing power parity (PPP) rate between the original currency and £ in year 2020 (most recent PPP data) [334].  3 Intervention reach refers to the number/proportion of persons receiving the intervention. It is a function of intervention’s *normative* reach defined by its eligibility criteria and targeting strategy and its *implementation* reach determined by the level of implementation (e.g., uptake and adherence) within the eligible population.  4 The study does not mention how falls risk progressed with age in the absence of falls incidence (which has a separate model state). Markov model should incorporate tunnel states to allow for secular risk progression, but this is not stated or graphically illustrated.  5 The study evaluated counterfactual scenarios where Maori/men had equal life expectancy as non-Maori/women and found that subgroup ICERs became similar (Maori/non-Maori only in Wilson (2017)). This does not estimate the equity-efficiency trade-off (efficiency cost) from Maori/men being prioritised for intervention under the actual circumstance of lower life expectancy.  6 Without individual identifiers, multiple falls experienced by the same person are counted as multiple fallers.  7 Background health utility level should vary in line with changes to underlying health status which are influenced by age and changes in comorbidities and frailty affected by falls.  8 Societal costs incur different opportunity cost to public sector costs. The cost-effectiveness threshold should be tiered or weighted to capture the differing opportunity costs across sectors.  9 Multifactorial intervention included tailored education, group balance exercises, Tai Chi, other physical activities and HAM. Environmental intervention included neighbourhood hazard removal and housing reconstruction.  10 The study incorporated cost of added life-years which was estimated as the consumption minus production level (i.e., net consumption) that varied by age group. The outcome changed from dominance to ICER of £16,980 per QALY.  11 The study estimated the proportion of target population who would be eligible for each of the interventions according to the prevalence of falls risk factors that defined eligibility: exercise for mobile older without disability (65.8%); HAM for frail older with disability (16.9%); vitamin D for women with fracture risk factors (52.9% of female); psychotropics withdrawal for psychotropic users (11.8%); and gait stabilizers for mobile seniors without disability (65.8%). However, the falls risk in the model was determined only by age, sex and MA falls history. Hence, different intervention subgroups had similar falls risk despite contrasting risk factor profiles.  12 HAM targeting subgroup with history of MA fall.  13 HAM targeting subgroup without history of MA fall. | | | | |

All models that conducted CUA except Eldridge (2005) produced ICER for at least one intervention relative to no intervention or usual care that can be deemed cost-effective under the NICE threshold. In the order of increasing ICER values, these interventions were:

* Johansson (2008): Combined multifactorial and environmental intervention for age 65+
* RCN (2005): Multifactorial intervention for high-risk group aged 60+
* Nshimyumukiza (2013): General physical activity promotion among women (without population-level fracture risk screening) aged 65+
* Honkanen (2006): Hip protector use for women aged 80 or 85 at baseline and men aged 85
* Wilson (2017): HAM for state-level population with or without MA falls history aged 65+
* Deverall (2018): Home exercise and peer-led group exercise for age 65+
* Pega (2016): HAM for national population with or without MA falls history aged 65+
* Zarca (2014): Vitamin D screening followed by supplementation for age 65+
* RCN (2005): Exercise for high-risk group aged 60+
* Farag (2015): Non-specific intervention of £420 per-participant cost and 25% reduction in risk for age 65+
* Church (2012): Tai Chi for age 65+

Given these interventions, a key decisional factor is their aggregate impacts determined by their reaches. The combined intervention in Johansson (2008) arguably has the greatest reach since it sets no risk-based eligibility criteria for multifactorial intervention, and its environmental components reduce risk factors independently of older people’s demand. Therefore, the decision-maker should consult stakeholders to determine the local scalability of the combined intervention.

Consideration of aggregate impacts likewise shows that HAM in Pega (2016) and Wilson (2017) should not be targeted at those with MA falls history unless there are significant budget or capacity constraints: the universal approach remains highly cost-effective and produces greater aggregate impact than the targeted approach. In Honkanen (2006), the sharp disparity in ICERs across baseline age subgroups justifies the age-based targeting of hip protector use, but the lack of age-related risk progression in the Markov cohort model may have disadvantaged the younger groups. In Zarca (2014), the different reaches of alternative strategies were not clearly specified, with outcomes (incremental costs and QALYs) being reported at per-participant rates only. Universal vitamin D supplementation generated less favourable per-participant outcomes than targeted supplementation but may have produced greater aggregate benefits, especially when the model allows individuals with sufficient baseline vitamin D level (75 nmol/L) to derive fracture risk reductions from further supplementation (up to 105 nmol/L). The study’s conclusion that targeted strategies are preferable to universal supplementation would be misleading if only per-participant outcomes were compared.

Eldridge (2005) demonstrated how considerations of cost-per-unit ratio and aggregate impact are in reality closely linked. The cost-effectiveness of the multi-pathway intervention was poor with 40% probability of it being cost-effective vs. usual care under the threshold of £30,000 per QALY (ICER point estimate was not reported). The study attributed this to low intervention uptake (6.5% among eligible population) which interacted with the substantial fixed intervention costs to worsen the cost-effectiveness. Hence, the uptake rate was the key policy variable: the model estimated that 100% screening uptake would reduce the number of fallers by 11.3% over one year compared to 2.8% under the base case. The potential impact on the ICER was not reported but can be anticipated to be highly positive. The study recommended a health promotion campaign to increase the uptake; the decision-maker should likewise consider investments in auxiliary implementation strategies.

Regarding intervention impact on social inequities of health, Deverall (2018), Pega (2016), and Wilson (2017) presented subgroup results across ethnicity (Maori vs. non-Maori) and found higher ICERs and lower health gains for Maori. The HAM and exercise interventions hence *worsened* the health inequity between ethnic groups relative to usual care, and this finding may generalise to other settings with similar social disparities in health opportunities. The decision-maker could choose to permit this increase in health inequity or design alternative strategies that generate equal or greater health gains for the socially deprived group. As noted, such strategies were not explored by the models, although they identified LED problem as the main cause of the inequitable impact. This presents a rationale for commissioning supplementary interventions at earlier life stages to reduce the LED problem.

## 4.6 Systematic review results part 3: methodological and commissioning recommendations

Methodological and commissioning recommendations are presented in Sections 4.6.1 and 4.6.2, respectively.

### 4.6.1 Methodological recommendations

Thirty recommendations in total were grouped under the following modelling categories: falls epidemiology (Section 4.6.1.1); falls prevention interventions (Section 4.6.1.2); key challenges for public health economic modelling (Section 4.6.1.3); and evaluation methods (Section 4.6.1.4).

#### 4.6.1.1 Falls epidemiology

1. Clearly state the type and source of data used to characterise the baseline falls risk and discuss the strengths and limitations of choice.
2. Use appropriate methods to characterise recurrent falls, particularly for individual-transitioning models with annual cycles.
3. Maximise the range of falls risk factors modelled including those highlighted by NICE CG161 (falls history, fear of falling, home hazards, gait deficit, balance deficit, mobility impairment, visual impairment, cognitive impairment, urinary incontinence) [13] and multivariate frailty [370]. Use individual-level data where available.
4. Maximise the range of fall-related health consequences modelled including the long-term impact on risks of mortality and health/functional decline.
5. For CUA, distinguish between acute and long-term impacts of fall-related events on health utility and discern whether assigning utility decrement (absolute or proportional) or level is more appropriate for each impact.
6. Maximise the range of fall-related economic consequences modelled including comorbidity care costs associated with the long-term mortality and morbidity impacts of falls. Where data permit, incorporate all-cause care costs which capture the full care consequences of falls, while also reporting fall-related care costs [105].

#### 4.6.1.2 Falls prevention interventions

1. Clearly describe the comparator(s); refrain from using the terms ‘usual care’ and ‘no intervention’ interchangeably and describe the usual care received [105].
2. Clearly state the access pathway(s) – reactive, proactive, or self-referred – for intervention(s) and describe the mechanisms facilitating access (e.g., marketing for self-referred pathway).
3. Use appropriate methods for modelling the falls risk screening process to identify subgroups within target populations or specific patient groups serving as target populations. Resource-use associated with screening should be appropriately characterised and costed.
4. Maximise the granularity of intervention resources incorporated and costed, including auxiliary implementation resources (see expert guideline for resource types [105]). Refrain from translating fixed costs into per-participant rates to capture interaction with implementation level.
5. Ensure that the efficacy metric (i.e., RR or RaR) and fall type match the falls incidence metric (falls risk or rate) and type. Refrain from making assumptions on long-term efficacy duration without adequate evidence [105].
6. Where evidence is available, maximise the range of health effects of interventions modelled beyond falls prevention. These effects include intervention benefits on mortality and comorbidity reduction and intervention side-effects.

#### 4.6.1.3 Key challenges for public health economic modelling

Sixteen recommendations for this section are sub-categorised by the four key challenges.

##### Capturing non-health outcomes and societal intervention costs

1. Consult stakeholders on the range of appropriate outcomes and costs; this will in turn decide the appropriate perspective to take (e.g., public sector, societal). For the societal perspective, see Table 3.4 for the range of potential outcomes and costs.
2. If the societal perspective is taken, incorporate balanced sets of outcomes and intervention costs (e.g., productivity gain from intervention matched by time opportunity cost of participation) to avoid over- or under-estimating the cost-effectiveness of the intervention. In the absence of balanced outcome and cost data, a narrower public sector perspective should be used.
3. If the societal perspective is taken, account for sector-specific productive efficiencies and consider the relevance of established/possible cost-effectiveness thresholds [161].

##### Considering heterogeneity and dynamic complexity

1. Incorporate variables depicting geriatric health variation within the same age and sex groups such as the multivariate frailty index [370]. These can serve as subgroup delineating characteristics and markers of dynamic geriatric health trajectory.
2. Intervention rankings can differ according to whether cost-per-unit ratio or aggregate outcome is used as the decision metric [167]. Hence, aggregate outcomes should be evaluated alongside ratios if there is significant difference in pre-specified subgroup size.
3. Where data permit, characterise the heterogeneity in intervention efficacy, cost, and implementation level.
4. Individual-level simulation is likely necessary to capture the dynamic complexities in falls risk and other geriatric health aspects (e.g., background health utilities, comorbidity care costs, mortality, LTC admission). The interactions between falls risk, intervention need, long-term impacts of falls and falls prevention, and background health should be characterised.
5. Model periodic falls risk screening to allow dynamic variation in the proactive intervention pathway [13]. The reactive pathway should be accessible after serious falls incidence, irrespective of whether a proactive pathway was used or not.
6. Incorporate incoming cohorts of newly eligible persons to correctly characterise the dynamic target population and capacity implications for the decision-making jurisdiction.

##### Considering theories of human behaviour and implementation

1. Incorporate individual- and social-level variables that influence health behaviour and intervention supply/demand where possible. Access to the self-referred intervention pathway should be determined by dynamic variations in demand.
2. Clearly distinguish between supply- and demand-side implementation factors and levels. If implementation level data are sourced externally, consult stakeholders on whether they are generalisable given local facilitators and barriers. Long-term sustainability should be based on evidence or stakeholder views, not assumption.
3. Conduct value of implementation analyses as alternative scenarios reflecting stakeholder views on important implementation strategies; total/aggregate INMB should be the outcome to estimate the monetary value of improved implementation.
4. Consider capacity and budget implications of intervention and implementation strategies. Models that explicitly incorporate capacity constraints may be used, such as discrete event simulation [168].

##### Considering issues of equity

1. Consult stakeholders to incorporate relevant social and health severity delineating characteristics.
2. Identify causal mechanisms behind vulnerable subgroups’ reduced capacity to benefit and incorporate appropriate model parameters.
3. Formulate intervention strategies that prioritise vulnerable subgroups and/or address causal mechanisms (e.g., upstream intervention to correct the LED problem) and conduct equity analysis of equity-efficiency trade-off according to stakeholders’ value judgement [109].

#### 4.6.1.4 Evaluation methods

1. Assess and report the model’s structural, internal, and external validities. Reduce the structural uncertainty prospectively by involving stakeholder and expert group in model development and retrospectively by evaluating scenarios associated with key structural assumptions.
2. Clearly state whether parameter variation represents DSA or scenario analysis. PSA should be conducted to assess the joint parameter uncertainty.

### 4.6.2 Commissioning recommendations based on the review results

The commissioning recommendations for the general older population over the lifetime horizon are:

1. Decision-makers should compare the feasible reaches of the following seven potentially cost-effective interventions in local settings within their budget and capacity constraints: (i) combined multifactorial and environmental intervention for age 65+; (ii) general physical activity promotion for women aged 65+; (iii) hip protectors for women aged 80+ and men aged 85+; (iv) home or peer-led group exercise for age 65+; (v) HAM for persons with or without MA falls history aged 65+; (vi) targeted vitamin D supplementation for age 65+; and (vii) Tai Chi for age 65+.
2. Results for interventions (i), (ii) and (vi) are the most credible since they are produced by validated models; (ii) and (vi) are also from individual-level simulations that incorporated age-related progression in fracture risk.
3. Auxiliary implementation strategies should be planned to achieve adequate cost-effectiveness (e.g., if fixed assets are under-employed) and aggregate impact.
4. There is some evidence that exercise and HAM exacerbate existing health inequity across social subgroups. The decision-maker should consider supplementary strategies that prioritise intervention access for the local socially marginalised groups and/or increase their upstream health opportunities. The potential equity-efficiency trade-off should be quantified.

For comparison, see Section 6.5 for the commissioning recommendations based on the developed model’s results.

## 4.7 Discussion

This systematic review identified 46 decision models of community-based falls prevention interventions, applied a checklist specifically designed for falls prevention economic evaluations, and synthesised the modelling methods for key features of falls epidemiology, falls prevention intervention, public health modelling and evaluation. It also formulated (i) 30 methodological recommendations for future model development and (ii) four commissioning recommendations based on the extracted evaluation outcomes around seven interventions found to be cost-effective in general population, lifetime models.

### 4.7.1 Commissioning recommendations and existing guidelines

For decision-makers in England and Wales, the commissioning recommendations based on the review results can be compared to those made by NICE CG161 [13]. The guideline prioritises the proactive pathway involving falls risk screening followed by multifactorial intervention. This is supported by RCN (2005) findings (which informed CG161) that multifactorial intervention for high-risk individuals dominates no intervention. By contrast, Eldridge (2005) found proactive multifactorial intervention to generate an unfavourable cost-effectiveness profile, likely due to the low pathway uptake that increased the per-participant cost. Hence, the simplistic costing assumptions in RCN (2005) may have overestimated the cost-effectiveness of proactive multifactorial intervention. Meanwhile, the consultation of local services in Eldridge (2005) to understand uptake and costs makes their result more credible. Yet multifactorial intervention for all risk groups combined with environmental modification (costed using primary data) yielded positive results in Johansson (2008). A similar intersectoral intervention was found to be cost-effective over a five-year horizon in Beard (2006). Both models do not explore to what extent the positive results can be attributed to the multifactorial rather than the environmental component. This warrants further modelling work in the coming chapters that incorporates both components and yet isolates their respective impacts. Based on the review results alone, the decision-maker should commission the CG161-recommended multifactorial intervention but supplement this with environmental modifications. Specifically, local stakeholders should be consulted to verify whether the intersectoral initiatives in Johansson (2008) and Beard (2006) can be replicated in their local context. In addition, auxiliary implementation strategies should be planned with stakeholders to avoid the unfavourable outcomes seen in Eldridge (2005); this would involve understanding the facilitators and barriers to implementation from older persons’ and professionals’ perspectives [139, 141, 208].

Interestingly, there were several positive cost-effectiveness outcomes for interventions that had *not* been recommended by CG161. First, CG161 does not recommend unsupervised brisk walking for women and untargeted group exercise; although the 2019 NICE SR guideline [130] recommends physical activity promotion in line with the 2019 UK CMOs’ physical activities guideline [113]. By contrast, Nshimyumukiza (2013) found general physical activity (including daily walking) for inactive older women to dominate no intervention. Second, CG161 does not recommend vitamin D supplementation even for those with vitamin D insufficiency or deficiency due to insufficient clinical evidence. By contrast, Zarca (2014) found targeted vitamin D supplementation to be highly cost-effective relative to no intervention. Likewise, hip protectors and CBT were not recommended by CG161 but found to be cost-effective in Honkanen (2006) and Tannenbaum (2015), respectively. These divergences reflect the difference in the underlying approach to statistics and probability. For example, CG161 is primarily informed by RCT evidence that takes the frequentist approach of drawing random samples to test the likelihoods of alternative hypotheses representing the true (fixed) state of the world; while decision models take the Bayesian approach of estimating the expected state of the world based on prior beliefs and diverse types of data (p. 323) [145]. The latter arguably better reflects the type of uncertainty faced by decision-makers and should be prioritised in commissioning considerations over clinical evidence alone, provided that the models are methodologically robust, validated, and assessed for the impact of parameter uncertainty on expected outcomes [371].

### 4.7.2 Conducting methodological appraisal of previous models

The above imbues additional importance to thorough methodological appraisal of models. This was conducted in the current review using two approaches: checklist application and narrative synthesis. The falls-specific rather than generic checklist helped identify features unique to falls and falls prevention [105], including whether the study gave the definition of a fall – only 19 (41.3%) fully did – and whether the intervention(s) was classified as single, multiple-component or multifactorial – only 15 (32.6%) did. However, the checklist – designed for both models and non-modelling evaluations – did not consider important modelling features such as baseline risk characterisation and model validation which are included in the HTA model quality checklist [372]. Moreover, modelling features typically involve methodological nuances that cannot be summarised in ordinal scores. It is also unclear whether the unweighted sum of item scores accurately captures the methodological quality of models given the study-specific combination of methodological caveats. This illustrates the importance of supplementing the checklist application with narrative synthesis: the latter was more comprehensive in this systematic review than in previous reviews in this area (Appendix C). That said, of the 12 general population, lifetime models used to inform commissioning, the three that had been most thoroughly validated also had the highest checklist scores [128, 336, 368], demonstrating some form of construct validity for the checklist scores.

### 4.7.3 Key methodological limitations of previous models

The checklist application also identified the most prevalent reporting and methodological limitations across models. The most prevalent issue was the non-incorporation of all-cause care costs as the main analysis cost outcome, with fall-related costs being reported in sensitivity analysis [105]. Older persons typically occupy a position on a continuous spectrum of frailty rather than one of binary healthy vs. diseased states [14, 45, 47]. A disease or fall incidence would shift the position on the spectrum and thereby incur myriad care costs only indirectly associated with the initial event [33, 64]; incorporating all-cause care costs helps capture these impacts as well as the wider benefits of interventions beyond falls prevention (Figure 1.1). Yet only four models incorporated all-cause costs [341, 349, 350, 354]; one of them even perceived all-cause costing as a limitation, compelled by lack of condition indicators in the routine data used [354]. The four also did not separately report fall-related costs, introducing difficulties in determining whether the cost reduction can be attributed to falls prevention *per se* rather than to wider intervention benefits. A major barrier is the lack of data on all-cause care consequences of falls, with costing studies focusing on fall-specific costs [61, 218]. Indeed, all four models that incorporated all-cause costs relied on primary data.

An alternative, more feasible approach is to incorporate comorbidity care costs (e.g., costs of added life-years and costs of dying) associated with background health status and life expectancy. The proximity of these costs to intervention effect makes their inclusion particularly important for geriatric populations [331]. The inclusion of health utilities to depict the transition in background health status also demands the inclusion of matching costs [145]. The higher cost of dying for younger age at death [373, 374] – as incorporated in the four BODE3 models – would improve the cost-effectiveness of interventions preventing premature mortality (e.g., of those below the average life expectancy). Yet comorbidity care costs were included in only six models (Table 4.7); data availability may again be the barrier. The six models also included *all-cause* background costs and did not subtract fall-related costs, meaning that the latter are double-counted. Moreover, all except Honkanen (2006) stratified the background costs by age and sex alone (Table 4.13), meaning that the costs are influenced only by falls affecting mortality and not by those affecting morbidity. In all, further research is warranted to incorporate comorbidity costs in falls prevention modelling. As discussed, a potential approach is to estimate the association between falls and multivariate frailty index, which in turn would determine all-cause care costs and subsequent falls risk [47, 279, 370].

The next two prevalent issues were reporting aggregate outcomes and detailing the comparator scenario. The importance of comparing aggregate outcomes was discussed under Section 4.5.5. In brief, models should assist decision-makers in estimating the aggregate, population-level impact of interventions as recommended by NICE PMG9 (recommendation 5.12.3) [154]. Regarding the comparator scenario, this should closely resemble current practice in the local setting [105, 375]. It should be noted that the current practice in most settings is likely not the total absence of falls prevention, but rather the under-implementation of existing clinical guidelines [139]. Likewise, the most relevant intervention scenario is likely not the provision of new interventions, but rather the upscaling of existing capacity and improving fidelity to recommended practice. With assistance from local stakeholders, future models should pay greater attention to the features of current practice in the decision-making setting and be more specific in the causal mechanisms being altered under intervention scenarios. As done in Eldridge (2005) and in Section 3.7.1 for Sheffield, consultation of local stakeholders can assess current referral pathways and demand levels, and detail component-specific strategies.

Generally, the key challenges for public health economic modelling were handled poorly by existing models; this review offers 16 methodological recommendations for addressing them. The four key challenges were appraised separately in Section 4.5.3; but the significant interactions between them (as explored conceptually in Section 3.8.2) should be noted by future appraisals.

### 4.7.4 Strengths and limitations of systematic review

This systematic review is a comprehensive review of community-based falls prevention models. It includes 26 models unidentified by previous systematic reviews in this area. It also provides a more detailed methodological appraisal than previous systematic reviews using both checklist application and narrative synthesis. The appraisal results arranged by topic areas should facilitate the conceptualisation and cross-validation of future models. With regards to key public health modelling challenges, the range of topics was informed by a previous systematic methodological review [18]. In comparison, the Huter review covered only the challenge of capturing non-health outcomes [331], while the PHE review covered only equity issues [147]. Another strength is the consideration of a broad range of outcomes for commissioning recommendations: previous reviews focused primarily on cost-per-unit ratios. Applying the 16-item AMSTAR 2 checklist [376], this systematic review scored 12 ‘Yes’ (out of 13 since three items concern meta-analysis methods not applied by previous and current reviews) which is higher than the top score of 10 ‘Yes’ among previous reviews in Table CS6, Appendix C. The sole deficit was the non-reporting of funding sources for the included models (item 10).

This review nevertheless has several limitations. First, appraisal of previous models was limited to what the studies reported. This presented difficulties in certain areas (e.g., whether Markov model incorporated tunnel states); contacting the study authors for enquiry would have reduced ambiguity. Second, in several ROI analyses (e.g., [207, 359, 364]), it was unclear whether the analyses constituted full comparative economic evaluations or partial non-comparative service evaluations [162]. Third, unlike previous reviews, this review excluded non-modelling evaluations which still offer useful information for commissioning [332]; however, their incommensurable methodological features relative to models would have over-extended the appraisal boundary. Fourth, the review did not test for possible publication bias; there is hence a risk that favourable cost-effectiveness results are over-represented. Finally, the commissioning recommendations were based solely on general population, lifetime models, even though non-general population and/or non-lifetime models still offer useful information to decision-makers.

## 4.8 Chapter summary

There is evidence from previous models that combined multifactorial and environmental intervention, general physical activity promotion for women, and targeted vitamin D supplementation are cost-effective relative to no intervention. This offers a point of comparison for commissioning recommendations formulated from *de novo* model analysis in Chapter 6. Narrative synthesis and appraisal found significant heterogeneity in modelling methods across falls epidemiology, falls prevention intervention and evaluation methods. Existing models contain major methodological limitations spanning the key challenges for public health economic modelling. This systematic review provides a comprehensive catalogue of modelling methods for community-based falls prevention which will inform the model development in the next chapter.

# Chapter 5. Falls Prevention Economic Model Development

## 5.1 Chapter outline

This chapter aims to develop the final implemented falls prevention economic model. The development process builds on the understanding of the problem conceptualised in Chapter 3. The review and methodological appraisal of previous falls prevention economic models in Chapter 4 constituted the first part of Phase (D) for developing and justifying the model structure according to public health modelling framework [1]. This chapter completes the rest of Phase (D) and follows the recommended steps such as determining the level of model detail given the available evidence/time and developing a transparent qualitative description of the model [1, 173]. Section 5.2 describes the model parameterisation. Section 5.3 conducts model validation. Section 5.4 outlines the model evaluation methods, and Section 5.5 concludes. Detailed appraisals of the model’s strengths and limitations are conducted in Chapter 6 after the results are presented.

## 5.2 Model development

The model was developed in several stages corresponding to sequential simulation steps:

1. Evaluation framework and model overview (Section 5.2.1)
2. Baseline characteristics (Section 5.2.2)
3. Outcomes estimated at baseline (Section 5.2.3)
4. Falls prevention strategy (Section 5.2.4)
5. Mortality risks and falls epidemiology (Section 5.2.5)
6. Dynamic transitions (Section 5.2.6)

### 5.2.1 Evaluation and model overview

This section lays out the evaluation setting and target population (Section 5.2.1.1) and the evaluation framework (Section 5.2.1.2). It then presents the model overview (Section 5.2.1.3), followed by introductions to key data sources used for parameterisation (Section 5.2.1.4).

#### 5.2.1.1 Setting and target population

The model is set in the Sheffield health economy overseen by the Sheffield NHS CCG and SCC. The target population is community-dwelling adults aged 60+. The minimum age was set at 60 rather than 65 to promote primary prevention, a key stakeholder aim (Section 3.4.2); 60 is also the youngest age at which falls are recorded in the main data source for parameterisation, the English Longitudinal Study of Ageing (ELSA) (see rationale for using ELSA in Section 5.2.1.4). The target population hence covers a broader age range than NICE CG161 that targets adults aged 65+ [13]. Sheffield commissioners oversee a geographical jurisdiction rather than a specific cohort; hence, the target population includes cohorts who newly enter the target age range during model simulation.

#### 5.2.1.2 Evaluation framework

##### Type of analysis

The primary type of analysis is CUA with QALY as the health outcome and EQ-5D as the generic health utility measure (Section 3.4.2). Wider outcomes such as individual-level outcomes are reported alongside CUA outcomes. The secondary type is ROI, the default type for Sheffield commissioners.

##### Perspective

The primary perspective is societal, accounting for societal intervention costs and societal consequences of falls in addition to the public sector costs accruing to Sheffield CCG and SCC. Under the societal perspective, it is assumed that productive efficiencies inside and outside the public sector are different. Specifically, the evaluation follows the method of Tong who used a cost-effectiveness threshold of £30,000 per QALY gained for the public sector health and social care perspective, consistent with NICE PMG9 [154], and a threshold of £60,000 per QALY gained for costs falling outside the public sector as recommended by the Department of Health [161]. The societal costs were converted to their equivalent QALY amount and added to QALY estimates to obtain the total societal QALY gains. A ratio of incremental public sector costs per societal QALY gained was then calculated. All costs were reported in pounds sterling (£) at year 2021 prices. The secondary perspective for ROI analysis is public sector.

##### Time horizon

For primary analysis, a 40-year horizon spanning year 2021 to 2060 was adopted to capture the long-term consequences as recommended by NICE PMG9 [154]. The 40-year horizon was a lifetime horizon for the baseline cohort (who would be deceased, admitted to LTC, or aged over 100 at model conclusion) but not for new entry cohorts. All costs (public sector and societal) and health outcomes were discounted at 3.5% annually as recommended by NICE [144, 154]. For ROI analysis, the time horizon was set at five years as preferred by Sheffield commissioners (Section 3.4.2). This is also the maximum time horizon suggested by NICE for public health investments at the local authority level [144].

#### 5.2.1.3 Model overview

##### Model type

The model type is discrete individual simulation according to a published model structure taxonomy (cell D3 in Table 1) [168] with annual cycles. This captures individual-level variations in baseline characteristics, dynamic trajectories, and evaluation outcomes; each model cycle captures events regarding falls, falls prevention, and associated processes (e.g., frailty progression) occurring within a year. The model can set maximum numbers of individuals receiving each intervention per year, and this feature is used to characterise annual capacity constraints under alternative intervention scenarios. This creates interactions between simulated individuals.

##### Model representation and schematic

Figure 5.1 graphically represents the model including its covariates, falls prevention pathway, fall types, exit points, and final outcomes. The initial cohort of Sheffield population aged 60+ (n=125,244) enter the model at simulation start. In subsequent years, new cohorts who turn 60 also enter. Entering individuals are assigned age, sex, SES, falls history in past year, and frailty index score (range 0-100). With these characteristics as independent variables, multivariate logistic regressions are used to estimate individuals’ baseline risks/probabilities of further covariates: engaging in high physical activity; cognitive impairment; fear of falling; and abnormal gait/balance. Using these covariates, the following baseline outcomes are estimated using logistic or linear regression: EQ-5D; control, autonomy, self-realisation and pleasure, 19 items (CASP-19), a measure of social wellbeing; comorbidity (i.e., not directly related to falls) primary and secondary healthcare cost; comorbidity community care cost; comorbidity short-term social care cost; productivity (paid employment and unpaid work) value; OOP care expenditure; and informal care cost.

Diagram

Description automatically generated**Figure 5.1** Model representation diagram. **Abbreviation:** CASP-19: control, autonomy, self-realisation and pleasure, 19 items; Comorb.: comorbidity; Int.: intervention; LTC: long-term care; MA fall: fall requiring medication attention; OOP: out-of-pocket; PS: public sector; SES: socioeconomic status. 1 Includes paid employment and unpaid work. 2 Intervention access rates are functions of eligibility (determined by covariates such as falls history) and implementation factors (demand and supply capacity); these can be altered by intervention scenarios. 3 Societal intervention costs include private co-payment (e.g., for transport), time opportunity costs for participants and accompanying caregivers. 4 For those experiencing recurrent falls with 1+ MA fall(s), the probability for experiencing a second MA fall is applied; MA falls are subdivided into hospitalised and non-hospitalised MA falls. 5 The share of LTC cost incurred by public sector depends on individual’s SES quartile. 6 Probability of GP contact and demand for self-referred intervention are updated longitudinally.

Individuals then enter the falls prevention pathway. There are three pathways: reactive; proactive; and self-referred. Individuals’ access to one of the pathways (or none) depends on eligibility and implementation factors (supply and demand). Both eligibility and implementation vary across usual care (UC) and recommended care (RC) scenarios under base case comparison. Table 5.1 provides a summary of the intervention eligibility conditions under UC and RC. More details on the intervention access conditions are given in Section 5.2.4. Intervention access gains efficacy and incurs intervention costs (public sector and societal).

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| **Table 5.1** Intervention eligibility conditions by pathway and scenario under base case analysis. | | |
| **Pathway** | **Usual care (UC)** | **Recommended care (RC)** |
| **Reactive** | HAM for hospitalised fallers only (around 28% of MA fallers). | Multifactorial intervention for all MA fallers. |
| **Proactive** | Multifactorial intervention for high falls risk individuals screened at routine GP contact,1 who are: (i) cognitively intact; (ii) not receiving the reactive intervention that year; (iii) have not previously received the proactive intervention. | Multifactorial intervention for high falls risk individuals screened at routine GP contact: (i) regardless of cognitive status; (ii) not receiving the reactive intervention that year; and (iii) regardless of proactive intervention history. |
| **Self-referred** | Self-financed exercise intervention for 0.1% of persons in the most privileged SES quartile who are not receiving the reactive/proactive intervention that year. | Publicly funded exercise intervention for persons who are not receiving the reactive/proactive intervention that year. |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; HAM: home assessment and modification; MA faller: faller requiring medical attention  1 According to ELSA: around 81% of older persons aged 60+ access routine GP contact each year; under usual care, only around 31% of persons receive falls risk screening at GP contact; around 34% of screened individuals receive the intervention. See Table 5.27 for greater detail on access conditions. | | |

After the intervention pathway, individuals face the risk of experiencing mortality of two types: fatal fall; and other-cause mortality. The mortality risks are stratified by age, sex, and frailty category (fit, mild, moderate, and severe). Those who experience mortality exit the model and incur the cost of dying. At model exit, individuals’ discounted lifetime outcomes are calculated. Those who do not experience mortality face risks of non-fatal falls. Multivariate logistic regressions are used to estimate the risks of: (1) any fall; (2) recurrent falls given any fall; (3a) MA fall given single fall; and (3b) MA fall(s) given recurrent falls. These divide individuals into five faller types: (i) no fall; (ii) single non-MA fall; (iii) single MA fall; (iv) recurrent non-MA falls; and (v) recurrent falls with 1+ MA fall(s). Individuals in (v) face the risk of experiencing two MA falls. Individuals in (iii) and (v) who experience MA fall(s) face a further risk of experiencing a hospitalised, as opposed to non-hospitalised, MA fall(s). Hence, type (v) individuals can experience two hospitalised falls, two non-hospitalised MA falls, or one of each. Healthcare costs and acute QALY loss directly associated with the fall are assigned by faller type.

The post-fall rate of frailty progression is then estimated by linear regression. The association between fall incidence and frailty progression propagates the secondary effects of falls. The frailty progression rate and the not-yet-updated covariates are used as independent variables to predict permanent LTC admission. Those admitted to LTC exit the model after incurring the cost of admission and being assigned the average remaining QALY in LTC. The LTC admission cost is shared between public and private funding depending on individuals’ SES. The model then concludes if the cycle is the final one. If so, all individuals exit, and their final outcomes are computed. Otherwise, their covariates and outcomes are updated for the next cycle. This process repeats until the final cycle.

Figure 5.2 shows the simulation model schematic. The simulation software was Simul8 Professional® [377]. Appendix E contains the Simul8 labels, distributions, spreadsheets, numbers, and visual logic used for constructing the UC and RC scenarios. STATA version 16 [378] was used to estimate the multivariate logistic and linear regressions applied to the ELSA data. All regressions were conducted to identify associative patterns for prediction rather than causal inference.

A picture containing text, sky, map, light

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**Figure 5.2** Simul8 model schematic. **Abbreviation:** Int: intervention; LTC: long-term care; MF Int: multifactorial intervention

#### 5.2.1.4 Key data sources

Two key data sources warrant further introductions: English Longitudinal Study of Ageing (ELSA); and community-based falls prevention RCTs that provide the efficacy and resource use data.

##### English Longitudinal Study of Ageing

ELSA was chosen as a key data source because: (a) It follows a nationally representative cohort of adults aged 50+ in England and was deemed representative of the Sheffield target population by the commissioners (Document 2 in Appendix B). (b) It collects a wide range of health, demographic, socioeconomic, lifestyle and environmental variables relevant to older populations (e.g., informal care receipt) and tracks their longitudinal trajectories via individual identifiers [379, 380]. (c) It contains falls incidence and falls prevention service use data with which falls risk equations and service use patterns can be estimated using individual-level characteristics.

To date (January 2022), nine two-year interim ELSA surveys have been conducted starting from Wave 1 in 2002 to Wave 9 in 2018. The anthropometric (e.g., weight, blood pressure) and physical capacity (e.g., walking speed) variables were collected by nurse visits on every even-number waves [381]. Though the Wave 1 cohort was recruited solely from community-dwelling persons, those admitted to residential or nursing homes were still interviewed at subsequent waves [382]. Among the nine waves, the Wave 4 data and the next follow-up Wave 5 were used for parameterisation because:

1. Wave 4 contains the most comprehensive data regarding falls and falls prevention: (i) It is the only wave with information on falls history in the previous *one year* rather than two years of survey interim. This variable is important because the falls prevention pathway emphasises falls history in the previous 12 months [13]. (ii) It is the only wave with information on fear of falling perceived while walking, a key causal variable (Section 3.6.2). (iii) Only Waves 2, 4 and 8 contain self-reported data on previous contact with falls prevention services: whether doctor/nurse tried to understand cause of fall; whether doctor/nurse tested balance and strength; and whether doctor/nurse recommended further risk assessments. These variables are important for estimating a plausible level of falls prevention access under UC.
2. The nurse-measured anthropometric and physical capacity variables are available only in even-numbered waves. In the absence of Wave 10 data, this ruled out the use of Wave 8 as the baseline. Wave 4 was then preferred over Wave 6 for the first reason.

Supplementary information on using ELSA for parameterisation is included in Appendix E, particularly Table E1 which lists the original labels and methods for handling missing observations.

##### Falls prevention randomised controlled trials

RCTs provide information on intervention recipient characteristics (from inclusion/exclusion criteria and sample characteristics), implementation level, resource use, and efficacy. Falls prevention interventions are characterised by substantial heterogeneity in component, mode of delivery, personnel, intensity, and duration; such heterogeneity is present across geographically defined care settings [364]. This limits the utility of secondary syntheses of RCT evidence from different jurisdictions. Therefore, this model relies on non-synthesised UK RCTs to improve the evidence generalisability to Sheffield.

A pragmatic approach was pursued in identifying the relevant RCTs, as shown in Table 5.2. This included a *de novo* systematic review conducted in July 2019: see Tables E2 and E3 in Appendix E for search strategy and inclusion/exclusion criteria. The Cochrane review by Gillespie and colleagues remains the most comprehensive review of community-based falls prevention RCTs to date, covering all intervention types published before March 2012 [124]. This was updated twice: for multifactorial and multiple-component interventions published before June 2017 [126]; and for exercise interventions published before May 2018 [125]. These were supplemented by forward citation searching of the three Cochrane reviews for the period between 2019 and June 2020.

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| **Table 5.2** Sources of community-based falls prevention randomised controlled trials. | | |
| **Review** | **Search methods1** | **Search results** |
| Gillespie (2012): Cochrane systematic review of all community-based falls prevention [124] | *Intervention type*: all types  *Exclusion*: stroke and Parkinson’s disease rehabilitation  *Period*: database inception to Feb-Mar 2012 | # of trials: 159; of which 63 were not included in Hopewell (2018) and Sherrington (2019) |
| *De novo* systematic review conducted in July 2019 for period 2012-20182 | *Intervention type*: all types  *Exclusion*: stroke and Parkinson’s disease rehabilitation  *Period*: 1st Jan 2012 to 31st Dec 2018 | # of trials: 61 not included in Gillespie (2012), Hopewell (2018) and Sherrington (2019) |
| Hopewell (2018): Cochrane systematic review of multifactorial and multiple-component community-based falls prevention [126] | *Intervention type*: multifactorial and multiple-component interventions  *Exclusion*: stroke and Parkinson’s disease rehabilitation  *Period*: Jan 2012 to June 2017 for studies not included in (Gillespie et al., 2012) | # of trials: 62; of which 17 were not included in Gillespie (2012) |
| Sherrington (2019) – Cochrane systematic review of community-based falls prevention exercise [125] | *Intervention type*: exercise  *Exclusion*: exercises for patients with stroke, Parkinson’s disease, multiple sclerosis, dementia, hip fracture and severe visual impairment  *Period*: Jan 2012 to May 2018 for studies not included in (Gillespie et al., 2012) | # of trials: 106; of which 54 were not included in Gillespie (2012) |
| Citation search of Cochrane systematic reviews | *Intervention type*: all types  *Exclusion*: stroke and Parkinson’s disease rehabilitation  *Period:* 1st Jan 2019 to 30th Jun 2020 | # of trials: 21 not included in Gillespie (2012), Hopewell (2018), Sherrington (2019) and *de novo* systematic review |
| **Total** |  | **# of trials: 312** |
| 1 All systematic reviews except citation search covered the same databases: Cochrane Library; Medline; Embase; CINAHL.  2 The search strategy and inclusion and exclusion criteria are reported in Tables E2 and E3 in Appendix E, respectively. | | |

This process identified 312 RCTs; of these, 45 were set in the UK. Table 5.3 describes 11 UK-based RCTs that were aligned with current or recommended practice conceptualised in Section 3.7. Five evaluated multifactorial interventions, while six evaluated exercise interventions; they are organised in Table 5.3 by target population characteristics (pathway, cognitive status, and falls risk). Where multiple RCTs targeted similar populations – e.g., Close (2009) and Davison (2005) targeted cognitively intact reactive patients – one of them was chosen for parameterisation rather than pooling both. Hence, for example, Close (2009) was chosen over Davison (2005) because the latter incorporated history of falls as an eligibility criterion for the reactive pathway, a criterion not mentioned in NICE CG161 [13]. See Section 5.2.4.4 for details on the RCTs finally used for parameterisation. Table E4 in Appendix E describes UK-based RCTs that were *not* aligned with current or recommended practice.

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| **Table 5.3** UK community-based randomised controlled trials of falls prevention interventions aligned with current or recommended practice in Sheffield. | | | | |
| **Intervention type** | **Target population** | **Reference** | **Description** | **N** |
| Multifactorial intervention (n=5) | Reactive | Close (2009) [62] | For cognitively intact persons aged 65+ admitted to A&E for fall; medical and OT assessment and treatment at geriatric day hospitals | 2 |
|  | Davison (2005) [383] | For cognitively intact persons aged 65+ admitted to A&E for fall *and* has history of falls; medical, PT and OT assessment and treatment at general hospitals |  |
| Reactive & CI-friendly | Shaw (2003) [384] | For cognitively impaired persons aged 65+ admitted to A&E for fall; medical, PT and OT assessment and intervention | 1 |
| Proactive | Conroy (2010) [25] | For cognitively intact persons aged 70+ screened to be high falls risk by fall history or FRAT; medical, PT and OT assessment and intervention at geriatric day hospitals | 2 |
|  | Spice (2009) [385] | For cognitively intact persons aged 65+ with recurrent falls history *and* no A&E admission for most recent fall; medical, PT and OT assessment and intervention at multidisciplinary secondary care clinic1 |  |
| Exercise (n=6) | General-risk group | Iliffe (2014) [135] | For cognitively intact and independently mobile persons aged 65+ with less than 3 falls in past year; 24-week FaME group exercise + Otago home exercise2 | 1 |
| High-risk group | Skelton (2005) [136] | For cognitively intact women aged 65+ with 3+ falls in past year; 36-week FaME group exercise + Otago home exercise | 3 |
|  | Stanmore (2019) [205] | For persons aged 55+ living in sheltered housing facilities; 12-week FaME/Otago-based Exergames at home |  |
|  | Clegg (2014) [386] | Feasibility trial (n=84); for frail persons (mean age 79) without severe dementia receiving case manager care, housebound or attending older outpatient clinics; 12-week progressive exercise for basic mobility skills |  |
| CI-friendly | Lamb (2018) [193] | For independently mobile persons (mean age 78) with mild or moderate dementia; 16-week aerobic and strength group exercise + continued physical activity support | 2 |
|  | Nyman (2020) [235] | For persons (mean age 78) with mild or moderate dementia able to participate in physical exercise and their informal caregivers; 20-week group- and home-based Tai Chi + behavioural change support |  |
| **Abbreviation:** CI-friendly: cognitively impaired-friendly; FaME: Falls Management Exercise; FRAT: Falls Risk Assessment Tool; HAM: home assessment and modification; MA fall: fall requiring medical attention; OT: occupational therapy/therapist; PT: physiotherapy/physiotherapist  1 The study contained an additional intervention arm for nurse-led multifactorial risk assessment (without active treatments) in primary care setting. This intervention did not produce a statistically significant reduction in the numbers of falls and fallers relative to usual care.  2 The study contained an additional intervention arm for home-based Otago exercise supervised by peer mentors. This intervention did not produce a statistically significant reduction in the numbers of falls relative to usual care**.** | | | | |

### 5.2.2 Baseline characteristics

Simulated individuals are assigned the following baseline characteristics upon model entry: demographics and residence (Section 5.2.2.1); SES (Section 5.2.2.2); falls history (Section 5.2.2.3); frailty (Section 5.2.2.4); and additional key covariates (Section 5.2.2.5).

#### 5.2.2.1 Demographics and residence

The size of the target population in Sheffield during the 40-year period 2021-2060 by age (60+), sex, and residence – community-dwelling vs. institutionalised – was estimated from five datasets: (1) ONS dataset on population size by age and sex disaggregated to local authority level in mid-2019 [387]; (2) ONS lifetables for annual mortality risk by age and sex based on data in 2016-2018 period [388]; (3) ONS projections on population size by five-year age group and sex at local authority level for period 2018-2043 based on demographic, mortality and migration patterns during the 2014-2018 period [389]; (4) NHS Digital estimate of the average institutionalisation rate for the Sheffield population aged 65+ at the end of the financial year 2018-19 [390]; and (5) ELSA Wave 4 for the relative odds of being institutionalised by five-year age group and sex for the English population aged 60+.

Annual mortality risks stratified by age and sex were applied twice to the 2019 Sheffield population aged 60+ to estimate the population size by age (now 62+) and sex in 2021. The projected sizes of the population aged 60 and 61 were added to form a Sheffield cohort aged 60+ in 2021. Because the projected sizes were reported in five-year age groups, the share of those aged 60 in that age group was estimated from the ONS 2019 population data [387]. According to the NHS Digital report, at the end of the financial year 2018-19 there were 1,580 Sheffield residents aged 65+ living in nursing homes or residential care facilities supported by the local authority [390]. This constituted 1.67% of the total Sheffield population aged 65+. However, this number does not include individuals living in private LTC facilities. According to the PHE model, 43.6% of new LTC admissions caused by hospitalised falls were privately funded [216]. If this percentage is assumed to apply to LTC admissions for any cause, then the percentage of the Sheffield population aged 65+ living in LTC would be 2.96%.

In comparison, the ELSA data appear to underestimate the prevalence of institutionalisation in the older population. According to a variable that recorded where the survey interview took place, only 0.9% of Wave 4 interviews were recorded to have taken place in an institution. Nevertheless, the ELSA information on the degree of variation in institutionalisation rate by age group and sex was assumed to apply to the model population. Hence, the odds ratios of being institutionalised for each age and sex subgroup relative to males aged 65-69 were estimated from ELSA Wave 4 (Table E5 in Appendix E). The subgroup-specific rates that produced a weighted average rate of 2.96% were then estimated. The multipliers of one minus subgroup-specific institutionalisation rates were then applied to the all-residence population to estimate the numbers of community-dwelling persons in each age and sex subgroup. The first three columns of Table 5.4 show the number of community-dwelling persons in Sheffield by age and sex for the initial cohort aged 60+ in 2021 (n=125,244). According to the overall sex ratio for the initial cohort across all ages, 46.5% of the individuals were assigned to be male. The age distribution for each sex was then assigned by the percentage of people of the same sex in each age (i.e., the parenthesised values in columns two and three of Table 5.4).

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| **Table 5.4** Community-dwelling Sheffield population for period 2021-2060: (a) initial cohort aged 60 and over in 2021; (b) new entry cohorts aged 60 between 2022 and 2060. | | | | |
| **(a) Initial cohort size by age and sex (% of sex total)** | | | **(b) New entry cohort size by year** | |
| **Age** | **Male** | **Female** | **Year** | **Number** |
| 60 | 3122 (5.35) | 3234 (4.84) | 2022 | 6527 |
| 61 | 3005 (5.15) | 3120 (4.66) | 2023 | 6671 |
| 62 | 2889 (4.95) | 3022 (4.52) | 2024 | 6794 |
| 63 | 2933 (5.03) | 2887 (4.32) | 2025 | 6902 |
| 64 | 2763 (4.73) | 2732 (4.08) | 2026 | 7011 |
| 65 | 2532 (4.34) | 2648 (3.96) | 2027 | 7084 |
| 66 | 2445 (4.19) | 2593 (3.88) | 2028 | 7163 |
| 67 | 2399 (4.11) | 2590 (3.87) | 2029 | 7247 |
| 68 | 2390 (4.10) | 2522 (3.77) | 2030 | 7278 |
| 69 | 2189 (3.75) | 2465 (3.69) | 2031 | 7272 |
| 70 | 2188 (3.75) | 2421 (3.62) | 2032 | 7185 |
| 71 | 2202 (3.77) | 2408 (3.60) | 2033 | 6988 |
| 72 | 2297 (3.94) | 2456 (3.67) | 2034 | 6743 |
| 73 | 2460 (4.22) | 2655 (3.97) | 2035 | 6503 |
| 74 | 2511 (4.30) | 2804 (4.19) | 2036 | 6229 |
| 75 | 1900 (3.26) | 2311 (3.46) | 2037 | 6021 |
| 76 | 1889 (3.24) | 2279 (3.41) | 2038 | 5920 |
| 77 | 1956 (3.35) | 2226 (3.33) | 2039 | 5970 |
| 78 | 1654 (2.83) | 1946 (2.91) | 2040 | 6094 |
| 79 | 1441 (2.47) | 1782 (2.66) | 2041 | 6220 |
| 80 | 1270 (2.18) | 1588 (2.37) | 2042 | 6329 |
| 81 | 1374 (2.35) | 1600 (2.39) | 2043 | 6421 |
| 82 | 1233 (2.11) | 1606 (2.40) | 2044 | 6448 |
| 83 | 1144 (1.96) | 1562 (2.34) | 2045 | 6475 |
| 84 | 1059 (1.81) | 1337 (2.00) | 2046 | 6502 |
| 85 | 907 (1.55) | 1238 (1.85) | 2047 | 6530 |
| 86 | 807 (1.38) | 1157 (1.73) | 2048 | 6557 |
| 87 | 692 (1.19) | 1009 (1.51) | 2049 | 6585 |
| 88 | 505 (0.86) | 896 (1.34) | 2050 | 6612 |
| 89 | 453 (0.78) | 781 (1.17) | 2051 | 6640 |
| 90+1 | 1751 (3.00) | 3008 (4.50) | 2052 | 6668 |
| **Total by sex** | 58,359 (100) | 66,885 (100) | 2053 | 6696 |
| **Total** | 125,244 (46.5% male) | | 2054 | 6724 |
|  |  |  | 2055 | 6752 |
|  |  |  | 2056 | 6780 |
|  |  |  | 2057 | 6809 |
|  |  |  | 2058 | 6837 |
|  |  |  | 2059 | 6866 |
|  |  |  | 2060 | 6895 |
|  |  |  | **Total** | 259,950 (48.6% male) |
| 1 No disaggregated data by integer age were available for those aged 90 and over from the Office for National Statistics data [387] or the English Longitudinal Study in Ageing. | | | | |

The sizes of incoming cohorts aged 60 were estimated using the ONS projections for each year between 2022 and 2043 [389], shown in the last two columns of Table 5.4. For the period after 2043, the average sex-specific annual growth rates over the period 2018-2043 (0.36% for male and 0.48% for female) were assumed to hold until 2060. Each new cohort entered the model at the start of each cycle, and 48.6% of them were assigned male according to the average sex ratio reported by ONS [389].

#### 5.2.2.2 Socioeconomic status

The SES characteristic of interest to the Sheffield decision-makers was the LSOA-level deprivation variable visible in the CCG routine data (Section 3.5.4). With the routine data inaccessible, an alternative SES characteristic was sought from ELSA. Section 3.6.1 had noted several SES factors serving as key causal variables: education; household wealth; and subjective report of financial difficulty. For education, ELSA Wave 4 contained information on the highest qualification obtained by the respondent. Three categories were formed: (1) university degree; (2) higher education below degree or high school qualification; and (3) below high school qualification, no qualification or foreign qualification. For household wealth, the composite measure used in a previous falls epidemiological study using ELSA was constructed [255]. This incorporated total value of savings, property, and business. Individuals were then divided into wealth quartiles. For self-reported financial difficulty, an ELSA variable measured the frequency of financial need as Never, Rarely, Sometimes, Often, and Most of the time.

From the three SES variables – education (3 categories), wealth (4) and self-reported financial difficulty (5) – a composite score was computed by summing the indicator levels. The score ranged between 3 and 12; higher score indicated greater deprivation. Individuals were then divided into quartiles for this composite measure. Using ELSA, proportions of social quartiles for each sex and five-year age subgroups were estimated, as shown in Table 5.5. The proportions were applied to individuals by age group and sex at model entry. For new cohorts aged 60, the proportions for age 60-64 were applied. Once assigned, individuals’ SES quartiles were assumed invariant over time. The discrete numbers of the categorical SES variable produced uneven quartile sizes. The varying prevalence across age in Table 5.5 reflected the heterogeneous mortality risks across quartiles: the third and fourth quartiles increasingly occupied smaller proportions of older subgroups due to their shorter life expectancy.

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| **Table 5.5** Proportions of SES quartiles by five-year age group and sex in ELSA. | | | | |
| % of age and sex subgroup | **Most privileged quartile** | **2nd quartile** | **3rd quartile** | **Most deprived quartile** |
| ***Male*** |  |  |  |  |
| Age 60-64 | 42.2 | 18.4 | 27.7 | 11.7 |
| Age 65-69 | 44.6 | 19.1 | 26.3 | 10.0 |
| Age 70-74 | 39.9 | 20.5 | 28.0 | 11.6 |
| Age 75-79 | 39.9 | 20.2 | 29.4 | 10.5 |
| Age 80-84 | 42.5 | 21.7 | 26.3 | 9.5 |
| Age 85-89 | 40.4 | 28.9 | 26.9 | 3.8 |
| Age 90+ | 54.9 | 20.9 | 16.5 | 7.7 |
| All age groups | 42.0 | 20.1 | 27.4 | 10.5 |
| ***Female*** |  |  |  |  |
| Age 60-64 | 37.5 | 17.6 | 30.9 | 14.0 |
| Age 65-69 | 38.1 | 17.5 | 31.6 | 12.8 |
| Age 70-74 | 32.2 | 19.1 | 33.4 | 15.3 |
| Age 75-79 | 29.8 | 22.2 | 33.5 | 14.5 |
| Age 80-84 | 31.6 | 22.5 | 36.1 | 9.8 |
| Age 85-89 | 34.5 | 22.5 | 35.2 | 7.8 |
| Age 90+ | 40.1 | 26.2 | 27.9 | 5.8 |
| All age groups | 34.7 | 19.5 | 32.6 | 13.2 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; SES: socioeconomic status | | | | |

#### 5.2.2.3 Baseline falls history

After age, sex and SES quartile, individuals were assigned their baseline falls history. In ELSA Wave 4, participants were asked: (i) whether they had fallen down last year; (ii) number of times they had fallen down last year; and (iii) whether they were injured seriously enough from the fall to need medical treatment. From these three variables five falls history types were formed: (1) no falls history; (2) history of single fall not requiring medical attention (non-MA fall); (3) recurrent non-MA falls history; (4) single MA fall history; and (5) history of recurrent falls with at least one MA fall. Note that it was not possible to discern from ELSA whether a person experienced one or multiple MA fall(s). Table 5.6 shows the proportions of falls history type for men in the most privileged SES quartile by age group and for women in the most deprived SES quartile. The full set of proportions is shown in Table E6.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Table 5.6** Proportions of baseline falls history types by age group, sex and SES quartile in ELSA: sample display for male in most privileged SES quartile and female in most deprived SES quartile. | | | | | |
|  | No falls history | Single non-MA fall history | Recurrent non-MA falls history | Single MA fall history | Recurrent falls with 1+ MA fall |
| ***Male – Most privileged SES quartile*** | | | | | |
| Age 60-64 | 83.5 | 9.1 | 5.5 | 1.2 | 0.7 |
| Age 65-69 | 83.2 | 6.7 | 6.4 | 2.2 | 1.5 |
| Age 70-74 | 77.7 | 10.9 | 5.5 | 3.4 | 2.5 |
| Age 75-79 | 73.3 | 10.6 | 9.3 | 4.6 | 2.2 |
| Age 80-84 | 68.4 | 13.8 | 11.3 | 3.9 | 2.6 |
| Age 85-89 | 61.9 | 11.4 | 14.3 | 3.8 | 8.6 |
| Age 90+ | 61.5 | 12.0 | 22.0 | 0.5 | 4.0 |
| ***Female – Most deprived SES quartile*** | | | | | |
| Age 60-64 | 72.0 | 11.4 | 8.7 | 3.9 | 4.0 |
| Age 65-69 | 65.5 | 12.8 | 9.9 | 5.4 | 6.4 |
| Age 70-74 | 71.3 | 11.7 | 7.8 | 5.7 | 3.5 |
| Age 75-79 | 66.0 | 11.8 | 11.7 | 4.6 | 5.9 |
| Age 80-84 | 51.4 | 11.8 | 11.8 | 14.7 | 10.3 |
| Age 85-89 | 52.9 | 11.8 | 17.6 | 5.9 | 11.8 |
| Age 90+ | 69.5 | 10.0 | 10.0 | 0.5 | 10.0 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; SES: socioeconomic status | | | | | |

#### 5.2.2.4 Baseline frailty

Multivariate frailty index was conceptualised as a key causal variable (Section 3.6.3). The original modelling plan had been to construct an index from the CCG routine data; with the routine data being inaccessible, the frailty index was constructed from ELSA, with care taken to ensure that it is broadly consistent in characteristics with indices previously used in frailty and falls prevention research.

Table 5.7 displays the characteristics and component items of four frailty indices used in literature: electronic frailty index (eFI) [47]; Beijing Longitudinal Study of Aging frailty index (BLSA FI) [52, 391]; Global Longitudinal Study of Osteoporosis in Women frailty index (GLOW FI) [53, 370]; and ProAct65+ trial frailty index [277]. Their component items comprised eight categories: chronic diseases; sensory/physical impairments and geriatric syndromes; cognitive impairment; subjective symptoms and health; lifestyle risk factors; activity limitation; healthcare contact; and social. The new frailty index was constructed to cover all categories. It also met the established criteria for frailty index construction (e.g., at least 30 deficit items) [49]. It also followed the stakeholder suggestion (by personal communication) that the index contain falls risk factors highlighted by NICE CG161 including: gait deficit; balance deficit; mobility impairment; visual impairment; cognitive impairment; urinary incontinence; and environmental hazards [13]. All factors were included except environmental hazards. The final index contained 52 items as shown in the last column of Table 5.7. The number of deficits per individual was divided by the total possible number (52) to derive the index score.

The score ranged between 0 and 0.615 and had mean of 0.11 (SD 0.09) for men and 0.13 (SD 0.10) for women. These were slightly lower than the sex-specific mean values for eFI of 0.13 (SD 0.09) for men and 0.15 (SD 0.10) for women. This is to be expected since the ELSA population is younger (aged 60+) than the eFI population (65+).

Previous studies took different approaches for establishing severity categories based on index scores. For example, eFI scores were divided into mild frailty (eFI >0.12-0.24), moderate frailty (eFI >0.24-0.36) and severe frailty (eFI >0.36) relative to fit reference category (eFI 0-0.12) at the 50th, 85th and 97th percentile eFI values, respectively. This study took this approach and established the cut-off levels for Fit, Mild, Moderate and Severe frailties at the 50th, 85th and 97th percentile values. The resulting index score ranges for each category were 0-0.10 for Fit, >0.10-0.23 for Mild, >0.23-0.37 for Moderate and >0.37 for Severe.

For parameterisation, the frailty scores were multiplied by 100 to range 0-100. A visual plot showed that the scores followed a lognormal distribution. The mean and SD for the lognormal distribution were obtained for each of the 280 subgroups delineated by age group (7 categories), sex (2), social deprivation quartile (4), and falls history (5), and similarly for the 40 subgroups within each new cohort aged 60. The frailty parameters for the initial cohort’s 280 subgroups are shown in Table E7. Individuals were assigned baseline frailty scores and associated frailty categories at model entry.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Table 5.7** Characteristics of multivariate frailty indices used in previous frailty and falls prevention studies and in this study. | | | | | |
|  | **eFI [47]** | **BLSA FI [52, 391]** | **GLOW FI [53, 370]** | **ProAct65+ FI1 [277]** | **This study** |
| Country | UK | China | Canada | England | England |
| Data source | Electronic health records | Cohort survey | Cohort survey | Cohort survey | Cohort survey |
| Total # of items | 36 | 332 | 34 | 40 | 52 |
| Mean (SD) | Men: 0.13 (0.09)  Women: 0.15 (0.10) | Men: 0.11 (0.10)  Women: 0.14 (0.12) | Women only: 0.24 (0.13) | Both sex: 0.16 (0.11) | Men: 0.11 (0.09)  Women: 0.13 (0.10) |
| Severity categories | [Fit] 0-0.12 (50%)  [Mild] >0.12-0.24 (35%)  [Moderate] >0.24-0.36 (12%)  [Severe] >0.36 (3%) | [1] 0-0.03  [2] >0.03-0.10  [3] >0.10-0.20  [4] >0.20-0.50  [5] >0.50 | [Robust] 0-0.20 (43.9%)  [Prefrail] >0.20-0.35 (34.1%)  [Frail] >0.35 (22.1%) | [Non-frail] 0-<0.25 (81.5%)  [Frail] >=0.25 (18.5%) | [Fit] 0-0.10 (50%)  [Mild] >0.10-0.23 (35%)  [Moderate] >0.23-0.37 (12%)  [Severe] >0.37 (3%) |
| ***Component items*** | | | | | |
| Chronic diseases | (17) Anemia; Arthritis; AF; CBVD; CKD; Diabetes; Heart failure; Heart valve disease; Hypertension; Hypotension; IHD; Osteoporosis; PD; PVD; RD; Thyroid disease; Urinary system disease | (8) Arthritis; Cataract; CHD; Glaucoma; Hypertension; Stroke; Thyroid disease; TIA | (13) Cancer; Celiac disease; Chronic bronchitis; Crohn’s disease; Diabetes; Heart disease; High cholesterol; Hypertension; Multiple sclerosis; Osteoarthritis; PD; RA; Stroke | (15) Blood disease; Cancer; Digestive disease; Ear disease; Endocrine disease; Eye disease; Genitourinary disease; Heart disease; Infectious disease; Mental disease; MSKD; Nervous disease; RD; Skin disease; Other disease | (20) Angina; Arrhythmia; Arthritis; Asthma; Cancer; Cataract; Depression; Diabetes; DED; DKD; Glaucoma; Heart attack; Heart disease – other; Heart murmur; Hypertension; High cholesterol; Lung disease; MD; Osteoporosis; Stroke |
| Sensory/physical impairments and geriatric syndromes | (12) Hearing impairment; Visual impairment; Dizziness; Dyspnea; Falls; Foot problems; Fragility fractures; Peptic ulcer; Skin ulcer; Sleep disturbance; UI; Weight loss and anorexia | (5) Hearing problem; Use a hearing aid; Use a walking aid; Tremor; UI | (1) Unintentional weight loss | (2) Use a walking aid; Balance problems | (8) Seeing difficulties; Hearing difficulties; Slow walking speed;3,4 Balance problems;4 Weak grip strength;3,4 Weak leg strength;4 UI; Significant weight loss3,4 |
| Cognitive impairment | (1) Memory and cognitive problems | (1) MMSE<15 |  |  | (1) Composite measure of cognitive problems across 4 tests of memory, mental speed and numeracy |
| Subjective symptoms and health status |  | (5) Lack of energy; Felt less useful; Don’t feel a lot of fun in life; Don’t feel very happy; Feel nothing to do | (6) Feels full of life; Has a lot of energy; Feels worn out; Feels tired; Self-rated health; Self-rated pain | (6) Feeling calm; Have a lot of energy; Feeling low; Social activity interfered by physical and emotional health; Self-rated health; Normal work interfered by pain | (4) Self-reported exhaustion;3 Self-rated health; Self-rated pain; Self-reported long-standing illness |
| Lifestyle risk factors |  |  |  | (2) Obesity (BMI>=30); Low physical activity | (2) Low physical activity;3 Obesity |
| Activity limitation | (3) Any activity limitation; Housebound; Mobility and transfer problems | (14) ADL & IADL limitations | (12) ADL limitations | (14) ADL & IADL limitations | (15) ADL & IADL limitations |
| Healthcare contact | (2) Polypharmacy (5+ medications); Requirement for care |  | (2) Polypharmacy (5+ medications); Frequency of healthcare visit in past year | (1) Polypharmacy (6+ medications) | (1) Polypharmacy (5+ medications) |
| Social | (1) Social vulnerability |  |  |  | (1) Living alone |
| **Abbreviation:** ADL: activities of daily living; AF: atrial fibrillation; BLSA: Beijing Longitudinal Study of Aging; CBVD: cerebrovascular disease; CHD: coronary heart disease; CKD: chronic kidney disease; DED: diabetic eye disease; DKD: diabetic kidney disease; eFI: electronic frailty index; FI: frailty index; GLOW: Global Longitudinal Study of Osteoporosis in Women; IADL: instrumental activities of daily living; IHD: ischemic heart disease; MD: macular degeneration; MMSE: mini-mental status examination; MSKD: musculoskeletal disease; PD: Parkinson’s disease; PVD: peripheral vascular disease; RA: rheumatoid arthritis; RD: respiratory disease; SD: standard deviation; TIA: transient ischemic attack; UI: urinary incontinence  1 The frailty index was constructed using data from the randomized controlled trial ProAct65+ which compared group- and home-based falls prevention exercise to usual care in London, Nottingham and Derby [135].  2 The original index contained 35 items including falls and fracture [391]; the latter were taken out from index and used as outcomes in subsequent study [52].  3 Components of the frailty phenotypes proposed by Fried and colleagues [275].  4 These variables had more than 5% missing values which were imputed by single imputation. | | | | | |

#### 5.2.2.5 Covariates estimated at baseline

Where data was available from ELSA, key causal variables identified by the conceptual model (Section 3.6) were estimated and assigned to individuals at model entry. The following variables were estimated: (a) high physical activity; (b) cognitive impairment; (c) fear of falling; and (d) abnormal gait/balance. Cross-sectional analyses were conducted using combined information from both Wave 4 and 5 cohorts (n=13,422) rather than Wave 4 alone (n=7,255) to improve the statistical power. Estimations were conducted sequentially in the order of the variables given above, with the preceding variable(s) serving as an explanatory variable (depending on model fit) for the next variable estimation. It should be noted that the estimations were conducted for associative patterns rather than causal inference.

For each dependent variable, the statistical model that produced the lowest Akaike and/or Bayesian information criterion (AIC and BIC) values was chosen as the best-fit model. Table E8 in Appendix E shows all model-fit comparisons for cross-sectional analyses. The coefficient point estimates from the best-fit models were inputted to the simulation model to generate probability for the individual having the characteristic in question. Since all four variables were binary indicators, equation (1) was used to estimate the individual-specific probability:

describes the set of *k* explanatory variables for the event in question and describes the value the explanatory variable *j* within the set takes for individual *i*. to are the estimated logistic regression coefficients for the explanatory variables, and is the estimated constant term. Having generated the probability, a random number was generated for each individual to determine whether he/she has the characteristic in question. The variance-covariance matrix generated by the best-fit model estimation was stored and later used in probabilistic sensitivity analysis (Section 5.4.1.3).

##### High physical activity

The conceptual model identified physical activity level as a key causal variable (Section 3.6.3) Therefore, the model incorporates a binary indicator for high physical activity. The UK CMO guideline recommended 150 minutes per week of at least moderate intensity exercise of any form for adults aged 65+ [113]. According to a UK survey in 2008, 20% of men and 17% of women aged 65-74 met this guideline level [198]. ELSA Waves 4-5 contained a variable summarising the physical activity levels of individuals (Not known; Sedentary; Low; Moderate; High), but the intensity or duration was not stated. Nevertheless, 21.5% of men and 15.9% of women aged 65-74 in ELSA reported ‘High’ level of physical activity. Given the comparable prevalence rates to the survey, the ELSA information of ‘High’ physical activity was assumed to indicate meeting of CMO guideline. The overall prevalence rate of high physical activity in the ELSA cohort aged 60+ was 17.3%.

A binary variable for high vs. non-high physical activity was created and used as the dependent variable in a multivariate logistic regression to estimate the probability of an individual engaging in high physical activity given his/her characteristics. Table 5.8 shows the regression coefficients for the best-fit model.

|  |  |  |
| --- | --- | --- |
| **Table 5.8** Logistic regression coefficients for high physical activity from ELSA Waves 4 and 5. | | |
| ***Dependent variable: High physical activity (N=13,422)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -4.187 (2.475) | 0.091 |
| Age | 0.151 (0.070) | 0.031 |
| Age^2 | -0.001 (0.0004) | 0.008 |
| Female | -0.255 (0.049) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | -0.115 (0.065) | 0.077 |
| *3rd quartile* | -0.202 (0.059) | 0.001 |
| *Most deprived quartile* | -0.366 (0.091) | <0.001 |
| Frailty (0-100) | -0.100 (0.004) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; Ref: reference; SE: standard error; SES: socioeconomic status | | |

The best-fit model excluded the categorical variable for falls history as an explanatory variable. The inclusion of quadratic age term showed a non-linear association with age. Women were less likely to engage in high physical activity, and there was a statistically significant social gradient in high physical activity probability. Frailer individuals were less likely to engage in high physical activity.

##### Cognitive impairment

The conceptual model identified cognitive impairment as a key causal variable (Section 3.6.3). The model hence incorporated a binary indicator for cognitive impairment. ELSA appeared to under-report the prevalence of severe cognitive impairment: the combined prevalence of self-reported dementia and Alzheimer’s disease diagnosis was less than 1% of the population aged 65+ compared to estimates of around 5% in other epidemiological studies [392]. ELSA also contained no validated measure of cognitive impairment such as the mini-mental state examination. However, ELSA reported other measures of cognitive function based on tests of memory, mental speed, and numeracy [382].

From these measures, a composite measure of cognitive impairment was constructed. Individuals in the bottom quartile for scores from all of the following cognition tests – date recall, word recall (with and without delay), and animal name recall (numeracy score was only available in Wave 4 and hence not used) – were classified as cognitively impaired. One UK survey reported a prevalence rate of mild cognitive impairment and dementia of 21.8% for men aged 65-84 [319]. In comparison, the composite measure estimated the prevalence of 23.0% for men aged 65-84 in ELSA Waves 4-5. Given the comparable prevalence, the ELSA variable was used as an indicator of cognitive impairment. Table 5.9 shows the regression coefficients for the best-fit model.

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| --- | --- | --- |
| **Table 5.9** Logistic regression coefficients for cognitive impairment from ELSA Waves 4 and 5. | | |
| ***Dependent variable: Cognitive impairment (N=13,422)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | 0.639 (2.475) | 0.723 |
| Age | -0.099 (0.049) | 0.042 |
| Age^2 | 0.001 (0.0003) | 0.003 |
| Female | -0.340 (0.045) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | 0.190 (0.062) | 0.002 |
| *3rd quartile* | 0.168 (0.055) | 0.002 |
| *Most deprived quartile* | 0.181 (0.074) | 0.015 |
| Frailty (0-100) | 0.025 (0.002) | <0.001 |
| High physical activity | -0.280 (0.070) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; Ref: reference; SE: standard error; SES: socioeconomic status | | |

There was a statistically significant non-linear relationship between cognitive impairment and age. Women were less likely to be cognitively impaired. There was evidence of a social gradient in impairment with all SES quartiles below the most privileged showing higher rates. Frailty was associated with higher prevalence, engaging in high physical activity with lower prevalence.

##### Fear of falling

The conceptual model identified fear of falling as a key causal variable (Section 3.6.2). ELSA Wave 4 contained a binary variable for whether the respondent experienced fear of falling while walking, with the overall prevalence of 6.8% for the ELSA cohort aged 60+. The variable was imputed for the Wave 5 cohort from the Wave 4 data. Table 5.10 shows the regression coefficients for the best-fit model.

|  |  |  |
| --- | --- | --- |
| **Table 5.10** Logistic regression coefficients for fear of falling from ELSA Waves 4 and 5. | | |
| ***Dependent variable: Fear of falling (N=13,422)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -8.095 (0.379) | <0.001 |
| Age | 0.018 (0.005) | <0.001 |
| Female | 0.246 (0.080) | 0.002 |
| Falls history (ref: No falls history) |  |  |
| *Single non-MA fall* | 0.879 (0.113) | <0.001 |
| *Recurrent non-MA falls* | 1.315 (0.100) | <0.001 |
| *Single MA fall* | 1.335 (0.139) | <0.001 |
| *Recurrent falls with MA* | 1.330 (0.138) | <0.001 |
| Frailty (0-100) | 0.235 (0.013) | <0.001 |
| Frailty^2 | -0.003 (0.0002) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; Ref: reference; SE: standard error | | |

There was a statistically significant linear relationship between age and fear of falling. Women were likelier to experience fear. There was no significant evidence of social gradient in fear prevalence. Falls history of any type was associated with increased prevalence, consistent with fear of falling being a consequence of falls. There was a non-linear relationship between frailty and fear of falling.

##### Abnormal gait and balance

The conceptual model identified gait and balance status as a key causal variable (Section 3.6.3). ELSA contained no validated measure for gait and balance impairment, such as TUG or Tinetti balance scale. Instead, measure of walking speed (time in seconds to walk eight feet) and self-reported level of balance difficulty were used as indicators. Following a previous practice [255], those with walking speed in the bottom sex-specific quintile and those who could not perform the walking speed test due to health reasons were deemed to have abnormal gait. The prevalence of abnormal gait for the ELSA cohort was 26.4%. For the measure of balance, those who self-reported having balance difficulties ‘Very often’, ‘Always’ or ‘Can’t walk’ were deemed to have abnormal balance. The overall prevalence of abnormal balance was 7.3%. A composite measure was constructed that gave a value of 1 if individual had abnormal gait/balance and 0 otherwise; the overall prevalence was 28.0%. Table 5.11 shows the regression coefficients from the best-fit model.

|  |  |  |
| --- | --- | --- |
| **Table 5.11** Logistic regression coefficients for abnormal gait and/or balance from ELSA Waves 4 and 5. | | |
| ***Dependent variable: Abnormal gait and/or balance (N=13,422)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | 7.135 (2.217) | 0.001 |
| Age | -0.335 (0.060) | <0.001 |
| Age^2 | 0.003 (0.0004) | <0.001 |
| Female | -0.349 (0.053) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | 0.338 (0.074) | <0.001 |
| *3rd quartile* | 0.386 (0.065) | <0.001 |
| *Most deprived quartile* | 0.520 (0.083) | <0.001 |
| Falls history (ref: No falls history) |  |  |
| *Single non-MA fall* | 0.112 (0.083) | 0.176 |
| *Recurrent non-MA falls* | 0.365 (0.090) | <0.001 |
| *Single MA fall* | 0.257 (0.121) | 0.033 |
| *Recurrent falls with MA* | 0.322 (0.148) | 0.030 |
| Frailty (0-100) | 0.170 (0.004) | <0.001 |
| High physical activity | -0.299 (0.088) | 0.001 |
| Cognitive impairment | 0.265 (0.063) | <0.001 |
| Fear of falling | 0.381 (0.103) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; Ref: reference; SE: standard error; SES: socioeconomic status | | |

Both age and sex were significantly associated with abnormal gait/balance. There was also a significant SES gradient to the prevalence. Falls history of any type except single non-MA fall increased the likelihood of having abnormal gait/balance, showing evidence of a feedback loop. Higher frailty and cognitive impairment were both associated with higher prevalence of abnormal gait/balance, while engaging in high physical activity was associated with lower prevalence. Finally, fear of falling was associated with abnormal gait/balance.

According to a previous model that incorporated gait/balance screening, TUG had sensitivity and specificity of 31.0% and 74.0%, respectively, for cohort aged 65-89 [363]. In comparison, the model predicted that 39.6% of those aged 65-89 who received falls risk screening and experienced any fall in the first cycle had abnormal gait/balance, while 72.0% of those who did not experience any fall did not, giving sensitivity of 39.6% and specificity of 72.0%. Hence, the ELSA variable approximates the performance of TUG, a screening tool recommended by NICE CG161 (p. 53) [13].

### 5.2.3 Outcomes estimated at baseline

Given the baseline characteristics, the following outcomes were estimated from ELSA: EQ-5D health utilities (Section 5.2.3.1); productivity level – paid employment and unpaid work (Section 5.2.3.2); CASP-19 social wellbeing (Section 5.2.3.3); and comorbidity care costs by sector – healthcare, social care, out-of-pocket care, and informal care (Section 5.2.3.4).

#### 5.2.3.1 Health utilities

The generic health utility measure for CUA should capture the primary and secondary health effects of falls (Figure 1.1) and background transition in health status. The ideal method is to use individual-level utility data. ELSA does not collect such data; although its parent survey, the annual cross-sectional Health Survey for England (HSE) from which ELSA participants are drawn, collects EQ-5D-3L data [393, 394]. Therefore, this study estimated EQ-5D-3L values from ELSA data by using published information on EQ-5D-3L item responses and average index values for older subgroups in HSE.

Table 5.12 lists: (i) the five dimensions and three levels of EQ-5D-3L; (ii) the prevalence rates of item responses for each level for the subgroup aged 75+ in HSE 2008 [393]; (iii) the ELSA variables used as proxy indicators of problems in the five dimensions and three levels; and (iv) the prevalence rates of item responses for the proxy variables in ELSA. ELSA was searched for variables that not only captured similar concept as the EQ-5D-3L responses but also had similar prevalence rates to the sub-cohort aged 75+ in HSE 2008. The final set of proxy variables produced similar prevalence rates for mobility, usual activities, and anxiety and depression, but overestimated the rate of ‘Some problems’ for self-care and underestimated the rate of ‘Some’ pain. Previous studies have used this approach of identifying proxy variables and items to estimate health utility values [395, 396].

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| --- | --- | --- | --- | --- |
| **Table 5.12** Proxy variable selection in ELSA to estimate EQ-5D-3L values. | | | | |
| **EQ-5D dimension** | **Dimension levels** | **Prevalence in HSE 2008 aged 75+1 (%)** | **ELSA proxy variable** | **Prevalence in ELSA Wave 4 aged 75+ (%)** |
| Mobility | No problem | 47.4 | Not (1) or (2) | 45.5 |
| Some problems | 52.3 | (1) Some difficulty walking ¼ mile unaided | 54.4 |
| Confined to bed | 0.3 | (2) Confined to bed | 0.1 |
| Self-care | No problem | 85.1 | No ADL limitation | 60.8 |
| Some problems | 13.6 | 1-5 ADL limitations | 37.8 |
| Unable to | 1.4 | 6+ ADL limitations | 1.4 |
| Usual activities | No problem | 58.8 | No IADL limitation | 58.0 |
| Some problems | 35.4 | 1-5 IADL limitations | 38.1 |
| Unable to | 5.8 | 6+ IADL limitations | 3.9 |
| Pain; discomfort | No | 38.1 | No pain most of the time | 59.6 |
| Some | 52.7 | Mild/moderate pain most of the time | 31.8 |
| Extreme | 9.2 | Severe pain most of the time | 8.6 |
| Anxiety; depression | No | 76.7 | Not (1) or (2) | 82.4 |
| Some | 21.8 | (1) Feels what happens in life is often beyond control | 15.6 |
| Extreme | 1.5 | (2) Diagnosis of psychiatric problem of anxiety | 2.0 |
| **Abbreviation:** ADL: activities of daily living; ELSA: English Longitudinal Study of Ageing; HSE: Health Survey for England; IADL: instrumental activities of daily living  1 Data reported in Janssen and Szende (2014) [393]. | | | | |

Having chosen the proxy variables, the time trade-off valuation set elicited from a representative UK adult population [397] was applied to derive the preference-based EQ-5D index scores. This was the same valuation set as that applied in the HSE studies [393, 394]. Table 5.13 shows the means and 95% confidence intervals for the index scores reported in HSE 2008 for age groups 65-74 and 75+ [393]. There were close overlaps between the HSE 2008 means and those estimated from ELSA Wave 4 (also conducted in year 2008) for both age groups. The ELSA estimates were further compared to those reported by Ara and Brazier who pooled four HSE cross-sections between 2003 and 2006 [394]. There were reasonable overlaps between the two sets of estimates, with the ELSA means falling within the 95% confidence intervals of HSE 2003-2006 for each five-year age group.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 5.13** Comparison between general population EQ-5D values estimated from ELSA Wave 4 and those reported in Health Survey for England. | | | | | | | |
|  |  | Age 65-74 | Age 75+ |  |  |  |  |
| HSE 20081 | Mean | 0.784 | 0.717 |  |  |  |  |
| 95% CInt | 0.772-0.796 | 0.703-0.731 |  |  |  |  |
| ELSA estimate | Mean | 0.783 | 0.718 |  |  |  |  |
| 95% CInt | 0.776-0.790 | 0.710-0.726 |  |  |  |  |
|  |  | Age 60-64 | Age 65-69 | Age 70-74 | Age 75-79 | Age 80-84 | Age 85+ |
| HSE 2003-20062 | Mean | 0.807 | 0.804 | 0.779 | 0.753 | 0.699 | 0.650 |
| 95% CInt | 0.793-0.821 | 0.790-0.817 | 0.766-0.791 | 0.739-0.767 | 0.677-0.719 | 0.624-0.675 |
| ELSA estimate | Mean | 0.797 | 0.790 | 0.777 | 0.744 | 0.705 | 0.670 |
| 95% CInt | 0.787-0.806 | 0.780-0.800 | 0.767-0.787 | 0.732-0.756 | 0.690-0.721 | 0.646-0.695 |
| **Abbreviation:** CInt: confidence interval; ELSA: English Longitudinal Study of Ageing; HSE: Health Survey for England  1 Data reported in Janssens and Szende (2014) [393]; n=14,763; UK time trade-off value set [397].  2 Data reported in Ara and Brazier (2011) [394]; n=41,174; UK time trade-off value set [397]. | | | | | | | |

Having estimated the individual-level EQ-5D scores, a linear regression estimated the associations between EQ-5D scores and individuals’ characteristics. Table 5.14 shows the results of the linear regression. To account for ceiling effects, individuals predicted an EQ-5D score greater than 1 (3.6% of the cohort) were reassigned the score of 1. Predicted scores were assigned to simulated individuals.

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| **Table 5.14** Linear regression coefficients for EQ-5D from ELSA Waves 4 and 5. | | |
| ***Dependent variable: EQ-5D (0-1) (N=13,422)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | 0.883 (0.010) | <0.001 |
| Age^2 | 0.00004 (0.000002) | <0.001 |
| Female | -0.015 (0.004) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | -0.009 (0.005) | 0.070 |
| *3rd quartile* | -0.021 (0.004) | <0.001 |
| *Most deprived quartile* | -0.053 (0.006) | <0.001 |
| Falls history (ref: No falls history) |  |  |
| *Single non-MA fall* | -0.010 (0.006) | 0.097 |
| *Recurrent non-MA falls* | -0.060 (0.006) | <0.001 |
| *Single MA fall* | -0.015 (0.009) | 0.095 |
| *Recurrent falls with MA* | -0.005 (0.011) | 0.644 |
| Frailty (0-100) | -0.021 (0.001) | <0.001 |
| Frailty^2 | 0.0001 (0.00001) | <0.001 |
| Cognitive impairment | -0.012 (0.004) | 0.008 |
| Abnormal gait/balance | -0.040 (0.005) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; Ref: reference; SE: standard error; SES: socioeconomic status | | |

Only the squared age term was significantly associated with EQ-5D, and the model fit improved when the ordinary age term was removed. Women had lower EQ-5D than men. Those in the two most deprived SES quartiles had lower EQ-5D than those in the most privileged quartile. Coefficients for falls history produced counterintuitive results, with recurrent non-MA falls history being the only type to be associated with a statistically significant decrement in EQ-5D. This can be explained by the closer relationship between MA falls history and frailty, such that estimation without frailty as explanatory variables produced more intuitive results: i.e., statistically significant EQ-5D decrements for both types of MA fall history which were of larger magnitude than that of recurrent non-MA falls. Higher frailty, cognitive impairment, and abnormal gait/balance were all significantly associated with lower EQ-5D.

Note that the coefficients on the falls history variable are unlikely to capture the primary/acute effect of falls on EQ-5D. This is because the EQ-5D data estimated from ELSA could have been recorded as much as 12 months after the fall incidence. Section 5.2.5.3 separately models the acute effect of falls on QALY using other published data. Moreover, Section 5.2.6.3 estimates the longitudinal progression of EQ-5D which capture the secondary effect of falls via dynamic propagators such as frailty.

#### 5.2.3.2 Productivity level

The conceptual model identified productivity level – via formal employment and voluntary work – as a key non-health outcome (Section 3.5.1). Using ELSA, this section estimates the probability of individuals engaging in paid and unpaid forms of productivity.

##### Paid employment

ELSA Waves 4-5 contained information on whether the respondent was in paid employment in the previous week. Overall, 17.4% of the combined cohort aged 60+ reported being in paid employment. Table 5.15 shows the regression coefficients from the best-fit model for being in paid employment.

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| **Table 5.15** Logistic regression coefficients for paid employment status from ELSA Waves 4 and 5. | | |
| ***Dependent variable: Paid employment status (N=13,422)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | 41.116 (2.975) | <0.001 |
| Age | -1.014 (0.085) | <0.001 |
| Age^2 | 0.006 (0.001) | <0.001 |
| Female | -0.698 (0.053) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | 0.005 (0.072) | 0.948 |
| *3rd quartile* | 0.089 (0.063) | 0.160 |
| *Most deprived quartile* | -0.258 (0.095) | 0.006 |
| Frailty (0-100) | -0.034 (0.011) | 0.002 |
| Frailty^2 | -0.001 (0.0004) | 0.003 |
| High physical activity | 0.170 (0.061) | 0.006 |
| Cognitive impairment | -0.136 (0.075) | 0.070 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; Ref: reference; SE: standard error; SES: socioeconomic status | | |

Older individuals and women were less likely to be in paid employment. Relative to those in the most privileged SES quartile, those in the most deprived quartile were less likely to be in paid employment, while those in the 2nd and 3rd quartiles did not have significantly different probabilities. Higher frailty was associated with reduced probability, while engaging in high physical activity was associated with higher probability. Cognitive impairment was associated with lower probability, but this was not statistically significant at the 95% confidence level.

The human capital approach was used to value the societal contribution of older persons in paid employment. Employed persons were assumed to generate an annual value of £24,192 which is the UK national average weekly pay in May 2020 before tax and other deductions [398] multiplied by 48 working weeks. This value was assumed to be constant over the model simulation time.

##### Unpaid work – volunteering and unpaid help

ELSA Waves 4-5 contained information on the frequency of ‘formal’ volunteering activities (i.e., as part of a volunteering organisation) in the past 12 months: at least once a week; less than once a week; and one-off. Similar frequency data was reported for provision of unpaid help (i.e., volunteering on a less formal basis), including informal caregiving for sick persons, childcare, and helping people with daily activities such as cooking, cleaning, and transporting. Together, they constituted unpaid work performed by older persons. It was assumed that only those who volunteered or provided unpaid help at least once a week generated consistent volume of societal contribution over a year. Therefore, a new binary variable was created to indicate weekly unpaid work, with 28.0% of the older population reporting to have done so in the previous 12 months.

Table 5.16 shows the logistic regression coefficients from the best-fit model estimating the prevalence of weekly unpaid work. Unlike paid employment, older individuals and women were likelier to be engaged in unpaid work. Nevertheless, there was a similar SES gradient, with the 3rd and the most deprived quartiles being significantly less likely to engage than the most privileged. Increasing squared frailty was associated with lower rate of work. Engaging in high physical activity was associated with higher rate, while cognitive impairment and abnormal gait/balance were associated with lower. Those in paid employment were less likely to engage.

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| **Table 5.16** Logistic regression coefficients for weekly unpaid work from ELSA Waves 4 and 5. | | |
| ***Dependent variable: Weekly unpaid work (N=13,422)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -16.403 (1.884) | <0.001 |
| Age | 0.432 (0.052) | <0.001 |
| Age^2 | -0.003 (0.0004) | <0.001 |
| Female | 0.382 (0.041) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | -0.007 (0.054) | 0.894 |
| *3rd quartile* | -0.100 (0.048) | 0.038 |
| *Most deprived quartile* | -0.366 (0.070) | <0.001 |
| Frailty^2 | -0.0006 (0.0001) | <0.001 |
| High physical activity | 0.127 (0.052) | 0.014 |
| Cognitive impairment | -0.479 (0.056) | <0.001 |
| Abnormal gait/balance | -0.314 (0.059) | <0.001 |
| Paid employment | -0.280 (0.058) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; Ref: reference; SE: standard error; SES: socioeconomic status | | |

The opportunity cost approach was used to value each hour of unpaid work. This approach values unpaid productivity in terms of the value of the next best use of the time. Where paid work is not the next best use, which is likely for the older population, literature recommends using wage at the previous paid job (possibly adjusted for lower productivity at unpaid work) or minimum wage to value the hourly contribution [234]. Therefore, each hour of unpaid work was valued at the UK national living wage since April 2021 of £8.91 [399]. Further assumptions were needed on the average annual number of unpaid work hours. A UK survey estimated that older people aged 65+ provided on average 159.1 hours of formal and informal volunteering per year [91]. Given the overall prevalence of weekly unpaid work of 27.8% among those aged 65+ in ELSA Wave 4, if each unpaid worker provided 11 hours per week, then this would amount to an average of 159 hours per person annually (11\*52\*0.278). Therefore, it was assumed that those engaged in weekly unpaid work provided 572 (11\*52) hours of work annually which is worth £5,097 at the national living wage.

For those providing informal care as unpaid work, the impact of caregiving on their health should be captured (Section 3.5.1). To identify the health impact, the best-fit linear model on EQ-5D (Table 5.14) was re-run with weekly informal caregiving – isolated from the weekly unpaid work variable – as a covariate. There was no statistically significant evidence of negative or positive effect of informal caregiving on EQ-5D. To verify whether this finding applies to younger informal caregivers aged less than 60, separate logistic regressions were estimated for the younger cohort with self-reported poor health status and anxiety as dependent variables (EQ-5D was not estimated for the cohort aged <60) and age, sex, and informal caregiving as explanatory variables. There was similarly no statistically significant evidence of informal caregiving affecting the likelihood of poor health status or anxiety. Therefore, health effect on informal caregivers was not incorporated in the model.

#### 5.2.3.3 Social wellbeing

Section 3.5.1 discussed the importance of capturing social wellbeing as a non-health outcome. ELSA contained the control, autonomy, self-realisation and pleasure, 19 items (CASP-19) scale measuring social wellbeing on a scale between 0 and 57 [400]. Missing CASP-19 data were imputed; the scores were rescaled to range 0-1. A linear regression estimated the associations between CASP-19 scores and the individual-level characteristics. Table 5.17 shows the results of the linear regression. Predicted rescaled CASP-19 scores were then assigned to individuals.

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| **Table 5.17** Linear regression coefficients for CASP-19 scores from ELSA Waves 4 and 5. | | |
| ***Dependent variable: CASP-19 (0-1) (N=13,422)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | 0.477 (0.091) | <0.001 |
| Age | 0.009 (0.002) | <0.001 |
| Age^2 | -0.0001 (0.00002) | <0.001 |
| Female | 0.020 (0.002) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | -0.020 (0.003) | <0.001 |
| *3rd quartile* | -0.044 (0.003) | <0.001 |
| *Most deprived quartile* | -0.081 (0.004) | <0.001 |
| Falls history (ref: No falls history) |  |  |
| *Single non-MA fall* | -0.009 (0.004) | 0.011 |
| *Recurrent non-MA falls* | -0.021 (0.004) | <0.001 |
| *Single MA fall* | -0.006 (0.005) | 0.288 |
| *Recurrent falls with MA* | -0.016 (0.007) | 0.017 |
| Frailty (0-100) | -0.008 (0.0003) | <0.001 |
| Frailty^2 | 0.00002 (0.00001) | 0.001 |
| High physical activity | 0.018 (0.002) | <0.001 |
| Abnormal gait/balance | -0.007 (0.003) | 0.022 |
| Unpaid work | 0.017 (0.002) | <0.001 |
| **Abbreviation:** CASP-19: control, autonomy, self-realisation and pleasure, 19 items; ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; Ref: reference; SE: standard error; SES: socioeconomic status | | |

There was a non-linear relationship between age and CASP-19 and between frailty and CASP-19. There was a SES gradient to the score. Those engaging in unpaid work were likelier to report higher scores. The dynamic progression of CASP-19 is estimated in Section 5.2.6.3, which allows the accumulation of CASP-adjusted life years (CALYs) using the same method as estimating QALYs with EQ-5D. Note that CALY is a metric constructed *ad hoc* and does not incorporate preference-based health utility in the way that QALYs are estimated. Results concerning CALY should therefore be interpreted with caution.

Unlike EQ-5D, no acute effects of falls on CASP-19 were incorporated, and the potential impact of falls prevention intervention (e.g., exercise enhancing self-realisation) on CASP-19 were similarly excluded. The modelled intervention impact on CASP-19 and CALY is hence conservative.

#### 5.2.3.4 Comorbidity care costs

The expert guideline on falls prevention economic evaluation recommends incorporation of all-cause care consequences in base case analysis, followed by fall-related care consequences alone in sensitivity analysis [105]. Using data from literature and ELSA, all-cause care costs were estimated by sector: (i) primary and secondary healthcare; (ii) community healthcare; (iii) short-term social care; (iv) OOP care cost; and (v) informal caregiving cost. The social care costs in (iii) exclude those associated with LTC which are parameterised separately in Section 5.2.6.2.

Importantly, to avoid double-counting the care costs, those directly related to falls – parameterised in Section 5.2.5.4 – were subtracted from all-cause care costs to obtain comorbidity care costs. However, as discussed in Section 5.2.5.4, reliable data on direct fall-related care costs could be obtained only for primary and secondary healthcare costs. Therefore, the distinction between all-cause and comorbidity care costs was made only for primary and secondary healthcare costs.

##### Primary and secondary healthcare costs

ELSA contains no information on individuals’ healthcare utilisation and cost. Hence, all-cause healthcare costs were obtained from literature: Han and colleagues used primary care records of 95,863 individuals aged 65-95 in 125 UK general practices to estimate the annual primary and secondary healthcare cost (comprising GP consultations and emergency and elective hospital admissions) by eFI category (Fit, Mild, Moderate and Severe) [279]. The costs were estimated using unit costs at 2013/14 prices and adjusted for age, gender, ethnicity, social deprivation, non-frailty long-term conditions, and registration drop-out. Because the current model’s frailty index used the same cut-off percentiles as the eFI and had similar cut-off values (Table 5.7), it was assumed that the healthcare costs estimated by Han and colleagues can be applied to modelled individuals by their frailty category.

The second column of Table 5.18 shows the annual all-cause healthcare cost by frailty category at 2013/14 prices as reported by Han and colleagues. The average NHS cost inflation rate for the period 2013-2019 (1.98%) obtained from the 2019 PSSRU unit costs data [401] was then applied to the 2013/14 costs to obtain the 2021/22 costs. As noted, the all-cause care costs incorporate fall-related costs which are later estimated in Section 5.2.5.4. The healthcare costs of MA falls were weighted by the prevalence of such falls by frailty category in ELSA to obtain the weighted average cost per frailty category. These were subtracted from the all-cause care costs to obtain the comorbidity care costs.

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| --- | --- | --- | --- |
| **Table 5.18** Annual all-cause and comorbidity primary and secondary healthcare costs by frailty category. | | | |
| **Frailty category** | **Annual all-cause primary and secondary healthcare cost** | | **Annual comorbidity primary and secondary healthcare cost** |
| **2013/14 £1** | **2021/22 £2** | **2021/22 £3** |
| Fit | 1628.35 | 1904.88 | 1866.07 |
| Mild | 2189.40 | 2561.21 | 2388.48 |
| Moderate | 2836.95 | 3318.73 | 2884.86 |
| Severe | 3736.55 | 4371.10 | 3823.14 |
| 1 Data source: Han et al (2019) [279]  2 Data source for average NHS cost inflation between 2013 and 2019 of 1.98%: Curtis and Burns (2019) [401].  3 See Section 5.2.5.4 for estimation of direct healthcare costs of falls. | | | |

##### Community healthcare costs

ELSA Waves 4-5 contain self-reported information on current receipt of care for the following seven basic and instrumental activities of daily living: moving around the house; washing/dressing; preparing a meal or eating; shopping and doing work around house; using phone/managing money; taking medication; and other difficulties. There is also information on the care source: (a) health visitor/district nurse – i.e., community healthcare; (b) local authority/social services – social care; (c) private paid help – OOP care; and (d) informal care. The cost associated with (a) is estimated in this section, and those associated with (b)-(d) in subsequent sections.

According to ELSA Waves 4-5, receipt of any community healthcare service differed significantly by frailty category: among Fit or Mild individuals, the prevalence of receipt was 0.02%, compared to 1.23% among Moderate and 5.49% among Severe. Given the very low prevalence among Fit and Mild groups, it was assumed that the receipt was restricted to those with Moderate and Severe frailty. Multivariate logistic regression also found a significant association between receipt and cognitive impairment after controlling for frailty, but none for other characteristics including age, sex, SES, and falls history. Hence, the receipt was assigned to: 0.62% of cognitively intact, Moderately frail individuals; 2.57% of cognitively impaired, Moderately frail; 2.52% of cognitively intact, Severely frail; and 9.05% of cognitively impaired, Severely frail.

Once assigned, the receipt was assumed to be maintained for the duration of the annual cycle. To estimate the cost of annual receipt, the 2019 PSSRU report estimated the average cost per hour of work performed by Band 5 district and community nurses [401]: £60 at 2018/19 price, equivalent to £64.10 at 2021/22 price after applying 2018/19 NHS pay inflation of 2.24%. Recent PSSRU reports did not state the estimated duration of each nurse visit, but the 2010 PSSRU report estimated this to be 20 minutes [402]. The 2019 PSSRU report estimated that the community nurse would work 225 days per year, and the NHS job description for a district nurse stated that the nurses would make daily visits on their assigned patients [403]. This equated to 225 visits by the nurse for each patient every year, or 75 hours of work if each visit lasted 20 minutes. Applying the hourly cost, this equated to £4,809.22 per patient. It was assumed that the number of visits and the length of each visit did not vary by frailty and cognitive status and hence that the same annual cost can be applied to all recipients. This was based on the observation that the intensity of care need – measured by the number of activities of daily living (ADLs) requiring assistance – varied only modestly between frailty and cognitive status subgroups.

##### Short-term social care costs

According to ELSA Waves 4-5, 2.5% of those aged 65+ received any social care from local authority or social services. This is close to the proportion reported for Sheffield in the 2018/19 Adult Social Care Activity and Finance Report which documented 2,500 new clients receiving short-term care from SCC in 2018, equivalent to 2.7% of the total Sheffield population aged 65+ in the same year (93,374) [390]. Disaggregating the prevalence rate by frailty category, 0.1% of those in Fit or Mild categories, 7.54% in Moderate and 24.26% in Severe received any social care. It was hence assumed that only the Moderately and Severely frail individuals received social care at their respective ELSA prevalence rates. The prevalence also varied significantly by cognitive status: 5.37% in Moderate frailty and cognitively intact; 12.33% in Moderate frailty and cognitively impaired; 18.91% in Severe frailty and cognitively intact; and 30.65% in Severe frailty and cognitively impaired.

According to the Age UK online care home cost calculator, the minimum hourly cost paid by SCC to home care providers was £20.75 in 2020 [404]. PSSRU 2019 reported that the average local authority-commissioned home care per patient per week was 12.8 hours. However, this figure neglects the variation in care hours/intensity by patients’ health status. As a measure of care intensity, ELSA Wave 4 contained a variable on the frequency of social care visit: every day or nearly every day; two/three times per week; and once per week or less (no corresponding variable was available for community healthcare). PSSRU 2019 described home care being received on weekdays as well as weekends. Therefore, those reporting receipt of daily or near-daily care in ELSA were assumed to receive seven visits per week; those reporting two/three visits, two visits; and those reporting one visit or less, one visit. If each visit was assumed to last 2.5 hours, this produced a weighted average of 13.0 hours per patient per week which is close to the 12.8 reported by PSSRU 2019. Hence, those receiving daily visits received 17.5 care hours per week costing £363.13 per week (at Age UK rate of £20.75), £103.75 for twice/week patients and £51.88 for once/week patients.

Given its short-term nature, social care would not be provided all-year around. According to the 2018/19 Adult Social Care Activity and Finance Report, SCC spent £5,539,000 in that year for 2,500 short-term social care clients aged 65+ [390]. This amounts to an average of £2,215.60 per client. Under the above assumptions of 2.5 hours per visit and £20.75 per care hour, the weighted average of care cost is £269.75 per week. If all clients receive the same number of weeks of care, this corresponds to 8.21 weeks of care per client. Hence, the total annual cost of social care is £2,981.26 for daily visit clients, £851.79 for twice/week clients, and £425.89 for once/week clients. The prevalence of different care intensity/visit frequency in ELSA varied by frailty category and cognitive status. From the per-recipient annual cost and the subgroup-specific prevalence of care intensity, the average cost per recipient was estimated for each frailty and cognitive status subgroup. These estimates are summarised in Table 5.19.

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| **Table 5.19** Annual all-cause short-term social care costs by frailty and cognitive status. | | | | | |
| **Frailty & cognitive status** | **Prevalence of care receipt** | **Care intensity given receipt** | **Prevalence of care intensity** | **Annual cost per recipient1** | **Average cost per recipient** |
| Moderate – Cognitively intact | 5.37% | 7 visits/week | 65.1% | £2,981.26 | £2,149.06 |
|  | 2 visits/week | 14.0% | £851.79 |  |
|  | 1 visit/week | 20.9% | £425.89 |  |
| Moderate – Cognitively impaired | 12.33% | 7 visits/week | 65.9% | £2,981.26 | £2,192.93 |
| 2 visits/week | 19.5% | £851.79 |  |
| 1 visit/week | 14.6% | £425.89 |  |
| Severe – Cognitively intact | 18.91% | 7 visits/week | 65.0% | £2,981.26 | £2,155.02 |
| 2 visits/week | 16.0% | £851.79 |  |
| 1 visit/week | 19.0% | £425.89 |  |
| Severe – Cognitively impaired | 30.65% | 7 visits/week | 83.9% | £2,981.26 | £2,611.16 |
|  | 2 visits/week | 9.7% | £851.79 |  |
|  | 1 visit/week | 6.4% | £425.89 |  |
| 1 Assumed 2.5 hours per visit, 8.21 weeks of visits per year and cost of £20.75 per hour. | | | | | |

##### Out-of-pocket care costs

ELSA Waves 4-5 contained information on the receipt of any privately paid help for ADL. The prevalence rates by frailty category were: 0.2% for Fit; 4.1% for Mild; 12.4% for Moderate; 19.9% for Severe; and 3.4% overall. Multivariate logistic regression showed that several covariates exerted statistically significant effects on OOP care receipt. Therefore, a multivariate risk equation for any OOP care receipt was estimated from ELSA. Table 5.20 shows the results from the best-fit model. Older and female individuals were likelier to require OOP care, as were frailer individuals. The SES gradient suggested that OOP care access depended on individuals’ ability to pay. High physical activity reduced the likelihood of requiring OOP care. Interestingly, those with cognitive impairment were less likely to access OOP care. This may be explained by cognitively impaired individuals receiving a greater amount of publicly financed community healthcare and social care (as well as informal care; see Table 5.22). That said, variables for receipts of community healthcare, social care, and informal care did not exert a statistically significant effect on OOP care receipt.

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| **Table 5.20** Logistic regression coefficients for out-of-pocket care receipt from ELSA Waves 4 and 5. | | |
| ***Dependent variable: OOP care receipt (N=13,422)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -11.184 (0.547) | <0.001 |
| Age | 0.050 (0.007) | <0.001 |
| Female | 0.703 (0.113) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | -0.175 (0.132) | 0.185 |
| *3rd quartile* | -0.499 (0.122) | <0.001 |
| *Most deprived quartile* | -1.137 (0.196) | <0.001 |
| Frailty (0-100) | 0.258 (0.019) | <0.001 |
| Frailty^2 | -0.003 (0.0003) | <0.001 |
| High physical activity | -0.640 (0.305) | 0.036 |
| Cognitive impairment | -0.523 (0.120) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; OOP: out-of-pocket; Ref: reference; SE: standard error; SES: socioeconomic status | | |

According to the Age UK online calculator, the hourly cost of privately paid home care in the Sheffield region was at least £21 in 2020 [404]. ELSA Wave 4 contained information on the frequency of OOP care visit as a measure of care intensity: every day or nearly every day; two/three times per week; and once per week or less. Therefore, similar assumptions were made as for social care to estimate the annual cost of OOP care: 2.5 hours per visit; seven visits per week for daily-visit group; two visits per week for two/three times per week; and one visit per week for once or less per week. However, unlike social care, it was assumed that OOP care was received all year around, and that the intensity of care (i.e., visits per week) varied by frailty category *and* SES quartile to account for the social gradient in access. Table 5.21 shows the estimated annual cost per OOP care recipient by SES quartile and frailty.

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| **Table 5.21** Annual all-cause out-of-pocket care costs by SES quartile and frailty category. | | | | |
| **Frailty/*SES quartile*** | ***Most privileged*** | ***2nd quartile*** | ***3rd quartile*** | ***Most deprived*** |
| Fit | £2,730.00 | £2,730.00 | £2,730.00 | £0 |
| Mild | £3,726.45 | £3,336.06 | £2,912.91 | £2,730.00 |
| Moderate | £7,067.97 | £5,460.00 | £5,571.93 | £6,046.95 |
| Severe | £10,537.8 | £7,275.45 | £6,491.94 | £2,730.00 |
| **Abbreviation:** SES: socioeconomic status  **Note:** The distribution of visit/week varied by frailty category and social quartile according to English Longitudinal Study of Ageing Wave 4 data. Assumed 2.5 hours per visit, 52 weeks of visits per year and cost of £21 per hour. | | | | |

##### Informal caregiving costs

ELSA Waves 4-5 contained information on the receipt of informal help for ADL. The prevalence by frailty category were: 7.2% for Fit; 30.3% for Mild; 66.4% for Moderate; 86.0% for Severe; and 25.3% overall. Multivariate logistic regression showed that several covariates exerted statistically significant effects on receipt. Therefore, a multivariate risk equation for any informal care receipt was estimated from ELSA. Table 5.22 shows the results from the best-fit model. Older and frailer individuals, as well as women and the cognitively impaired, were likelier to receive informal care, as were those with fear of falling and abnormal gait/balance. Those with high physical activity were less likely to require informal care. There was significant evidence that those receiving community healthcare (but not other care types) were likelier to receive informal care.

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| **Table 5.22** Logistic regression coefficients for informal care receipt from ELSA Waves 4 and 5. | | |
| ***Dependent variable: Informal care receipt (N=13,422)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -3.299 (0.243) | <0.001 |
| Age | -0.015 (0.003) | <0.001 |
| Female | 0.388 (0.050) | <0.001 |
| Frailty (0-100) | 0.205 (0.009) | <0.001 |
| Frailty^2 | -0.002 (0.0002) | <0.001 |
| High physical activity | -0.432 (0.087) | <0.001 |
| Cognitive impairment | 0.401 (0.058) | <0.001 |
| Fear of falling | 0.405 (0.086) | <0.001 |
| Abnormal gait/balance | 0.330 (0.060) | <0.001 |
| Community healthcare | 1.572 (0.642) | 0.014 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; Ref: reference; SE: standard error | | |

Unlike social care and OOP care receipts, there was no variable in ELSA for weekly frequency of informal care receipt which could be used as a measure of care intensity. Hence, requiring informal care for two or more ADLs was used as an alternative measure of intensity. Among informal care recipients, 53.4% required care for a single need; the rest required it for multiple needs. Multivariate logistic regression showed that several covariates exerted statistically significant effects on the probability of having multiple vs. single needs given informal care receipt. Therefore, a multivariate risk equation for having multiple care needs given receipt was estimated from ELSA. Table 5.23 shows the results from the best-fit model. Older individuals and women were less likely to have multiple needs, and there was a significant SES gradient. Those engaging in high physical activity were less likely to have multiple needs, as well as those accessing OOP care. Frailer individuals and those with cognitive impairment and abnormal gait/balance were likelier to have multiple needs.

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| **Table 5.23** Logistic regression coefficients for multiple informal care needs given informal care receipt from ELSA Waves 4 and 5. | | |
| ***Dependent variable: Multiple informal care needs given informal care receipt (N=3,401)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -1.428 (0.432) | 0.001 |
| Age | -0.021 (0.005) | <0.001 |
| Female | -0.422 (0.085) | <0.001 |
| SES deprivation (ref: Most privileged quartile) |  |  |
| *2nd quartile* | -0.319 (0.120) | 0.008 |
| *3rd quartile* | -0.357 (0.103) | 0.001 |
| *Most deprived quartile* | -0.494 (0.128) | <0.001 |
| Frailty (0-100) | 0.201 (0.017) | <0.001 |
| Frailty^2 | -0.002 (0.0003) | <0.001 |
| High physical activity | -0.436 (0.208) | 0.036 |
| Cognitive impairment | 0.476 (0.092) | <0.001 |
| Abnormal gait/balance | 0.405 (0.100) | <0.001 |
| OOP care receipt | -0.578 (0.150) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; OOP: out-of-pocket; Ref: reference; SE: standard error; SES: socioeconomic status | | |

Having divided the informal care recipients into single vs. multiple need subgroups, further assumptions were required on the number of hours of informal care received per week and year to estimate the annual cost of informal care. First, it was assumed that the association between the number of care needs and the number of weekly visits for *social* care can be generalised to that for informal care. Social care was chosen as reference because its access does not depend on ability to pay (unlike OOP care). In Table 5.24, the first three columns show the distribution of *social* care receipt frequency by the number of social care needs (single vs. multiple). Assuming that these apply to informal care and that each visit lasted 2.5 hours, the average numbers of care hours per week for those with single (10.1 hours) or multiple (15.2 hours) care needs were estimated. Proxy goods method was used to value the informal care hours [234]: it was assumed that in the absence of informal care, individuals would purchase OOP care as a direct substitute at £21 per hour. Assuming that informal care would be received all-year around, the annual cost of informal care per needs category was estimated.

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| **Table 5.24** Annual all-cause informal care cost by single vs. multiple care needs. | | | | |
| **Number of care needs** | **Care receipt frequency1** | **Prevalence1** | **Average care hours per week2** | **Estimated annual informal care cost3** |
| Single | 7 days/week | 47.6% | 10.1 | £11,089.26 |
|  | 2 days/week | 20.6% |  |  |
|  | 1 day/week | 31.8% |  |  |
| Multiple | 7 days/week | 83.5% | 15.2 | £16,601.13 |
|  | 2 days/week | 7.1% |  |  |
|  | 1 day/week | 9.4% |  |  |
| 1 Data taken from weekly social care receipt frequency. It is assumed that the frequency distribution by number of care needs for social care is generalisable to informal care.  2 Assumed 2.5 hours per visit.  3 Estimated using proxy goods method: cost of £21 per care hour; 52 weeks of care per year. | | | | |

Finally, whether any receipt of informal care confers a measurable health benefit to the patient was explored. Tong, for example, incorporated an EQ-5D increment of 0.051 to dementia patients living with their caregivers, after adjusting for their MMSE score, behavioural score and residence [161]. Using a similar multiple linear regression technique as Tong, the best-fit linear model for EQ-5D (Table 5.14) was re-estimated for a subset of ELSA individuals receiving any form of care with informal care receipt as an additional covariate. There was no statistically significant evidence of an EQ-5D increment associated with informal care receipt relative to other forms of care. Hence, potential health benefit of informal care was not incorporated in the model. This, however, neglects potential non-health process benefits associated with informal care receipt that are not captured by EQ-5D.

### 5.2.4 Falls prevention strategy

As part of the conceptual model, Section 3.7 had discussed the current intervention practice in Sheffield (Section 3.7.1) and the recommended practices by the UK guidelines (Section 3.7.2). The model represents these as UC and RC scenarios, respectively, for the base case analysis. Further intervention scenarios are discussed in Section 5.4.2.3. Section 5.2.4.1 provides an overview of the intervention pathways and types. Subsequent sections parameterise the following intervention features: access conditions (Section 5.2.4.2); resource use and cost (Section 5.2.4.3); and efficacy (Section 5.2.4.4).

#### 5.2.4.1 Intervention overview

The model incorporates three intervention pathways operating in tandem (i.e., non-mutually exclusive from the decision-maker’s perspective): reactive, proactive, and self-referred. These pathways are mutually exclusive for individuals in any given annual cycle, though the same individual could enter multiple pathways over the life-course as his/her characteristics and falls risk change. Table 5.25 describes the current and recommended practices alongside their respective model scenarios. The final column lists the falls prevention RCTs from which relevant intervention evidence (e.g., efficacy, uptake rate) are obtained for each intervention.

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| **Table 5.25** Falls prevention intervention features by intervention pathway and configuration. | | | | | |
| **Pathway** | **Configuration** | **Target population** | **Intervention type** | **Access condition** | **RCT evidence** |
| Reactive | Current practice | MA fall patients | * Mixed1 |  |  |
|  | Cognitively impaired | * Mixed1 |  |  |
|  | With intervention history | * Mixed1 |  |  |
| *Model usual care scenario* | MA fall patients | * Home assessment and modification (HAM) | Limited access2 | [405] |
| Cognitively impaired | * HAM | Limited access2 | [405] |
| With intervention history | * HAM | Limited access2 | [405] |
| Recommended practice | MA fall patients | * Multifactorial intervention |  |  |
| Cognitively impaired | * No specific recommendation |  |  |
| With intervention history | * No specific recommendation |  |  |
| *Model recommended care scenario* | MA fall patients | * Multifactorial intervention | Access pending demand2 | [62] |
| Cognitively impaired | * Multifactorial intervention | Access pending demand2 | [384] |
| With intervention history | * Multifactorial intervention | Access pending demand2 | [62]; [384] |
| Proactive | Current practice | General older population in community | * Falls risk screening in community; referral to multifactorial intervention by ICT team and Falls Clinic for high falls risk |  |  |
| Cognitively impaired | * No intervention: referral to Memory Clinic |  |  |
| With intervention history | * No repeated intervention: monitoring in primary care |  |  |
| *Model usual care scenario* | Persons not receiving reactive intervention | * Falls risk screening at GP routine contact; referral to multifactorial intervention if high falls risk | Limited access3 | [385] |
| Cognitively impaired | * No intervention |  |  |
| With intervention history | * No intervention |  |  |
| Recommended practice | General older population in community | * Falls risk screening in community; referral to multifactorial intervention if high falls risk |  |  |
| Cognitively impaired | * No specific recommendation |  |  |
| With intervention history | * No specific recommendation |  |  |
| *Model recommended care scenario* | Persons not receiving reactive intervention | * Falls risk screening at GP routine contact; referral to multifactorial intervention if high falls risk | Access pending demand3 | [385] |
| Cognitively impaired | * CI-specific group- and home-based Tai Chi together with informal caregiver if high falls risk | Access pending demand3 | [235] |
| With intervention history | * Multifactorial intervention with reduced components, up to 3 re-receipts of falls clinic for cognitively intact persons4 * CI-specific Tai Chi | Access pending demand3 | [385]; [235] |
| Self-referred | Current practice | General older population in community | * Dance to Health strength and balance group exercise – individually tailored, supervised, progressive difficulty, 2 hours/week, ongoing duration |  |  |
| Cognitively impaired | * Dance to Health group exercise |  |  |
| With intervention history | * Encourage sustained participation |  |  |
| *Model usual care scenario* | Persons not receiving reactive or proactive intervention | * Strength and balance group exercise5 * Increased likelihood of achieving physical activity target for group exercise participants | Limited access6 | [135]; [136] |
| Cognitively impaired | * Balance group exercise (efficacy from Tai Chi) | Limited access6 | [235] |
| With intervention history | * Sustained participation pending access | Limited access6 | [135]; [136]; [235] |
| Recommended practice | General older population in community | * Strength and balance exercise – individually tailored, progressive difficulty, 50+ hours (2+ hours/week) * Achieve recommended 150 (75) minutes/week of moderate (vigorous) intensity physical activity |  |  |
| Cognitively impaired | * Exercise should have supervision and appropriate intensity |  |  |
| With intervention history | * Encourage sustained participation |  |  |
| *Model recommended care scenario* | Persons not receiving reactive or proactive intervention | * Strength and balance group exercise5 * Increased likelihood of achieving physical activity target for group exercise participants | Access pending demand6 | [135]; [136] |
| Cognitively impaired | * Balance group exercise (efficacy from Tai Chi) | Access pending demand6 | [235] |
| With intervention history | * Sustained participation pending demand | Access pending demand6 | [135]; [136]; [235] |
| **Abbreviation:** CCG: Clinical Commissioning Group; FLS: Fracture Liaison Service; HAM: home assessment and modification; ICT: Integrated Community Therapy; MA fall: fall requiring medical attention; PT: physiotherapy; SCC: Sheffield City Council; STH: Sheffield Teaching Hospitals  1 HAM for hospitalised fallers by SCC; multifactorial intervention by ICT team and Sheffield Falls Clinic; Tai Chi and PT by CCG FLS and STH; fall alarm service.  2 See Table 5.26 for access conditions and rates.  3 See Table 5.27 for access conditions and rates.  4 The cap on the number of receipts (four in total; three re-receipts) was necessary to keep the annual flow of clients constant at around 21,000; see Section 5.2.4.3 for discussion. The cap does not affect cognitively impaired persons who are not referred to the falls clinic.  5 Individually tailored, supervised, progressive difficulty, 50+ hours (2+ hours/week)  6 See Table 5.29 for access conditions and rates. | | | | | |

##### Reactive pathway

The current reactive pathway in Sheffield makes use of several interventions commissioned and delivered by different system actors, including HAM provided by SCC and multifactorial intervention by diverse multidisciplinary teams (Section 3.7.1.1). But the client flows for multifactorial intervention appear to be low. Hence, the UC scenario makes a simplifying assumption that the reactive pathway relies mainly on HAM provided by SCC. Eligibility does not depend on cognitive status or intervention history. Regarding the recommended practice, NICE CG161 recommends that all MA fallers receive a multifactorial intervention without any specific recommendation for cognitively impaired and intervention history subgroups [13]. Therefore, the RC scenario provides multifactorial intervention to all MA fallers regardless of cognitive status and intervention history.

The level of access to reactive HAM under current practice is limited, with hospitalised fallers being prioritised by SCC. This limited access pattern is parameterised for UC using ELSA data in Section 5.2.4.2. For RC, the model characterises full supply-side coverage of CG161-recommended level of intervention provision; but the access rate would still depend on uptake (i.e., ‘pending demand’ in Table 5.25) taken from the relevant RCTs; these are parameterised in Section 5.2.4.2.

The intervention study evidence for the reactive pathway was drawn from one Australia-based and two UK-based RCTs: (i) a reactive HAM evaluated against usual care in Australia for hip fracture patients aged 55+ with diverse cognitive status [405]; (ii) a reactive multifactorial intervention against usual care for cognitively intact persons aged 65+ admitted to A&E for a fall [62]; and (iii) a reactive multifactorial intervention against usual care for cognitively impaired persons aged 65+ admitted to A&E for a fall [384]. The Australian RCT was used for the reactive HAM in (i) because no UK-based RCT was identified (although two RCTs for proactive HAM were identified; see Table E4).

##### Proactive pathway

For the proactive pathway, the current practice in Sheffield relies on falls risk screening at routine contact with care professionals in community followed by referral of high-risk individuals to multifactorial intervention delivered by multidisciplinary teams. The current access rate for the proactive intervention is low, with the Falls Clinic managing around 300 clients per year (including reactive pathway clients). Accordingly, UC incorporates limited access to falls risk screening at GP contact and limited referral of high-risk individuals to multifactorial intervention; see Section 5.2.4.2 for parameterisation using ELSA. By contrast, RC incorporates 100% falls risk screening at GP contact and 100% referral of high-risk individuals, resulting in access to all eligible persons pending demand.

Under current practice, cognitively impaired persons are not generally referred to the proactive intervention (Section 3.7.3). Therefore, UC incorporates no intervention for the cognitively impaired subgroup. NICE CG161 makes no specific recommendation for the cognitively impaired. But it would be reasonable to assume that cognitively impaired persons are offered a proactive multifactorial intervention under RC, just as they are offered a reactive one. Unlike the reactive pathway, there was no identified RCT (UK or non-UK) that evaluated a proactive multifactorial intervention targeting the cognitively impaired. Therefore, on discussion with the falls modelling expert, it was decided that high-risk cognitively impaired persons are referred to a tailored Tai Chi evaluated in a UK setting [235].

Also under the current practice, those who have already received the proactive multifactorial intervention are not generally referred again to the multidisciplinary team but monitored in primary care (Section 3.7.3). Hence, UC incorporates no intervention for those with proactive intervention history. NICE CG161 makes no specific recommendation for this subgroup. However, as discussed in Section 3.7.3, the falls specialist geriatrician confirmed that those who remain at high falls risk would ideally be referred again for further assessments. Hence, RC refers high-risk individuals with intervention history to appropriate proactive interventions. But the number of re-receipts of proactive multifactorial intervention for cognitively intact was limited to three to maintain the annual flow of clients to a level managed by seven falls clinics; see Section 5.2.4.3 for further discussion.

The intervention study evidence for the proactive pathway was drawn from two UK-based RCTs: (i) a proactive multifactorial intervention evaluated against usual care for cognitively intact persons aged 65+ (recruited at GP practices) with recurrent falls in past year and no A&E presentation for the latest fall [385]; and (ii) the aforementioned 20-week group- and home-based Tai Chi intervention for dementia patients accompanied by their caregivers [235].

##### Self-referred pathway

For the self-referred pathway, the sole intervention under current practice in Sheffield is the Dance to Health exercise intervention which meets the recommendations on the requisite features of falls prevention exercise: i.e., individually tailored, supervised, progressive difficulty, and 50+ hours (at least 2 hours/week) [143]. But the current access rate is minimal, with around 20 regular self-financing participants. Therefore, UC incorporates highly limited access to self-referred group exercise. RC incorporates full coverage of self-referred group exercise intervention pending demand. Section 5.2.4.2 describes the parameterisation using ELSA.

Under current practice, cognitively impaired persons are still eligible to participate in group exercise [196]. Hence, UC does not exclude this subgroup from intervention receipt. Moreover, those with intervention history are actively encouraged to sustain participation in the exercise programme. Therefore, UC also does not exclude this subgroup from intervention receipt. The UK guidelines similarly recommend supervised, tailored exercise interventions for cognitively impaired persons and sustained participation for all with intervention history [113, 143]. Therefore, RC incorporates full coverage for cognitively impaired persons and those with intervention history pending demand.

The intervention study evidence for the proactive pathway was drawn from three UK-based RCTs: (i) a 24-week group- and home-based exercise intervention evaluated against usual care for cognitively intact persons aged 65+ (recruited via postal invites) who have experienced less than three falls in the past year [135]; (ii) a 36-week group- and home-based exercise for cognitively intact women aged 65+ with three or more falls in past year [136]; and (iii) the aforementioned 20-week group- and home-based Tai Chi intervention for cognitively impaired [235].

#### 5.2.4.2 Intervention access conditions

This section parameterises the intervention access rates for UC and RC scenarios. Initial and long-term access rates are determined by eligibility and implementation levels (i.e., supply and demand levels).

##### Reactive pathway

In practice, reactive interventions would be accessed by fallers immediately after being discharged from the fall-related medical attention. This process is simulated in the model by making reactive intervention accessible to eligible individuals at the very start of the given cycle (i.e., before routine GP contact). Those who access the intervention would have a reduced risk of falling in the given cycle. A limitation of this approach is that the MA fall in the previous cycle (for which the intervention is given) has already influenced the dynamic trajectories between the previous and given cycles (see Section 5.2.6.1) and the intervention is unable to modify this influence; this underestimates the reactive intervention benefits.

Table 5.26 summarises the eligibility and access rates for the reactive pathway under UC and RC. Under UC, only the hospitalised MA fall patients are eligible for HAM. This means that only a proportion of MA fallers receive HAM, though access would not depend on cognitive status and intervention history.

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| **Table 5.26** Eligibility and access rates for the reactive falls prevention pathway under usual care and recommended care scenarios. | | |
|  | **Usual care** | **Recommended care** |
| **Pathway component: Reactive HAM or multifactorial intervention** | | |
| Eligibility | HAM for severe MA fall patients regardless of cognitive status or intervention history | Multifactorial intervention for all MA fall patients regardless of fall severity, cognitive status, and intervention history |
| Access rate | Limited access rate by frailty category according to ELSA: 28.7% overall; 9.6% if Fit; 23.5% if Mild; 51.7% if Moderate; and 72.7% if Severe | All eligible persons pending demand: 53.8% uptake rate for cognitively intact [62]; 49.6% for cognitively impaired [384] |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; HAM: home assessment and modification; MA fall: fall requiring medical attention | | |

To estimate the limited access under UC, ELSA data was used. ELSA Wave 4 contained variables for whether the individual received a balance and gait test from a doctor/nurse, whether further fall risk tests were recommended, and whether falls risk factors were discussed in the past year. It also contained variables for whether the individual received HAM and physiotherapy. From these, it was possible to construct a variable indicating receipt of falls risk screening/assessment by a medical professional in the past year plus HAM and/or physiotherapy in the same period. Assuming that the latter treatments are related to the falls risk assessment, the variable served as a proxy measure of annual access to falls risk assessment followed by treatment(s). Among those who had experienced at least one MA fall in the past year, 28.7% had received such assessment and treatment.[[3]](#footnote-3) Under a further assumption that the assessment and treatment took place in response to the MA fall, this percentage measured the annual access to reactive falls prevention. According to the national HES data incorporated in the PHE model, 28% of MA falls resulted in hospital inpatient stay [216]. This is close to the 28.7% estimate. It is plausible that the ELSA variable approximates the access to standard discharge package for hospitalised fallers corresponding to the current practice in Sheffield. According to this variable, 1.9% of the population aged 60+ accessed the reactive intervention in one year, corresponding to around 2,300 individuals if applied to the Sheffield population.

A multivariate logistic regression was estimated to assess whether this access rate was significantly associated with individual-level characteristics. The result showed no significant association except with frailty. The lack of association with cognitive impairment was consistent with the reactive intervention being accessed regardless of cognitive status. Therefore, the model incorporated the access rate that varied by frailty category: 9.6% if Fit; 23.5% Mild; 51.7% Moderate; and 72.7% Severe.

Under RC, eligibility is expanded to all MA fall patients regardless of cognitive status and intervention history. The intervention supply would expand without barrier to accommodate all eligible persons, but the final access rate would depend on demand. The uptake rates from relevant UK-based RCTs were used as measures of demand: 53.8% for cognitively intact persons [62]; and 49.6% for cognitively impaired [384]. There was no data on the individual-level variation in the uptake rates.

##### Proactive pathway

Table 5.27 summarises the eligibility and access conditions under UC and RC for three components of the proactive pathway: (1) routine GP contact; (2) falls risk screening at GP contact; and (3) access to appropriate falls prevention intervention for high-risk, eligible individuals.

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| **Table 5.27** Eligibility and access rates for the proactive falls prevention pathway under usual care and recommended care scenarios. | | |
|  | **Usual care** | **Recommended care** |
| **Pathway component: Routine GP contact** | | |
| Eligibility | All persons not receiving reactive intervention that year | All persons not receiving reactive intervention that year |
| Access rate | Limited access rate according to ELSA: 81.3% overall; varying by individual-level characteristics (see Table 5.28) | Limited access rate according to ELSA: 81.3% overall; varying by individual-level characteristics (see Table 5.28) |
| **Pathway component: Fall risk screening at routine GP contact** | | |
| Eligibility | All persons at routine contact | All persons at routine contact |
| Access rate | Limited access rate by frailty category according to ELSA: 15.7% overall among those with recurrent non-MA or MA falls history; 12.0% if Fit; 15.1% if Mild; 19.7% if Moderate; 21.9% if Severe | 100% access |
| **Pathway component: Proactive falls prevention intervention** | | |
| Eligibility | Cognitively intact persons without intervention history; prioritisation by unknown criteria in ELSA (see Access rate) | Individuals at high risk by NICE criteria1 and varying by cognitive status:  (i) Multifactorial intervention for cognitively intact persons, up to three re-receipts  (ii) Tai Chi for cognitively impaired with or without intervention history |
| Access rate | Limited access rate by frailty category according to ELSA: 33.5% overall among cognitively intact persons who received falls risk screening; 10.9% if Fit; 24.7% if Mild; 53.6% if Moderate; 100% if Severe | All eligible persons pending demand: 82.4% uptake rate for (i) [385]; 44.5% for (ii) [235] |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; NICE: National Institute for Health and Clinical Excellence  1 Recurrent non-MA falls or MA fall history and/or abnormal gait/balance | | |

Under both UC and RC, the proactive pathway is initiated through routine GP contact at which older persons are screened for falls risk. ELSA contained a variable for whether the individual received a blood pressure check at the GP in the past 12 months. This was used as an indicator of at least one GP visit in a year. According to this measure, 83.8% of the ELSA Wave 4 community-dwelling cohort aged 65+ had visited their GP at least once in the past year, which is slightly below the 87.4% estimated from another survey of 1,685 adults aged 65+ in Northwest England [406]. The discrepancy could be due to GP visits not involving blood pressure checks that were measured in the latter survey. Since the model is interested in GP visits long enough to conduct falls risk screening, it may be reasonable to restrict attention to those long enough to carry out blood pressure checks. Multivariate logistic regression indicated that the probability of GP visit was significantly associated with several individual-level covariates. Table 5.28 shows the coefficient estimates from the best-fit model. The sample was restricted to those who did not receive a reactive falls prevention intervention that year and hence qualified for the proactive pathway.

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| **Table 5.28** Logistic regression coefficients for GP contact from ELSA Waves 4 and 5. | | |
| ***Dependent variable: routine GP contact (N=13,280)1*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -17.444 (1.960) | <0.001 |
| Age | 0.495 (0.054) | <0.001 |
| Age^2 | -0.003 (0.0004) | <0.001 |
| Female | -0.212 (0.049) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | 0.132 (0.066) | 0.045 |
| *3rd quartile* | 0.118 (0.059) | 0.045 |
| *Most deprived quartile* | 0.223 (0.088) | 0.012 |
| Falls history (ref: No falls history) |  |  |
| *Single non-MA fall* | 0.172 (0.082) | 0.036 |
| *Recurrent non-MA falls* | 0.450 (0.108) | <0.001 |
| *Single MA fall* | 0.701 (0.161) | <0.001 |
| *Recurrent falls with MA* | 0.930 (0.242) | <0.001 |
| Frailty (0-100) | 0.175 (0.008) | <0.001 |
| Frailty^2 | -0.002 (0.0002) | <0.001 |
| Cognitive impairment | -0.944 (0.058) | <0.001 |
| Fear of falling | 0.339 (0.141) | 0.016 |
| Abnormal gait/balance | -0.455 (0.076) | <0.001 |
| Community healthcare | -0.933 (0.341) | 0.006 |
| Social care | -1.023 (0.179) | <0.001 |
| OOP care | -0.300 (0.156) | 0.055 |
| Informal care | -0.345 (0.072) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; OOP: out-of-pocket;Ref: reference; SE: standard error; SES: socioeconomic status  1 Sample was restricted to those who did not receive reactive falls prevention intervention that year. | | |

Older individuals were likelier to visit the GP, and women less so. There was a SES gradient in GP contact in favour of more deprived quartiles. Falls of all types were predictors of GP contact, suggesting that GPs are well-positioned to identify high-risk individuals with fall history. But those with abnormal gait/balance were less likely to visit their GPs which reduces the probability of GPs identifying high-risk individuals. Higher frailty score was associated with increased probability. Cognitively impaired persons were less likely to visit, while those with fear of falling were likelier. There were also significant associations between receipt of other forms of care and the GP visit probability.

For falls risk screening at GP contact, all persons in the target population (aged 60+) were assumed to be eligible. This deviates from the NICE recommendation that screening be targeted at those aged 65+ [13], but was consistent with the stakeholder preference for early prevention. Cognitively impaired persons and those with intervention history still received falls risk screening under UC even though they would not be referred to the multifactorial intervention. This was consistent with the falls specialist geriatrician’s opinion that falls risk among these subgroups should still be monitored in primary care even if they are referred to different services. The key difference between UC and RC was the level of screening access. To parameterise the screening access under UC, ELSA data was used. As for the reactive pathway, a composite variable was created from ELSA to measure whether the individual had received fall risk screening in the past year. According to this variable, 31.4% of the ELSA cohort aged 60+ who had a history of recurrent non-MA falls or MA fall(s) (but did not receive the reactive intervention) received falls risk screening.[[4]](#footnote-4) A multivariate regression showed no significant association between access rate and individual characteristics except for frailty. Therefore, the modelled rate varied by frailty (given recurrent non-MA or MA falls history): 12.0% if Fit; 15.1% Mild; 19.7% Moderate; and 21.9% Severe. The rate was 100% for RC.

The referral to falls prevention intervention after the screening differed significantly between UC and RC. Under UC, only cognitively intact persons without intervention history were eligible for multifactorial intervention. ELSA contained variables that indicated the receipt of physiotherapy and/or HAM. These were used to create a composite variable which showed that 33.5% of cognitively intact individuals who received falls risk screening subsequently received any falls prevention treatment. The recipients comprised 1.0% of the ELSA cohort aged 65+, which, if applied to the Sheffield population, would constitute around 1,000 clients per year. This is consistent with the currently low access rate in Sheffield. A multivariate regression showed no significant association between access rate and individual characteristics except for frailty. Therefore, the modelled access rate varied by frailty category: 10.9% if Fit; 24.7% Mild; 53.6% Moderate; and 100% Severe. Those with proactive intervention history were excluded from referral from the second model cycle.

Under RC, all individuals deemed to be at high falls risk were eligible for proactive intervention according to their cognitive status. The NICE criteria were used to determine high falls risk: i.e., recurrent non-MA falls history or MA fall history without reactive intervention access and/or abnormal gait/balance [13]. The intervention supply would expand to accommodate all referred persons, but the final access would depend on demand estimated from uptake rates in UK-based RCTs: 82.4% for cognitively intact persons [385]; and 44.5% for cognitively impaired [235]. The uptake rates were assumed not to vary by other characteristics such as frailty.

##### Self-referred pathway

Table 5.29 summarises the eligibility and access conditions for the self-referred falls prevention pathway under UC and RC.

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| **Table 5.29** Eligibility and access rates for the self-referred falls prevention pathway under usual care and recommended care scenarios. | | |
|  | **Usual care** | **Recommended care** |
| **Pathway component: Self-referred exercise intervention** | | |
| Eligibility | All persons not receiving reactive or proactive intervention that year | All persons not receiving reactive or proactive intervention that year |
| Access rate | Limited access rate:  0.1% among most privileged SES quartile | All eligible persons pending demand: uptake rate according to ELSA; 9.5% overall; varying by individual-level characteristics (see Table 5.30) |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; SES: socioeconomic status | | |

Under both scenarios, all persons not receiving reactive or proactive intervention that year are eligible for the intervention. For the final access rate, UC should portray the very low uptake of the Dance to Health programme (20-30 regular attendees) under current practice. According to the focus groups in Chapter 2, current attendance was concentrated in a well-off neighbourhood with participants who can self-finance the intervention. Therefore, the model assumed that 0.1% of individuals in the most privileged SES quartile (around 30 individuals) would enrol in self-referred exercise.

For the access rate under RC, ELSA was used to parameterise the uptake rate. ELSA contained variables which together indicated whether an individual is currently participating in an exercise or PT session. It was unclear whether these sessions were evidence-based falls prevention exercises or ‘conventional’ exercises for general physical difficulties. The overall uptake rate of 9.5% among those aged 60+ was substantially higher than that known for Dance to Health in Sheffield. Therefore, it was assumed that: (i) the ELSA variable captured the uptake rate for conventional exercise; and (ii) the uptake rate represented a *latent* demand for falls prevention exercise. Assumption (i) means that the uptake of falls prevention exercise remains low in UC. Assumption (ii) holds that if falls prevention exercise is commissioned and marketed on a wide scale, those who would take up conventional exercise would take up falls prevention exercise as a substitute or complement. This is reasonable given that falls prevention exercises typically aim to resemble conventional leisure programmes to promote uptake [196]. Indeed, the qualitative research participants in Chapter 2 did not draw a clear distinction between conventional and falls prevention exercises and cited previous/concurrent engagement in other exercises as a facilitator for falls prevention exercise uptake.

Another issue is that the ELSA variable may better reflect current *supply* rather than demand conditions for exercise. In other words, the access rate would be higher than 9.5% under RC with unlimited supply. It is also unclear whether the variable better reflects recommendations (or direct referrals) made by care professionals than ‘pure’ self-referrals. But given the frequent contact between older persons and those in supportive roles, external facilitation is a constant feature of geriatric health promotion. Nevertheless, the ELSA uptake rate was similar to that observed in a UK trial of falls prevention exercise that mainly relied on community marketing for recruitment [135]: among those aged 65+ with less than three falls in the past year, the ELSA uptake rate was 8.8% compared to 6.1% in the trial.

A multivariate logistic regression was estimated to assess the variation in exercise uptake. Table 5.30 shows the results.

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| **Table 5.30** Logistic regression coefficients for self-referred exercise uptake from ELSA Waves 4 and 5. | | |
| ***Dependent variable: exercise uptake (N=13,173)1*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -11.206 (2.665) | <0.001 |
| Age | 0.209 (0.074) | 0.005 |
| Age^2 | -0.002 (0.0005) | 0.001 |
| Female | 0.781 (0.067) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | 0.038 (0.082) | 0.645 |
| *3rd quartile* | -0.276 (0.076) | <0.001 |
| *Most deprived quartile* | -0.409 (0.108) | <0.001 |
| Falls history (ref: No falls history) |  |  |
| *Single non-MA fall* | 0.269 (0.093) | 0.004 |
| *Recurrent non-MA falls* | 0.246 (0.105) | 0.019 |
| *Single MA fall* | 0.434 (0.136) | 0.001 |
| *Recurrent falls with MA* | 0.549 (0.158) | 0.001 |
| Frailty (0-100) | 0.081 (0.010) | <0.001 |
| Frailty^2 | -0.001 (0.0002) | <0.001 |
| High physical activity | 0.763 (0.080) | <0.001 |
| Cognitive impairment | -0.151 (0.084) | 0.072 |
| Abnormal gait/balance | -0.187 (0.088) | 0.035 |
| Community healthcare | 0.743 (0.371) | 0.045 |
| Social care | 0.485 (0.194) | 0.012 |
| OOP care | 0.609 (0.134) | <0.001 |
| Informal care | 0.412 (0.077) | <0.001 |
| GP routine contact | 0.213 (0.093) | 0.022 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; OOP: out-of-pocket;Ref: reference; SE: standard error; SES: socioeconomic status  1 Sample was restricted to those who did not receive reactive or proactive falls prevention intervention that year. | | |

Older individuals and women were likelier to take up exercise. There was a SES gradient to uptake with the bottom two SES quartiles less likely to take up the intervention than the top two. Falls history of any type was associated with higher uptake. Interestingly, higher frailty and high physical activity were both associated with greater likelihood. Cognitively impaired persons were less likely to take up exercise, though association was not statistically significant at 95% confidence level. Those with abnormal gait/balance were less likely to take up, suggesting that these high-risk individuals may be disadvantaged under the self-referred pathway (if they fail to enter the proactive pathway). Finally, all forms of care contact in the community setting were associated with greater likelihood of exercise uptake, suggesting that supportive environment facilitated health promotion.

#### 5.2.4.3 Intervention resource use and cost

Falls prevention interventions under UC and RC can be divided into two groups: multifactorial interventions for reactive and proactive pathways; and single-component interventions including HAM for the reactive pathway and exercise for proactive and self-referred pathways. The two groups have marked differences in resource and cost structures. Multifactorial interventions typically require in-house facilities and equipment with major fixed cost components [207], although several component services may be outsourced to other clinical facilities [167]. The NHS professionals in the multidisciplinary team likely receive salaries that do not vary directly with the client numbers [401]. By contrast, single-component interventions, particularly exercise, may not operate at a single dedicated venue and their professionals are likely paid at piece rates per session/hour [216]. The model should assign similar type and volume of resources as RCTs to derive corresponding efficacies.

##### Multifactorial interventions – resource use

Table 5.31 summarises the intervention resource use detailed in each of the three UK-based RCTs that evaluated multifactorial interventions: Close (1999) [62] and Shaw (2003) [384] under the reactive pathway; and Spice (2009) [385] under the proactive. The resource uses are catalogued by three components: participant screening and recruitment; falls risk assessment; and therapeutic treatment. Strictly research-related resource uses such as phone calls to collect falls diaries are excluded.

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| **Table 5.31** Resource use in UK-based randomised controlled trials of multifactorial interventions. | | | |
| **RCT reference** | **Intervention type** | **Component** | **Resource use** |
| Close (1999) [62] | Reactive multifactorial intervention for cognitively intact persons at MA fall presentation | Participant screening & recruitment1 | (1) Eligibility screening by researcher using A&E records  (2) Invitation by letter with information sheet and telephone call to answer questions |
| Falls risk assessment | Assessments conducted by one physician at a day hospital  (A) Medical and cardiovascular assessments: balance; vision; medication; affect; cognition; postural hypotension; cardiac arrhythmias; carotid sinus hypersensitivity  (B) OT assessment at home: function; environmental hazards; psychological status after fall |
| Therapeutic treatment | (I) In-house treatments: 92.1% received HAM and falls prevention education by OT  (II) Outsourced treatments: 44.1% to specialist services in outpatient setting; 25.0% to multidisciplinary falls clinic in day hospital; 21.7% referred to GPs mainly for medication modification; 17.8% to optician/ophthalmologist; 15.8% received no referrals; major home modifications referred to social services |
| Shaw (2003) [384] | Reactive multifactorial intervention for cognitively impaired persons at MA fall presentation | Participant screening & recruitment2 | (1) 52-week eligibility screening at A&E  (2) Participant consent sought from patient, immediate caregiver and next of kin |
| Falls risk assessment | Assessments conducted at a secondary care clinic  (A) Medical and cardiovascular assessments: medication; vision; depression; epilepsy; cerebrovascular; orthostatic hypotension; carotid sinus hypersensitivity; syncope  (B) PT assessment: gait; balance; feet; footwear; walking aid  (C) OT assessment: environmental hazards |
| Therapeutic treatment | (I) In-house treatments: 96.2% prescribed balance treatment and 90.0% gait treatment contained in 3-month PT-supervised home exercise, continued by caregiver; 80.8% prescribed HAM; 70.8% prescribed medication modification; 35.4% prescribed treatment for orthostatic hypotension; 10.8% prescribed treatment for carotid sinus hypersensitivity  (II) Outsourced treatments: 28.5% had feet or footwear problems addressed by chiropody; 17.7% had vision problems addressed by optician or ophthalmologist; 6.9% had depression addressed by psychogeriatric assessment |
| Spice (2009) [385] | Proactive multifactorial intervention for cognitively intact persons at high falls risk | Participant screening & recruitment3 | (1) Consent by 19 GP practices in same PCT area  (2) GP nurse conducted baseline risk screening: AMT; Barthel index; TUG test; medical history; falls history; osteoporosis risk factors  (3) Information leaflet given to older persons for participation consent |
| Falls risk assessment | Assessments conducted at a one-stop multidisciplinary clinic  (A) Medical and cardiovascular assessments: medication; vision; alcohol; neurological; musculoskeletal; postural hypotension; other cardiovascular  (B) PT assessment: mobility  (C) OT assessment: environmental hazards; feet/footwear |
| Therapeutic treatment | (I) In-house treatments: 53.6% received any PT treatment; 51.8% received any medication modification; 33.8% received any OT treatment; 3.6% received any nursing treatment |
| **Abbreviation:** AMT: Abbreviated Mental Test; HAM: home assessment and modification; MA fall: fall requiring medical attention; OT: occupational therapy/therapist; PCT: primary care trust; PT: physiotherapy/therapist; RCT: randomised controlled trial; TUG: Timed Up and Go test  1 Uptake rate was 53.8%.  2 Uptake rate was 46.9%.  3 Uptake rate was 82.4%. | | | |

All three RCTs allocated resources to participant screening and recruitment. The reactive interventions used A&E admission records for eligibility screening, while the proactive intervention relied on screening by GP nurses. MA fallers did not automatically participate in the reactive interventions and resources were needed for their recruitment. Falls risk assessments comprised three main types: (A) medical and cardiovascular assessments; (B) PT assessments; and (C) OT assessments. The range of risk factors covered was broadly similar for the three RCTs, but the method of delivery differed. Close (1999) referred only 25% of intervention participants to a full multidisciplinary assessment at falls clinic, while the rest received a bi-disciplinary assessment by physician and OT. By contrast, Shaw (2003) and Spice (2009) conducted all assessments at multidisciplinary clinics.

The therapeutic treatments based on identified risk factors were either delivered in-house or outsourced to external providers. The proportion delivered in-house differed between RCTs. In Close (1999), only HAM and falls prevention education were delivered in-house by the OT. By contrast, Spice (2009) mentioned no external referrals, suggesting that most treatments were delivered in-house at the multidisciplinary clinic. Shaw (2003) mentioned external referrals for several treatments including chiropody, vision correction, and geriatric psychiatry.

The RCTs provided little details on the timeframe and professional workload associated with intervention delivery. Close (1999) mentioned that a single physician carried out the medical assessments for all 184 intervention participants completed within three weeks of A&E discharge. The OT assessment and treatments were delivered within a single home visit per patient by the OT. The study did not report what assessments and treatments were prescribed for the 25% of intervention participants who were referred to the multidisciplinary falls clinic. Shaw (2003) did not report how many and which professionals were involved in the delivery of multidisciplinary assessment and treatments. It nonetheless reported that all assessments and treatments were completed by the three-month follow-up. The home-based exercise was the longest component, delivered by PT for three months and ideally sustained thereafter by participants’ caregivers. Spice (2009) provided no detail on the workflow except the proportions of participants receiving different treatment components.

It was overall clear that full implementation of multifactorial interventions would rely extensively on referrals to multidisciplinary falls clinics. The falls specialist geriatrician at the Sheffield Falls Clinic confirmed that his team had the expertise, equipment, and links to other specialist services to deliver all assessment and treatment components recommended by NICE CG161. It is hence plausible that a group of multidisciplinary falls clinics – each clinic equipped to operate like the current Sheffield Falls Clinic (but on an expanded scale) – could cater to both reactive and proactive referrals.

##### Multifactorial interventions – cost

Table 5.32 shows the estimated annual cost of delivering the multifactorial interventions. The costing is divided into two parts: (1) referral to multidisciplinary falls clinic; and (2) bi-disciplinary assessment and treatment for 75% of cognitively intact MA fallers under the reactive pathway [62].

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| **Table 5.32** Resource use and cost of multifactorial interventions. | | | |
| **Component** | **Resource use** | **Mean cost1** | **Reference** |
| **(1) Referral to multidisciplinary falls clinic (21,000 clients; 3,000 per clinic per year)** | | | |
| Risk screening and access | Reactive clients – A&E record screening for eligibility and invitation by letter/phone2 | £16.37 per client | [167] |
| Proactive clients – TUG test set-up and staff time and training3 | £10.83 per client | [363] |
| Bi-disciplinary assessment for 25% of cognitively intact reactive clients (n=903) | £121.46 per client | [167] |
| Falls clinic operation | 1 falls specialist geriatrician (medical consultants) – salary & oncosts | £121,393 annual fixed | [401] |
| 2 registrars – salary & oncosts | £112,644 annual fixed | [401] |
| 2 PTs (band 6 & 7) – salary & oncosts | £94,906 annual fixed | [401] |
| 2 OTs (band 6 & 7) – salary & oncosts | £94,906 annual fixed | [401] |
| 2 PT assistants (band 4) – salary & oncosts | £56,919 annual fixed | [401] |
| 2 OT assistants (band 4) – salary & oncosts | £56,919 annual fixed | [401] |
| 3 nurses (band 4) – salary & oncosts | £75,834 annual fixed | [401] |
| 1 falls prevention facilitator – salary & oncosts4 | £33,123 annual fixed | [401]; [207] |
| 2 administrative staffs – salary & oncosts5 | £58,754 annual fixed | [401] |
| Capital overheads – land and office6 | £9,256 annual fixed | [401] |
| Non-staff overheads – travel/transport, telephone, education and training, office supplies, clinical/general services, utilities7 | £400,898 annual fixed | [401] |
| ***Total cost per falls clinic*** | **£1,115,552 annual fixed** |  |
| ***Total cost for 7 falls clinics*** | **£7,808,864 annual fixed** |  |
| Outsourced services and equipment8 | 2 specialist outpatient visits for 30% of clients | £32.89 expected9 per client | [167] |
| Optician and/or ophthalmologist referral for 17.7% of clients | £51.33 expected per client | [167] |
| 1 podiatry visit for 17% of clients | £5.77 expected per client | [167] |
| Geriatric psychiatry for 6.9% of cognitively impaired clients | £0.16 expected per client | [167]; [384] |
| Walking aid for 25% of clients | £21.29 expected per client | [167] |
| Hip protectors for 17% of clients | £11.81 expected per client | [167] |
| New footwear for 19% of clients | £10.79 expected per client | [167] |
| HAM major modifications (social care) | £94.97 expected per client | [216] |
| Handouts and amenities | £22.71 per client | [207] |
| ***Total cost per client*** | **£251.73** |  |
| Non-public sector cost per participant | Travel cost | £62.45 per year | [207] |
| HAM major modifications (self-funded) | £94.97 per receipt | [216] |
| Time opportunity cost – if employed10 | £348.80 per year |  |
| Time opportunity cost – if engaged in regular unpaid work10 | £87.20 per year |  |
| Time opportunity cost – informal caregiver for CI client11 | £348.80 per year |  |
| **(2) Bi-disciplinary assessment and treatment [62] (2,700 clients per year)** | | | |
| Risk screening and access | Reactive pathway screening and invitation2 | £16.37 per client | [167] |
| Bi-disciplinary assessment | Physician assessment | £121.46 per client | [167] |
| OT assessment for 92.1% of clients | £269.63 expected per client | [167]; [62] |
| Outsourced services and equipment8 | Specialist outpatient visit for 44.1% of clients | £45.90 expected per client | [167]; [62] |
| 2 GP visits for medication change for 21.7% of clients | £16.63 expected per client | [167]; [62] |
| Optician and/or ophthalmologist referral for 17.8% of clients | £51.62 expected per client | [167]; [62] |
| HAM major modifications (social care) for 92.1% of clients | £87.47 expected per client | [216]; [62] |
| Non public sector cost per participant | Travel cost | £62.45 per year | [207] |
| HAM major modifications (self-funded) for 92.1% of clients | £87.47 expected per client | [216]; [62] |
| Time opportunity cost – if employed12 | £69.76 per year |  |
| Time opportunity cost – if engaged in regular unpaid work12 | £17.44 per year |  |
| **Abbreviation:** CI: cognitively impaired; HAM: home assessment and modification; MA fall: fall requiring medical attention; OT: occupational therapy/therapist; PT: physiotherapy/therapist; TUG: timed up and go  1 All costs are expressed in 2021/22 £. Earlier estimates were inflated at the annual rate of 1.98% which is the average NHS cost inflation between 2013 and 2019 [401]. Costs in Australian dollar were converted to £ at rate of £0.55/AUS$1.  2 This incorporated cost of 30 minutes of hospital staff time, 28% premium as cost of recruitment (i.e., letters and phone calls), and 50% premium as office overheads. The costs were converted from 2008/09 Australian dollar to 2021/22 £.  3 This included cost of set-up (i.e., office overheads) at £24 per GP practice which amounted to £0.02 per person when spread across all recommended scenario recipients. The 28% premium for recruitment was applied as in reactive pathway (see note 2) to obtain the final per-participant cost of £10.83.  4 Salary/oncosts of social work assistant from PSSRU depository were used [401].  5 Salary/oncosts of administrative staff for medical consultant were used [401].  6 Assumed to be four times the capital overheads for Dementia Memory Clinic operating 40 hours per week for 50.4 weeks per year and catering to 708 dementia patients as costed in PSSRU depository. The overheads were annuitized over 60 years at a discount of 3.5%, declining to 3% after 30 years [401].  7 Assumed to be two times the non-staff overheads for Dementia Memory Clinic [401].  8 Assumed that those with intervention history incurred 20% of the costs of outsourced services.  9 Expected cost given the probability of receiving the given service.  10 Assumed that average time committed per client is 40 hours: 2 hours for falls risk assessment at falls clinic; 4 hours for in-house medical treatments at falls clinic; 30 hours for in-house exercise treatments; 2 hours for HAM; 2 hours per outsourced services amounting to 2 hours on average per client (2 outpatient visits for 30%, optician/ophthalmologist visit for 17.7%, podiatry visit for 17%). Those in paid employment assumed to incur an hourly opportunity cost equal to the national living wage (£8.72). Those engaged in unpaid work assumed to incur an hourly opportunity cost equal to quarter of the national living wage (£2.18) due to shorter weekly working hours (11 vs. 40 hours for employed).  11 Assumed that cognitively impaired clients are accompanied by their informal caregivers for all 40 hours of intervention, incurring an hourly opportunity cost equal to the national living wage.  12 Assumed that average time committed per client is 8 hours: 2 hours for physician assessment; 4 hours for OT HAM and falls prevention education; and 2 hours per outsourced services. The hours were valued in the same way as in note 10. | | | |

Given the high fixed costs of falls clinics, it is important to estimate the total number of clinics required. For the reactive pathway under RC, all MA fallers would access the multifactorial intervention pending demand. According to ELSA Wave 4, 6.8% of the population aged 60+ experienced at least one MA fall in the past year and were eligible for the reactive intervention. This equates to 8,542 individuals out of 125,244 aged 60+ in Sheffield. Of these, 78.4% (n=6,695) were cognitively intact and the other 21.6% (n=1,847) impaired. According to the RCTs, the uptake rate for the reactive intervention was 53.8% for cognitively intact [62] and 49.6% for impaired [384]. Hence, 3,602 cognitively intact and 916 impaired persons would access the intervention. However, given that only 25% of cognitively intact MA fallers are referred to the clinic [62], the final client number for the clinic would be around 900, while the other 2,700 would receive bi-disciplinary intervention.

For the proactive pathway under RC, all cognitively intact individuals screened to be at high falls risk at GP contact are eligible for multifactorial intervention. Among those who did not experience an MA fall, 29.0% or 36,333 individuals in Sheffield had abnormal gait/balance or experienced recurrent non-MA falls in the past year and hence were at high falls risk. Of these, 71.9% (n=26,131) were cognitively intact and hence eligible for the multifactorial intervention, while the other 28.1% (n=10,202) were impaired. But not all eligible persons would have a GP contact in that year for the fall risk screening. The average annual probability of having a GP contact was 89.0% for the cognitively intact at high falls risk, meaning that 23,257 would be referred. For those referred, the uptake rate was 82.4% according to the RCT [385], meaning that the final number accessing the intervention would be 19,163.

Therefore, across both reactive and proactive pathways under RC, the total number accessing the falls clinic would be 20,979. Annual falls clinic capacity should thus be planned for 21,000 clients of whom 91.3% (n=19,173) are cognitively intact proactive clients, 4.4% (n=924) cognitively impaired reactive clients, and 4.3% (n=903) cognitively intact reactive clients. A further 2,700 clients would receive the bi-disciplinary intervention. The Sheffield Falls Clinic under current practice ran for a single afternoon per week and catered to around 300 clients per year. If the Clinic operates full-time (i.e., 10 morning and afternoon sessions), it would have an annual capacity of 3,000 clients. At this workflow, seven clinics would be needed to manage 21,000 clients per year. That said, initial model simulation showed that the clinic client flow averaged around 25,000 over 40 years due to the unlimited re-receipt of intervention by those with proactive intervention history. Capping the number of proactive intervention re-receipts to three returned the annual flow to around 21,000.

Resource uses and costs for referrals to multidisciplinary falls clinics were divided into four components: (i) risk screening and access; (ii) falls clinic operation; (iii) outsourced services and equipment; and (iv) non-public sector costs. The falls clinic operation was assumed to mainly incur fixed annual costs in the form of salaries and overheads, while other components were costed at per-client rates. This is a simplification since many of the latter components (e.g., specialist outpatient services) also operate in facilities incurring fixed costs. However, unlike the falls clinic, these facilities are not dedicated to falls prevention and hence the per-client rates were deemed more appropriate.

Two previous falls prevention models informed the per-client cost of risk screening, recruitment and physical assessment for the bi-disciplinary intervention [167, 363]. No cost was assigned to GP contact since it would be included in the annual comorbidity care costs for primary and secondary care. The costing of the falls clinic operation is described in detail in Appendix E, Table E9 and commentary. In brief, the annual salary and overhead cost of operating a full-time clinic (40 hours per week) was estimated based on stakeholder consultations and literature. The PSSRU unit cost depository [401] served as an important data source. Treatments outsourced to external providers were costed at per-client rates. The proportion of multifactorial intervention clients requiring each outsourced service and cost per service were obtained from a previous model [167] to estimate the expected cost per service.

Based on consultation with the falls modelling expert, clients with previous receipt history were assumed to incur only 20% of the cost of outsourced services to reflect the lower number of newly identified falls risk factors at the repeat visit. Attending the falls clinic also incurred costs outside the public sector. The annual travel cost was sourced from a previous model [207]. Time opportunity costs were estimated for participants who are employed or engaged in unpaid work, and for informal caregivers accompanying cognitively impaired participants.

The bi-disciplinary intervention was costed at per-client rates. The RCT for the bi-disciplinary intervention reported the proportions of clients receiving different outsourced services [62]. These proportions were combined with unit costs from the previous model [167] to estimate the expected costs.

##### Single-component interventions – resource use

Table 5.33 summarises the intervention resource use in RCTs for: reactive HAM for hip fracture patients [405]; and three exercise interventions for different subgroups [135, 136, 235].

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| **Table 5.33** Resource use in randomised controlled trials of single-component interventions. | | | |
| **RCT reference** | **Intervention type** | **Category** | **Resources** |
| Lockwood (2019) [405] | HAM for hip fracture patients discharged from hospital (reactive pathway under usual care only) | Participant screening & recruitment | (1) Eligibility screening method unclear  (2) Hip fracture patients approached after surgery; consent given by family member if have moderate/severe cognitive impairment |
| Therapeutic treatment | (I) 1-hour OT home visit with patient (and family member if cognitively impaired) 1-5 days before discharge1 – assessed home safety, mobility, self-care and function, followed by education, advice and recommendation on home modifications, equipment and community services2 |
| Nyman (2020) [235] | Group- and home-based Tai Chi for dementia patients (proactive and self-referred pathways) | Participant screening & recruitment | (1) Potential participants identified from: NHS research/clinic databases; memory services; local charities; self-referrals  (2) Eligibility confirmed and consent obtained from participant and caregiver at home visit by researcher  (3) Reimbursed travel cost for intervention |
| Therapeutic treatment | (I) Group Tai Chi: 90-minute (45-minute exercise and 45-minute informal discussion) weekly Tai Chi class (10 patient-caregiver dyads) for 20 weeks – delivered by qualified lead/assistant Tai Chi instructor; individually-tailored and progressing in difficulty  (II) Home-based Tai Chi: 20-minute daily Tai Chi for 20 weeks – instructed by Tai Chi instructor and supervised by caregiver  (III) Behavioural change techniques: e.g., solutions to personal barriers, self-monitoring, peer support  (Note) Programme designed to accumulate 50 hours of exercise over 20 weeks; the mean number of hours spent in exercise was 25 |
| Iliffe (2014) [135] | Group-based FaME and home-based Otago exercises for cognitively intact persons at general falls risk (self-referred pathway) | Participant screening & recruitment | (1) GP practices with suitable venues for exercise classes created a list of potentially eligible older persons; random number generator selected 600 persons per GP practice; invitation letters were sent |
| Therapeutic treatment | (I) FaME: 1-hour weekly group class (up to 15 participants per class) for 24 weeks – delivered by PSI at local venues; individually-tailored and progressing in difficulty  (II) Otago home exercise: 30-minute exercise 2 times per week for 24 weeks using instruction booklets  (III) Walking: 30 minutes at moderate pace 2+ times per week for 24 weeks  (Note) 72 hours of exercise including walking over 24 weeks; 17% completed 75% of FaME and Otago exercise hours |
| Skelton (2005) [136] | Group-based FaME and home-based Otago exercises for cognitively intact women at high falls risk (self-referred pathway) | Participant screening & recruitment | (1) Direct community marketing: posters at NHS clinics and voluntary organizations; advertisement in local and national newspapers and local radio station  (2) Eligibility screening: initial telephone call to people who responded to marketing; postal questionnaire sent for further screening |
| Therapeutic treatment | (I) FaME: 1-hour weekly group class for 36 weeks – delivered by qualified geriatric exercise instructors with additional FaME training at local venues; individually tailored and progressing in difficulty  (II) Otago home exercise: 30-minute exercise 2 times per week for 36 weeks using instruction booklets  (Note) 72 hours of exercise over 24 weeks; adherence not reported but 68% continued exercising at trial end |
| **Abbreviation:** FaME: Falls Management Exercise; HAM: home assessment and modification; OT: occupational therapy/therapist; PSI: postural stability instructor  1 Both intervention and control group participants received multidisciplinary inpatient rehabilitation and (depending on functional level) community rehabilitation after discharge. The OT who conducted the 1-hour home visit was also involved with the inpatient rehabilitation for the same patient.  2 The study did not mention major home modifications being made at the single home visit or being financed by the evaluated intervention, suggesting that external social services were referred for major modifications with their costs being borne by the social care sector or by participants themselves. | | | |

Lockwood (2019) for reactive HAM did not clearly describe the eligibility screening method, perhaps because hip fracture patients were readily identifiable; but implementing the same intervention on all hospitalised MA fallers will require screening resources. The intervention consisted of an OT home visit 1-5 days before discharge to make safety assessment and relevant recommendations.

Nyman (2020) evaluated a 20-week group- and home-based Tai Chi intervention that was tailored to dementia patients. The participants were screened and recruited in a largely proactive manner, with dementia patients being identified from their routine contacts with clinical and nonclinical services, although self-referrals were also accepted. Those whose dementia was too severe to be able to give informed consent (assisted by the caregiver) were excluded from participation. Due to the initially low uptake, the intervention travel costs were reimbursed. There were three therapeutic components: group-based Tai Chi delivered by qualified Tai Chi instructor; home-based Tai Chi instructed by the instructor but supervised by the caregiver; and behavioural change techniques delivered by the instructor. The aim was to accumulate 50 hours of exercise per participant over 20 weeks. But dose adherence was low: the average hours of exercise was 25, with only three of 42 participants (7.1%) reaching 50 hours.

Iliffe (2014) evaluated a 24-week multi-component exercise intervention that targeted a relatively low falls risk (less than three falls in past year) cognitively intact older population. The recruitment was conducted via invitation letters; the access mode was hence self-referral. There were three therapeutic components: group-based FaME delivered by postural stability instructors (PSIs); self-implemented Otago home exercise; and encouragement of walking. The total number of exercise hours was 72 hours over 24 weeks. But adherence was low, with 17% completing 75% of FaME and Otago doses.

Skelton (2005) evaluated a 36-week multi-component exercise intervention that targeted a high falls risk (three or more falls in past year) cognitively intact older women. The trial recruitment relied on direct marketing – posters and newspaper and radio advertisements – consistent with the self-referred pathway. The therapeutic components were like those in Iliffe (2014), except that encouragement of walking was excluded. This meant that even though the overall number of exercise hours (72) was the same – spread across 36 weeks in Skelton (2005) vs. 24 weeks in Iliffe (2014) – the intervention in Skelton (2005) was more intensive than that in Iliffe (2014), composed entirely of FaME and Otago. The adherence rates were not reported.

##### Single-component interventions – cost

Table 5.34 shows the resource use and cost parameters for single-component interventions.

|  |  |  |  |
| --- | --- | --- | --- |
| **Table 5.34** Resource use and cost of single-component interventions. | | | |
| **Component** | **Resource use** | **Mean cost1** | **Reference** |
| **(1) Reactive HAM under usual care** | | | |
| Risk screening and access | Hospital record screening for eligibility and invitation before discharge | £16.37 per client | [167] |
| Therapeutic component | OT (band 7) home visit and assessment (2 hours including travel) | £128.23 per client | [401] |
| HAM major modifications (social care) | £94.97 per client | [216] |
| Walking aid for 25% of clients | £21.29 expected2 per client | [167] |
| Hip protectors for 17% of clients | £11.81 expected per client | [167] |
| New footwear for 19% of clients | £10.79 expected per client | [167] |
| 2 referrals to community OT service for 20% of clients | £19.97 expected per client | [401] |
| Non-public sector cost per client | HAM major modifications (self-funded) | £94.97 | [216] |
| Time opportunity cost – informal caregiver for CI patient3 | £17.44 per year |  |
| Public sector cost | **Average cost per client** | **£303.43 per year** |  |
| **Average cost per client with intervention history4** | **£176.37 per year** |  |
| **(2) 20-week Tai Chi for cognitively impaired persons and their caregivers** | | | |
| Risk screening and access | Screening at GP contact (proactive only) | £10.83 per client | [363] |
| Travel cost (proactive only) | £62.45 per client | [207] |
| Ongoing administration5 | £50 per client | PCS |
| Direct marketing (self-referred only) | £25.31 per client | [167] |
| Therapeutic component | Staff time | £367.06 per client | [235] |
| Staff training | £8.25 per client | [216] |
| Staff travel | £15.01 per client | [216] |
| Equipment | £5 per client | [216] |
| Venue hire | £30 per client | [216] |
| Non public sector cost per client | Travel cost (self-referred only) | £62.45 | [207] |
| Time opportunity cost – if employed6 | £218 per year |  |
| Time opportunity cost – if engaged in regular unpaid work6 | £54.5 per year |  |
| Time opportunity cost – informal caregiver7 | £218 per year |  |
| Public sector cost | **Average cost per proactive client** | **£537.77 per year** |  |
| **Average cost per self-referred client8** | **£500.63 per year** |  |
| **(3) 24-week self-referred FaME and Otago for general-risk cognitively intact persons** | | | |
| Access | Direct marketing | £10.03 per client | [355] |
| Therapeutic component | Staff time | £126 per client | PCS |
| Staff training | £4.60 per client | [216] |
| Staff travel | £21.11 per client | [216] |
| Equipment | £20.02 per client | [216] |
| Venue hire | £18 per client | [216] |
| Non public sector cost per client | Travel cost | £62.45 | [207] |
| Time opportunity cost – if employed9 | £340.60 per year | [135] |
| Time opportunity cost – if engaged in regular unpaid work9 | £85.15 per year | [135] |
| Public sector cost | **Average cost per client** | **£199.76 per year** |  |
| **(4) 36-week self-referred FaME and Otago for high-risk cognitively intact persons** | | | |
| Access | Direct marketing | £10.03 per client | [355] |
| Therapeutic component | Staff time | £189 per client | PCS |
| Staff training | £4.60 per client | [216] |
| Staff travel | £31.66 per client | [216] |
| Equipment | £20.02 per client | [216] |
| Venue hire | £27 per client | [216] |
| Non public sector cost per client | Travel cost10 | £93.68 | [207] |
| Time opportunity cost – if employed9 | £340.60 per year | [135] |
| Time opportunity cost – if engaged in regular unpaid work9 | £85.15 per year | [135] |
| Public sector cost | **Average cost per client** | **£272.28 per year** |  |
| **Abbreviation:** FaME: Falls Management Exercise; HAM: home assessment and modification; OT: occupational therapy/therapist; PCS: personal communication with stakeholder  1 All costs are expressed in 2021/22 £. Earlier estimates were inflated at the annual rate of 1.98% which is the average NHS cost inflation between 2013 and 2019 [401]. Costs in Australian dollar were converted to £ at £0.55/AUS$1.  2 Expected cost given the probability of receiving the given service.  3 Assumed that cognitively impaired patients are accompanied by informal caregivers for 2 hours of OT home visit, incurring an hourly opportunity cost equal to the national living wage (£8.72).  4 Assumed that those with intervention history incurred 20% of the costs of HAM major modifications, equipment and community OT services.  5 The manager for Dance to Health Sheffield informed that each weekly session for 20 participants incurred an administrative cost of £25, which equates to £500 for a 20-week programme. This translates to £50 per client if each Tai Chi class is attended by 10 participant-caregiver dyads as mentioned in Nyman (2020).  6 Assumed that average time committed per participant is 25 hours according to the average exercise time in RCT [235]. Those in paid employment assumed to incur an hourly opportunity cost equal to the national living wage. Those engaged in unpaid work assumed to incur an hourly opportunity cost equal to quarter of the national living wage.  7 Assumed that cognitively impaired clients are accompanied by their informal caregivers for all 25 hours of intervention, incurring an hourly opportunity cost equal to the national living wage.  8 Under usual care, the cost of self-referred intervention is entirely self-paid.  9 According to Iliffe (2014) [135], 17% of general-risk persons receiving the 24-week intervention completed 75% of prescribed time for FaME and Otago exercises. Assuming the other 83% completed 50% of prescribed time and that the pattern was the same for 24-hour walking, then the average time committed was 39.06 hours. If the same pattern was applied to the 36-week intervention evaluated by Skelton (2005) [136] which contained 72 hours of FaME and Otago, the average time committed was again 39.06 hours. Time opportunity costs were assigned as in note 6.  10 Travel cost was assumed to be proportional to the programme duration. Hence, the 36-week programme for high-risk group incurred 1.5 times the travel cost of the 24-week programme for general-risk. | | | |

For reactive HAM under UC, the cost of screening was taken from a previous model [167]. In the intervention RCT, each OT home visit lasted one hour [405]. But the OT involvement during the inpatient stay would have reduced the required length of home visit. The RCT also excluded travel time which was costed separately for HAM in previous models [167, 216]. A simplifying assumption was made that each OT home visit lasted two hours including travel time. The hourly cost for OT band 7 was obtained from PSSRU [401]. The costs of major home modifications, sourced from a previous model [216], were split equally between social care sector and participants themselves. The home visit also resulted in equipment recommendations and community service referrals. Further details on costing the equipment and services are given in Appendix E, Table E10 and commentary. Patients with history of reactive HAM incurred 20% of the equipment/service costs. Lockwood (2019) described cognitively impaired patients being accompanied by their caregivers at the OT home visit. Hence, HAM incurred the opportunity cost of two hours of caregivers’ time. It was assumed that hospitalised MA fallers engaged in minimal paid/unpaid work and hence incurred no time opportunity cost.

For the three exercise interventions, the dosage costed for the year was that evaluated in their respective RCTs. The Tai Chi operated under both proactive and self-referred pathways. The former would incur the cost of falls risk screening taken from a previous model [363]. Nyman (2020) also mentioned that participants’ travel costs were reimbursed to increase uptake. Hence, participant travel costs, taken from a previous model [207], accrued to the public sector under the proactive pathway but not under the self-referred pathway. The administration cost was included at per-client rate. The cost of direct marketing under the self-referred pathway was taken from a previous model [167]. The marketing cost for FaME and Otago exercises targeting cognitively intact persons was assumed to be lower than that for cognitively impaired Tai Chi participants and taken from a previous economic evaluation [355]. The cost categories for the therapeutic components of all three exercises were taken from the PHE model [216]: staff time; staff training; staff travel; equipment; and venue hire. Further details on costing the therapeutic components are given in Appendix E. The costs were assumed not to vary by intervention history. Societal costs included travel cost (except for proactive Tai Chi) which was assumed proportional to the programme duration. Time opportunity costs for those in paid/unpaid work and for accompanying caregivers were assumed proportional to the number of hours committed.

#### 5.2.4.4 Intervention efficacy

The RCT efficacy evidence should match the model specification in terms of: (i) the main fall event of interest – e.g., any fall, recurrent fall, MA fall; (ii) the incidence metric – RR for falls risk reduction and RaR for falls rate reduction [407]; and (iii) efficacy duration – i.e., no longer than the RCT duration, unless implementation is sustained [105]. Table 5.35 summarises the efficacy data for base case analysis extracted from seven RCTs and one Cochrane meta-analysis.

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| **Table 5.35** Falls prevention intervention efficacy parameters for base case analysis. | | | | | |
| **Target population** | **Intervention** | **RCT source** | **Follow-up duration** | **Efficacy type** | **RR (95% CInt)** |
| ***Reactive pathway*** | | | | | |
| MA fall patients (UC) | HAM | Lockwood (2009) [405] | 6 months | RR – any faller | 0.828 (0.472-1.452) |
|  |  | RR – recurrent faller given any fall1 | 1.383 (0.788-2.427) |
| Cognitively intact MA fall patients (RC) | Multifactorial intervention | Close (1999) [62] | 12 months | RR – any faller | 0.615 (0.485-0.793) |
|  | RR – recurrent faller given any fall2 | 0.719 (0.486-1.063) |
|  | RR – MA faller given any fall | 0.942 (0.428-2.071) |
| Cognitively impaired MA fall patients (RC) | Multifactorial intervention | Shaw (2003) [384] | 12 months | RR – any faller | 0.925 (0.811-1.054) |
| RR – recurrent faller given any fall1 | 1.183 (1.037-1.349) |
| ***Proactive pathway*** | | | | | |
| Cognitively intact high-risk persons | Multifactorial intervention | Spice (2009) [385] | 12 months | RR – any faller | 0.874 (0.778-0.982) |
|  | RR – MA faller given any fall3 | 0.854 (0.441-1.652) |
| Cognitively impaired high-risk persons (RC) | Tai Chi | Nyman (2020) [235] | 6 months | RR – any faller | 1.024 (0.608-1.723) |
|  | RR – recurrent faller given any fall1 | 0.379 (0.225-0.638) |
| ***Self-referred pathway*** | | | | | |
| Cognitively intact general-risk persons | Exercise | Sherrington (2019) [125] | 3-25 months | RR – any faller | 0.850 (0.810-0.890) |
| Iliffe (2014) [135] | 12 months | RR – recurrent faller given any fall4 | 0.964 (0.921-1.009) |
|  |  |  |  | RR – engaging in high physical activity5 | 2.308 (1.156-4.909) |
| Cognitively intact high-risk persons | Exercise | Skelton (2005) [136] | 50 weeks | RR – any faller | 0.733 (0.567-0.946) |
|  | RR – recurrent faller given any fall1 | 0.863 (0.669-1.113) |
|  | RR – MA faller given any fall6 | 0.429 (0.190-0.968) |
| Cognitively impaired persons | Tai Chi | Nyman (2020) [235] |  | *See proactive pathway above* |  |
| **Abbreviation:** CInt: confidence interval; HAM: home assessment and modification; MA fall: fall requiring medical attention; OR: odds ratio; RaR: rate ratio; RC: recommended care; RCT: randomized controlled trial; RR: relative risk; UC: usual care.  1 Calculated from the RR, RaR and SE for log(RR any faller) reported by the RCT and recurrent fall pattern value (A) of 0.903 from a UK RCT [25]; see Equation (2) for formula. The 95% CInt for RRRF was obtained by assuming that the SE for log(RR any faller) equals SE for log(RRRF).  2 Proxied by RR of experiencing 3+ falls given any fall reported by the same RCT.  3 Proxied by RR of being hospitalized faller given any fall reported by the same RCT and assumed to apply to both single and recurrent fallers.  4 Calculated from RaR reported by the RCT, RR and SE for log(RR any faller) from Cochrane meta-analysis [125] and A of 0.903. The 95% CInt for RRRF was obtained by assuming that SE for log(RR any faller) equals SE for log(RRRF).  5 Calculated from OR and baseline risk of 38% of control group being highly physically active from the RCT.  6 Proxied by RR of being injurious faller given any fall reported by the RCT; applied to both single and recurrent fallers. | | | | | |

Several RCTs reported both RR and RaR for the intervention relative to comparator. Nyman (2020), for example, reported RR of 1.024 (95% confidence interval: 0.608-1.723) and RaR of 0.350 (95% CInt: 0.150-0.810); hence, the intervention lacks statistically significant evidence for reducing the number of fallers but has such evidence for the number of falls per faller [235]. Using one of RR or RaR individually would neglect the information content of the other. Therefore, where the RCT reported both RaR and RR, the following equation (2) was used to estimate RR of being a recurrent faller given any fall, or RRRF, from the information in the two metrics:

where is a composite term expressing the pattern of falls among recurrent fallers (henceforth, ‘recurrent fall pattern’). and are ratios between the numbers of recurrent fallers and single fallers in the intervention group and control group, respectively. and are the average numbers of falls experienced by recurrent fallers in the intervention group and control group, respectively. and are the average length of follow-up duration expressed in person-years for the intervention group and control group, respectively. Equation (2) is derived in Appendix E. Only one UK RCT (not used for parameterisation) reported sufficient data to estimate the recurrent fall pattern of value 0.903 [25]. This estimate was assumed to hold for other RCTs when equation (2) was applied. In the example of Nyman (2020) given above, the RR of being a recurrent faller given any fall (*RRRF*) would be 0.350/(1.024\*0.903) = 0.379. The intervention’s high efficacy in reducing the number of falls per faller thus translates to around 62% reduction in the risk of being a recurrent faller having fallen.

Where sufficient data were reported, RR of being an MA faller given any fall was computed. Technically, the model could have distinguished between RR of being an MA faller given a single fall and RR given recurrent falls, but no RCT provided sufficient detail for this distinction. The RR was hence applied to both single and recurrent fallers. No RCT reported RR of experiencing a fatal fall. The reliance on reported data meant that the evidence availability varied across RCTs: Lockwood (2009), for example, lacked the data for RR of being an MA faller given any fall, while Spice (2009) lacked it for RRRF. Yet the absence of reported evidence does not imply the absence of effect. Iliffe (2014) provided the sole wider health effect of falls prevention, namely the higher likelihood of engaging in high physical activity. The OR was converted into RR and applied to the individual-level probability of engaging in high physical activity in the next cycle (see Section 5.2.6.3). Iliffe (2014) nevertheless lacked the data on RR of experiencing any fall; this was thus obtained from the Cochrane meta-analysis on community-based falls prevention exercise [125].

Five of the seven RCTs had follow-up durations of 12 months (or approaching 12 months at 50 weeks), while the other two had durations of six months; the meta-analysis pooled RCTs of follow-up durations ranging between three and 25 months. The model assumed that the efficacies of the six-month follow-up RCTs were durable for the year in which the interventions are accessed. This is a limitation since there is no evidence that the efficacies are durable in the second half of the year. A further caveat is the model’s lack of consideration of per-protocol efficacy evidence, incorporating intention-to-treat (ITT) efficacy data only. The per-protocol evidence would have captured heterogeneity in the intervention benefit access by adherence level. But only Nyman (2020) conducted per-protocol analysis and did not report its outcome beyond stating that it was close to the ITT outcome.

### 5.2.5 Mortality risks and falls epidemiology

After individuals have received their appropriate falls prevention interventions (if any), the model proceeds to generate the risk and incidence of mortality (Section 5.2.5.1), followed by the risk and incidence of falls of various types (Section 5.2.5.2).

#### 5.2.5.1 Fatal falls and other-cause mortality

According to the 2019 Global Burden of Disease (GBD) study, falls constituted 0.76% of all deaths in men aged 50-69 in Sheffield; 0.45% in women aged 50-69; 1.09% in men aged 70+; and 0.96% in women aged 70+ [408]. From this information, estimates of all-cause mortality rates can be partitioned into fall-related and other-cause mortality rates. The costs of health and social care by cause of death in the final year of life were assigned to deceased individuals.

##### Risk of fatal falls

The ONS Life Tables provided the annual all-cause mortality risks stratified by age and sex based on death incidence for the period 2016-2018 [388]. The Life Tables covered both community-dwelling and institutionalised populations who have significantly different mortality rates. A prospective cohort study of primary care records of 9,772 care home residents and 354,306 community-dwelling persons in England and Wales aged 65-104 reported one-year mortality rates for the two populations by age group [409]. From this data, the relative risks of death in an institutional setting compared to community were computed by age group: 10.67 for age 65-74; 5.51 for age 75-84; and 3.07 for age 85+. Using the relative mortality risks and the ELSA-estimated proportions of the total population institutionalised by age group and sex (Section 5.2.2.1), annual mortality rates were estimated for the community-dwelling and institutionalised populations. It was assumed that the relative risk for age 65-74 applied also to age 60-64. The weighted average of the two rates equalled the stratified rates in the ONS Life Tables.

The age- and sex-stratified annual mortality rates for the community-dwelling population were further stratified by frailty category. The UK study of eFI reported the hazard ratios of annual mortality (adjusted for age and sex) by frailty category: 1.92 (95% CInt: 1.81-2.04) for Mild relative to Fit; 3.10 (95% CInt: 2.91-3.31) for Moderate relative to Fit; and 4.52 (95% CInt: 4.16-4.91) for Severe relative to Fit [47]. Using the hazard ratios and the ELSA-estimated proportions of community-dwelling by frailty category in each age and sex subgroup, the frailty-stratified mortality rates were estimated for the community-dwelling population by age and sex. Having estimated the stratified mortality rates, the percentages reported by GBD 2019 were applied to estimate the rates of fatal falls. This assumed that: (i) GBD percentages for age group 50-69 applied equally to the age group 60-69; and (ii) GBD percentages did not vary by frailty. Table 5.36 shows the annual fatal fall rates stratified by age, sex, and frailty category incorporated in the model.

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| --- | --- | --- | --- |
| **Table 5.36** Annual fatal fall rate (range 0-1) by age group, sex and frailty category. | | | |
| **Sex** | **Frailty** | **Age 60-69** | **Age 70+** |
| Male | Fit | 0.000063 | 0.000354 |
|  | Mild | 0.000121 | 0.000680 |
|  | Moderate | 0.000196 | 0.001097 |
|  | Severe | 0.000285 | 0.001600 |
| Female | Fit | 0.000024 | 0.000198 |
|  | Mild | 0.000046 | 0.000381 |
|  | Moderate | 0.000074 | 0.000615 |
|  | Severe | 0.000108 | 0.000896 |

The weighted average of the estimated fatal fall rates for the whole community-dwelling population aged 60+ was 0.00029. The PHE model incorporated an estimate from HES that 2.39% of hospitalised falls were fatal [216]; it also estimated that 5.6% of falls required hospitalisation. This meant that 0.13% of all falls were fatal. If it is assumed that 30% of the population aged 60+ experience a fall each year (the PHE model assumed that 34% of the population aged 65+ fell at least once per year and that the average falls per person was 1.06), then the fatal fall rate for this population would be 0.00039. Hence, this model underestimates the rate of fatal falls relative to the PHE model, though both rates are likely too low to substantially affect the evaluation results.

##### Risk of other-cause mortality

The factor of one minus GBD (age group- and sex-specific) percentages were applied to the all-cause mortality rates to obtain the other-cause rates by age, sex, and frailty category. These rates are displayed in Figure 5.3 and Table E11 in Appendix E.

**Figure 5.3** Annual other-cause mortality rate (range 0-1) by age, sex and frailty category.

##### Costs in final year of life

Table 5.37 shows the costs in the final year of life by care sector and primary cause of death. The data source was the 2019 PSSRU unit cost depository which reported the final-year costs for falls patients and all patients [401]. Assuming that falls accounted for 0.82% of all deaths as estimated from the GBD data [408], weighted fall-related costs were subtracted from the all-cause costs to obtain the other-cause costs. They were assigned to the deceased individuals as they exited the model.

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| --- | --- | --- | --- |
| **Table 5.37** Costs in final year of life by care sector and primary cause of death. | | | |
| **Cause of death** | **Healthcare1,2** | **Social care** | **Total public sector** |
| Falls | £10,492.48 | £6,507.61 | £17,000.09 |
| Other causes3 | £7,666.08 | £4,226.05 | £11,892.13 |
| **Source:** 2019 PSSRU unit cost depository [401].  1 All costs are expressed in 2021/22 £. Healthcare costs were inflated at 1.98% per annum according to average NHS cost inflation rate over the period 2013-19; social care costs were inflated at 2.13% per annum according to average PSS pay & price inflation rate over the same period [401].  2 Secondary care only: inpatient emergency and non-emergency; outpatient; A&E  3 Assumed that falls accounted for 0.029% of all deaths; weighted fall-related costs were then subtracted from all-cause costs. | | | |

#### 5.2.5.2 Non-fatal falls

The risks of non-fatal falls were estimated prospectively using the ELSA data on fall incidence and type during the two-year interim between Waves 4-5, then annualised. There are five fall-related outcomes of interest which match the five types of fall history: (1) no fall; (2) single non-MA fall; (3) recurrent non-MA falls; (4) single MA fall; and (5) recurrent falls with at least one MA fall. To estimate the risk of each of these outcomes, four separate multivariate logistic regressions are estimated for: (a) risk of being any faller; (b) risk of being a recurrent faller given any fall; (c) risk of being an MA faller given single fall; and (d) risk of being an MA faller given recurrent fall. These are sufficient to generate the five fall incidence types above: e.g., yes for (a), no for (b) and yes for (c) generate type (4) single MA fall. Nevertheless, the issue of recall bias in the use of ELSA falls data is first discussed.

##### Recall bias in the ELSA falls data

A key methodological issue in prospective analyses of falls incidence between ELSA Waves 4-5 is the quality of the falls data collected at Wave 5. Whilst the Wave 4 survey asked the respondent ‘Whether fallen down in the last year (for any reason)?’, the Wave 5 survey asked ‘[Since we last talked to you on [date of last interview], have/Have] you fallen down [BLANK/in the last two years] for any reason?’. Despite the different recall periods, the two-year prevalence rates of falls of different types reported in Wave 5 were comparable to the annual rates reported in Wave 4. These are shown in Table 5.38.

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| --- | --- | --- | --- |
| **Table 5.38** Comparison of falls risk between: (1) ELSA falls incidence between Waves 4-5; (2) ELSA falls prevalence/history in Wave 4; and (3) estimates in literature. | | | |
| **Fall type: target population** | **(1) Two-year [annualised] risk from ELSA Waves 4-5** | **(2) Annual risk from ELSA Wave 4** | **(3) Annual risk in literature [reference]** |
| Any fall: aged 65+ | 29.7% [16.2%] | 27.0% | NICE: 30% [13] |
| Any fall: aged 80+ | 39.1% [22.0%] | 35.5% | NICE: 50% [13] |
| Recurrent fall given any fall: aged 60+ | 43.2% [24.6%] | 43.9% |  |
| Any fall: women aged 65+ with 3+ falls in past year | 67.6% [43.1%] |  | RCT: 88.9% [136]1 |
| Any fall: mean age 78 with MA fall history | 47.8% [27.8%] |  | RCT: 52.0% [62]1,2; 68.5% [383]1,2 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; NICE: National Institute for Health and Care Excellence; RCT: randomized controlled trial  1 One-year falls risk is taken from the control group that received no falls prevention intervention.  2 Presented to A&E for an MA fall at trial baseline. | | | |

According to Wave 5 data, 29.7% of the cohort aged 65+ (at Wave 4) and followed up in Wave 5 reported the experience of at least one fall. This two-year risk was only marginally greater than the prevalence of 27.0% for falls experienced one year prior to Wave 4. The 29.7% two-year risk was equivalent to an annualised risk of 16.2%. This is substantially lower than the Wave 4 annual prevalence and the 30% annual risk cited by the NICE guideline as generalisable to the UK population aged 65+ [13]. A noticeable pattern is that the original two-year risks from Waves 4-5 are comparable to the annual prevalence from Wave 4. The last column also gives the annual risks reported for the control groups of three UK-based RCTs that used high-frequency prospective falls recording methods as recommended for falls epidemiological research [24, 124]. A noticeable pattern is that the two-year risks from ELSA Waves 4-5 are all lower than the *annual* RCT risks.

A plausible explanation for the observed patterns is recall bias in ELSA falls measurement. It may be that despite the specific wording of the fall-related survey questions in Wave 5, the older respondents are recalling the falls that occurred over the past 12 months or so rather than 24 months, which explains the close correspondence to annual risks from Wave 4. Such recall bias is a prominent methodological issue in falls research [24, 105]. A systematic review of studies on fall-related recall bias found that the sensitivity of retrospective recording at quarterly or longer intervals can be as low as 31% relative to prospective weekly recording [410]. In the UK setting, a recent RCT found that the four-month recall method reported on average 32% fewer falls than prospective monthly recording [411]. Given the above features of ELSA falls data and the likelihood of recall bias, it was deemed reasonable to treat the Waves 4-5 data as *annual* rather than two-year risks. This meant *not* annualising the Waves 4-5 risks and assigning them to the modelled individuals. Even so, a key caveat is that two years, rather than one, have elapsed since Wave 4 which would overestimate the risk transition over time.

##### Risk of any fall

As mentioned, 27.8% of the ELSA Wave 4 cohort reported the incidence of at least one fall of any type at Wave 5 follow-up. Table 5.39 shows the results of the logistic regression for incidence of any fall. See Table E8 for all model-fit comparisons concerning falls risk estimation. Older individuals and women were likelier to experience any fall. Any falls history prior to Wave 4 was associated with increased risk. Recurrent non-MA falls history had a higher coefficient than other fall types. Fear of falling was associated with higher risk.

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| **Table 5.39** Logistic regression coefficients for any fall incidence between ELSA Waves 4 and 5. | | |
| ***Dependent variable: Incidence of any fall (N=6,205)1*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -2.709 (0.297) | <0.001 |
| Age | 0.009 (0.004) | 0.028 |
| Female | 0.187 (0.061) | 0.002 |
| Falls history (ref: No falls history) |  |  |
| *Single non-MA fall* | 0.845 (0.090) | <0.001 |
| *Recurrent non-MA falls* | 1.654 (0.102) | <0.001 |
| *Single MA fall* | 0.657 (0.141) | <0.001 |
| *Recurrent falls with MA* | 0.974 (0.166) | <0.001 |
| Frailty (0-100) | 0.049 (0.010) | <0.001 |
| Frailty^2 | -0.0007 (0.0002) | 0.002 |
| Fear of falling | 0.279 (0.125) | 0.026 |
| Abnormal gait/balance | -0.148 (0.084) | 0.079 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; Ref: reference; SE: standard error  1 Sample restricted to those interviewed in both ELSA Waves 4 and 5. | | |

##### Risk of recurrent fall given any fall

Of those who experienced any fall, 43.2% experienced recurrent falls. Table 5.40 shows the results of logistic regression for incidence of recurrent falls given any fall. Interestingly, older fallers were less likely to be recurrent fallers. Falls history was associated with recurrent falls risk, though the coefficient for single MA fall was not significantly different from zero. Higher frailty score was associated with greater recurrent falls risk at a decreasing rate. Abnormal gait/balance was associated with greater recurrent falls risk.

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| **Table 5.40** Logistic regression coefficients for incidence of recurrent falls given any fall between ELSA Waves 4 and 5. | | |
| ***Dependent variable: Incidence of recurrent falls given any fall (N=1,731)1*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -0.692 (0.494) | 0.161 |
| Age | -0.015 (0.007) | 0.037 |
| Falls history (ref: No falls history) |  |  |
| *Single non-MA fall* | 0.322 (0.151) | 0.033 |
| *Recurrent non-MA falls* | 1.678 (0.151) | <0.001 |
| *Single MA fall* | 0.089 (0.238) | 0.708 |
| *Recurrent falls with MA* | 1.314 (0.262) | <0.001 |
| Frailty (0-100) | 0.089 (0.017) | <0.001 |
| Frailty^2 | -0.001 (0.0004) | 0.001 |
| Abnormal gait/balance | 0.319 (0.143) | 0.026 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; Ref: reference; SE: standard error  1 Sample restricted to those interviewed in both ELSA Waves 4 and 5 who experienced any fall. | | |

##### Risk of MA fall given single or recurrent fall

Single and recurrent fallers likely face differing risks of experiencing at least one MA fall. Therefore, estimation of the risk of being an MA faller given any fall was conducted separately for single and recurrent fallers. Table 5.41 shows the regression coefficients for single fallers, while Table 5.42 shows those for recurrent fallers. The best-fit model for single fallers contained only age, sex, and high physical activity as covariates. Older individuals and women were likelier to experience a single MA fall. High physical activity was associated with *greater* risk, though this was not statistically significant at 95% confidence level. It may be that high-intensity physical activity, despite its health benefits, leaves older persons more susceptible to an injurious fall.

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| **Table 5.41** Logistic regression coefficients for incidence of MA fall given single fall between ELSA Waves 4 and 5. | | |
| ***Dependent variable: Incidence of MA fall given single fall (N=984)1*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -4.636 (0.736) | <0.001 |
| Age | 0.043 (0.009) | <0.001 |
| Female | 0.340 (0.149) | 0.023 |
| High physical activity | 0.366 (0.188) | 0.052 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; Ref: reference; SE: standard error  1 Sample restricted to those interviewed in both ELSA Waves 4 and 5 who experienced a single fall. | | |

Among recurrent fallers, women were likelier to experience at least one MA fall, while the coefficient on age was not significantly different from zero at 95% confidence level. In contrast to single fallers, histories of single MA fall and recurrent falls with MA fall were associated with greater risk of MA fall. Higher frailty was also associated with greater risk at a decreasing rate.

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| **Table 5.42** Logistic regression coefficients for incidence of MA fall given recurrent falls between ELSA Waves 4 and 5. | | |
| ***Dependent variable: Incidence of MA fall given recurrent falls (N=747)1*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -4.159 (0.811) | <0.001 |
| Age | 0.020 (0.010) | 0.063 |
| Female | 0.426 (0.180) | 0.018 |
| Falls history (ref: No falls history) |  |  |
| *Single non-MA fall* | 0.152 (0.268) | 0.570 |
| *Recurrent non-MA falls* | 0.118 (0.207) | 0.570 |
| *Single MA fall* | 0.983 (0.383) | 0.010 |
| *Recurrent falls with MA* | 0.912 (0.310) | 0.003 |
| Frailty (0-100) | 0.091 (0.028) | 0.001 |
| Frailty^2 | -0.002 (0.0006) | 0.002 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; Ref: reference; SE: standard error  1 Sample restricted to those interviewed in both ELSA Waves 4 and 5 who experienced recurrent falls. | | |

Unlike single fallers who experience an MA fall, recurrent fallers can experience multiple MA falls. However, ELSA does not report the number of MA falls. Hence, the proportion of MA fallers who experienced recurrent MA falls was obtained from literature. The falls prevention model Howland (2015) targeted persons aged 65+ in the US who were admitted to ED for MA fall [200]. The model incorporated a parameter from a primary survey that 18% of MA fallers admitted to ED are readmitted for the same cause within one year. Between ELSA Waves 4-5, 7.7% of the cohort experienced at least one MA fall. Of these, 57.7% were single MA fallers, while the other 42.3% were recurrent fallers with one or more MA falls. If 18% of all MA fallers experienced recurrent MA falls – and these individuals are necessarily found among recurrent fallers with one or more MA falls – then calculation shows that 42.6% of those in this group would have experienced recurrent MA falls. This parameter was incorporated without any adjustment since there was no information on its variation (e.g., by frailty).

In Section 5.2.4.2 where access to reactive intervention was parameterised, it was noted that the access rate under UC from ELSA Wave 4 likely represented the proportion of MA fallers who are hospitalised. Hence, this proportion stratified by frailty category – 9.6% for Fit; 23.5% for Mild; 51.7% for Moderate; and 72.7% for Severe – was incorporated in the model to estimate the proportion of (single or recurrent) MA fallers who were hospitalised. For recurrent MA fallers, this proportion was applied again to determine the nature of the second MA fall. Hence, the nature of the first MA fall was assumed not to influence the risk of the second MA fall requiring hospitalisation.

#### 5.2.5.3 Acute QALY loss due to falls

It was discussed in Section 5.2.3.1 that the EQ-5D decrements associated with falls history are unlikely to capture the acute impact of falls. Therefore, this section incorporates the latter separately. Table 5.43 shows the point estimates for acute QALY loss obtained from literature.

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| **Table 5.43** Acute QALY loss associated with fall types. | | |
| **Fall type** | **QALY loss** | **Source reference** |
| Single non-MA fall | 0.012 | Albert (2016) [354] |
| Recurrent non-MA falls | 0.031 | Albert (2016) [354] |
| Non-hospitalized MA fall | 0.040 | Peasgood (2009) [265] |
| Hospitalized MA fall | 0.239 | Peasgood (2009) [265] |
| **Abbreviation:** MA fall: fall requiring medical attention; QALY: quality-adjusted life year | | |

Albert (2016) developed a decision tree model using individual-level data, including EQ-5D values, collected at a quasi-experimental evaluation of multifactorial intervention in the US [354]. The EQ-5D values for control and intervention groups were categorised by the number of falls experienced (none, single or multiple) and all-cause healthcare utilisation frequency over the 12-month follow-up. Control group participants who experienced a single fall and had no healthcare utilisation had an average EQ-5D value 0.024 less than control group participants who experienced no fall or healthcare utilisation. Hence, single non-MA fallers were assumed to experience a non-permanent EQ-5D decrement of 0.024 for the year in which the fall occurs, which is equivalent to a QALY loss of 0.012 if the fall is experienced mid-year. The QALY loss for recurrent non-MA falls was similarly estimated.

As noted, 28.7% of MA falls required hospitalisation. McLean (2015) reported the distribution of fall-related injuries by secondary care utilisation type (requiring vs. not requiring hospital inpatient stay) from a falls prevention RCT [355]. Of all injuries reported (hip fracture, wrist fracture, shoulder fracture, other fracture, head injury, cuts/bruises, other), wrist fracture had the highest likelihood of requiring secondary care but not hospitalisation (87.5%). Hence, it was assumed that the QALY impact incurred by wrist fracture is representative of that incurred by injuries requiring non-hospitalised secondary care. The QALY loss in the first year of wrist fracture was estimated by Peasgood and colleagues who conducted a systematic review and meta-analysis of studies measuring the health utility impact of fractures [265]; the authors estimated a QALY loss of 0.040 over 12 months. For hospitalised MA falls, McLean (2015) reported that hip fracture had the highest likelihood of requiring hospitalisation (100%) relative to other injuries [355]. Hence, the QALY impact of hip fracture was assumed to be representative of injuries requiring hospitalisation; Peasgood and colleagues estimated QALY loss of 0.239 in the first year of hip fracture [265]. For recurrent MA fallers, a simple assumption was made that the relevant QALY losses would be added: e.g., QALY loss of 0.279 was assigned to a person whose first MA fall did not require hospitalisation but the second one did.

#### 5.2.5.4 Economic consequences of falls

Economic consequences directly attributable to falls can be categorised by sector and care type: healthcare – A&E, hospitalisation, ambulatory/community, and rehabilitation; social care – short-term and long-term; and societal – OOP care, informal caregiver burden, and productivity loss. These direct costs complement the comorbidity care costs parameterised in Section 5.2.3.4. Costs of LTC are parameterised separately in Section 5.2.6.2 as part of dynamic transition.

##### Public sector costs

Table 5.44 summarises the direct healthcare costs of MA falls in the year of incidence. Data were obtained from two UK-based models, Franklin (2019) [363] and PHE model [216], that incorporated nationally representative cost estimates. For those who experienced recurrent MA falls, the resource consequences were assumed not to overlap, and their costs were added. Healthcare costs incurred after the year of incidence were incorporated as comorbidity care costs associated with higher frailty.

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| **Table 5.44** Direct healthcare costs of falls in the year of incidence. | | | |
| **Fall type** | **Resource consequence** | **Cost1** | **Source reference** |
| MA fall – not hospitalised | 999 call | £7.77 | [363] |
| Ambulance | £265.96 | [363] |
| A&E only | £157.48 | [363] |
| Rehabilitation2 | £47.57 | [363] |
| **Total** | **£478.78** |  |
| MA fall – hospitalised | 999 call | £7.77 | [363] |
| Ambulance | £265.96 | [363] |
| A&E attendance before hospitalisation | £101.56 | [216] |
| Hospitalisation3 | £9,292.13 | [216] |
| Rehabilitation2 | £81.20 | [216] |
| Geriatric ward4 | £956.36 | [216] |
| **Total** | **£10,704.98** |  |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; SE: standard error  1 All mean unit costs obtained from previous models were inflated to 2021/22 prices using the average annual inflation rate between 2013-19 (1.98%) for healthcare services as reported in PSSRU unit cost depository [401].  2 Rehabilitation costs comprised of costs of GP and outpatient visits weighted by age group-specific probabilities of their need [363]. The probabilities were higher for hospitalised falls – hence the higher average. This was further weighted by proportion of target population in each age group from ELSA to obtain the final weighted average.  3 Hospitalisation costs were originally disaggregated by two types of fall-related injuries that caused hospitalisation: hip fracture vs. other injuries [216]. The weighted average was obtained from the information that 31% of hospitalised falls were caused by hip fracture [216].  4 Only 5.8% of hospitalised falls required long-stay geriatric ward which cost £14,659 per person in 2015/16 price [216]. In the absence of individual-level data on the risk of geriatric ward admission, its expected cost was applied to all hospitalised falls. | | | |

There were some differences in how the two models had parameterised the healthcare costs. First, Franklin (2019) included rehabilitation costs (GP and outpatient visits) for all MA falls, while the PHE model included them for hip fracture only. This model chose the first approach since the PSSRU unit cost repository showed significant care costs – mean of £1,128 excluding inpatient costs – after hospital discharge for any cause [401]. Secondly, the hospitalisation cost was substantially higher in the PHE model: mean of £9,292.13 as in Table 5.44 compared to £3,935.15 in Franklin (2019) (in 2021/22 price). The disparity can be attributed to the differing sources of data for the cost estimates. Franklin (2019) used the weighted average cost of orthopaedic related items recorded in NHS reference costs, while the PHE model drew on cost-of-illness studies that focused specifically on falls and hip fractures [324, 412]. This model chose the second approach because the estimates from the fall-specific cost-of-illness studies are likely more accurate than the average costs for orthopaedic conditions. Finally, the PHE model included the cost of admission to long-stay geriatric wards which was not considered in Franklin (2019). This model followed the PHE model since the ward admission was a separate resource consequence to ambulatory rehabilitation. Having estimated the healthcare costs, ELSA Wave 4 data was used to estimate the annual prevalence of MA falls by frailty category. The expected cost of MA falls by frailty category was then estimated and subtracted from the all-cause primary and secondary care costs to obtain the comorbidity care costs by frailty category in Section 5.2.3.4 (Table 5.18).

The direct healthcare costs estimated here did not include those of district nursing which were included as all-cause community healthcare cost in Section 5.2.3.4. The systematic review in Chapter 4 identified three UK-based economic evaluations that included district nursing as a resource consequence of falls [75, 349, 350]. Of these, two targeted highly specific populations of women requiring cataract surgeries [349, 350], while the third, Sach (2012) [75], targeted older persons requiring an ambulance following a fall. To estimate the district nursing cost *directly* attributable to falls from Sach (2012), the difference in the district nursing cost between intervention and control groups was examined since the intervention group experienced significantly lower number of falls. The intervention group used on average 0.36 less hours of district nursing during the 12-month study at £9.25 cost reduction per person. This amount was considerably smaller than the annual cost of district nursing estimated in Section 5.2.3.4 (£4,809.22), and the 95% confidence interval around the mean cost reduction was very wide (-£352.73 to £307.23). Hence, falls were assumed to incur community healthcare cost only via frailty progression, and no costs were subtracted from the all-cause care cost in Section 5.2.3.4.

##### Societal costs

Sach (2012) also reported costs of short-term social care (home care worker, day centre visits, meals on wheels, and special equipment), OOP care (meals on wheels and home care workers), and informal care (time opportunity cost) [75]. Interestingly, the intervention group incurred on average £381.58 *more* per person for short-term social care, £132.66 *more* for OOP care and £1,303.71 *more* for informal care relative to the control group. A potential explanation is that the multifactorial intervention evaluated by the trial identified previously unrecognised care needs and induced greater care provision. In the absence of evidence, these costs were not directly attributed to falls in the model; and hence no costs were subtracted from the all-cause estimates in Section 5.2.3.4.

### 5.2.6 Dynamic transitions

Following the incidence of some type of non-fatal falls (if any), individuals’ characteristics are updated for the next cycle. First, their frailty scores are updated (Section 5.2.6.1) according to the fall incidence type and current cycle characteristics. Second, the risk and incidence of LTC admission are estimated (Section 5.2.6.2). If the current cycle is the final one, the model concludes at this point, and all individuals exit the model with or without the LTC admission. For non-admitted individuals in non-final cycles, their characteristics are updated for the next cycle (Section 5.2.6.3).

#### 5.2.6.1 Frailty progression

Between ELSA Waves 4-5, the frailty score (range 0-100) increased on average by 2.60 points. If the rate of change is assumed to be constant over the two-year interim, this is equivalent to an annual change of 1.30 points. Table 5.45 shows the coefficient estimates from the best-fit multivariate regression for (two-year) change in frailty. Table E12 in Appendix E shows the results of all model fit comparisons for dynamic transitions.

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| **Table 5.45** Linear regression coefficients for two-year change in frailty (0-100) between ELSA Waves 4 and 5. | | |
| ***Dependent variable: Change in frailty (0-100) (N=6,205)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -5.460 (0.696) | <0.001 |
| Age W4 | 0.134 (0.010) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | 0.089 (0.215) | 0.680 |
| *3rd quartile* | 0.011 (0.184) | 0.951 |
| *Most deprived quartile* | 0.701 (0.219) | 0.001 |
| Falls incidence W5 (ref: No fall incidence) |  |  |
| *Single non-MA fall* | 0.684 (0.227) | 0.003 |
| *Recurrent non-MA falls* | 2.329 (0.261) | <0.001 |
| *Single MA fall* | 1.648 (0.350) | <0.001 |
| *Recurrent falls with MA* | 3.870 (0.412) | <0.001 |
| Frailty W4 (0-100) | -0.198 (0.010) | <0.001 |
| High physical activity W4 | -0.730 (0.192) | <0.001 |
| Cognitive impairment W4 | 0.620 (0.187) | 0.001 |
| Social care receipt W4 | 2.643 (0.589) | <0.001 |
| Informal care receipt W4 | 1.612 (0.202) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; Ref: reference; SE: standard error; SES: socioeconomic status; W4: ELSA Wave 4; W5: ELSA Wave 5 | | |

Older individuals were likelier to experience a higher increase in frailty. Those in the most deprived SES quartile were likelier to experience a higher increase relative to those in the most privileged quartile. Falls incidence of any type between Waves 4-5 had a significant impact on the frailty progression; these associations capture the secondary effects of falls. Frailer individuals at Wave 4 were less likely to experience a faster rate of frailty increase. High physical activity was associated with lower rate of frailty increase, capturing the wider health benefits of exercise that habituates physical activity [135]. Cognitive impairment was associated with higher rate. Interestingly, social and informal care receipts were associated with higher rate of increase. This likely indicates the vulnerability of care recipients that is not wholly captured by frailty.

The estimated change in frailty was halved to obtain the annualised rate. It was then used as an explanatory variable in other longitudinal estimations below. The annualised change was also added to individuals’ pre-change frailty score to obtain the score used in the next cycle.

#### 5.2.6.2 Long-term care admission and cost

This section estimates the likelihood of surviving individuals entering LTC. Due to data limitations, the distinction is not made between fall-related and other-cause LTC admissions; ELSA did not specify the cause of LTC admission. Table 5.46 shows the coefficient estimates from the best-fit logistic regression for the risk of LTC admission between ELSA Waves 4-5. Older individuals were likelier to enter LTC. Falls incidence between Waves 4-5 was in fact excluded from the best-fit model, indicating a weak direct association between falls and LTC admission. Change in frailty was associated with admission risk; falls thus raise the admission risk indirectly via frailty progression. The cognitively impaired were likelier to require LTC. Interestingly, receipts of various forms of care in the community were associated with increased risk. Care receipts are indicators of broader vulnerability that eventually requires permanent institutionalisation.

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| **Table 5.46** Logistic regression coefficients for long-term care admission between ELSA Waves 4 and 5. | | |
| ***Dependent variable: New LTC admission between ELSA Wave 4-5 (N=6,205)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -15.281 (1.919) | <0.001 |
| Age W4 | 0.107 (0.025) | <0.001 |
| Change in frailty1 | 0.061 (0.020) | 0.003 |
| Cognitive impairment W4 | 1.736 (0.413) | <0.001 |
| Community healthcare receipt W4 | 2.376 (0.822) | 0.004 |
| Social care receipt W4 | 1.821 (0.408) | <0.001 |
| OOP care receipt W4 | 1.000 (0.454) | 0.028 |
| Informal care receipt W4 | 1.302 (0.446) | 0.003 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; LTC: long-term care; MA fall: fall requiring medical attention; OOP: out-of-pocket; Ref: reference; SE: standard error; W4: ELSA Wave 4; W5: ELSA Wave 5.  1 Covariate included in logistic regression is two-year change in frailty measured in ELSA. In model simulation, annualised change is used to predict dependent variable. | | |

In applying the estimated admission risk, the estimates were not halved for annualisation in the same way that change in frailty estimates were halved. Instead, estimated coefficients were applied to a one-year increase in age and annualised change in frailty to obtain a ‘quasi-annualised’ risk of LTC admission. According to ELSA, 0.74% of the Wave 4 cohort aged 65+ were newly admitted to LTC in the two years between Waves 4-5. This is equivalent to an annualised risk of 0.37%, while the quasi-annualised risk would lie somewhere between. There are reasons to believe that the latter is a better estimate of the true LTC admission risk than the two-year risk or its annualised version. First, given the high mortality rate in LTC, the true two-year (annual) risk is likely higher than 0.74% (0.37%) since there would have been LTC admissions between Waves 4-5 that are unobservable due to participant deaths prior to Wave 5 follow-up. Secondly, it was noted in Section 5.2.2.1 that ELSA underestimates the prevalence of institutionalisation. Thirdly, according to NHS Digital, there were 365 new requests for Council-supported LTC admission in 2018/19 in Sheffield for persons aged 65+ (sheet T11) [390]; this constitutes 0.4% of the population aged 65+. As also noted in Section 5.2.2.1, publicly funded LTC admissions account for 56.4% of all LTC admissions if the public-private ratio observed for fall-related LTC admissions hold for other causes [216]. If so, new LTC admissions would account for around 0.6% of the population aged 65+: i.e., close to the quasi-annualised risk within the range 0.37-0.74%.

In costing the LTC admission, the PHE model divided the admissions into three categories [216]:

1. 43.6% of LTC admissions are into private care homes and require no full-time nursing care funded by the NHS. All residential costs are self-funded since persons in this category do not meet the condition for local authority financial support: savings/capital of £23,250 or less [404].
2. 40.8% of LTC admissions are into nursing homes with full-time nursing care funded by the NHS. Residential costs are shared by private savings and local authority. The extent of local authority funding is determined by individual means. In England, individuals with savings below £14,250 would qualify for full funding. Those with savings between £14,250 and £23,250 would quality for partial funding [404]. The PHE model used an estimate from literature that the average local authority share of the residential cost is two-thirds while the rest is borne by private expenditure [216].
3. 15.6% of LTC admissions are into residential facilities and require no full-time nursing care. Residential costs are shared by private savings and local authority as for category (2). The PHE model again assumed that the public sector incurs two-thirds of the residential cost [216].

In this model, category (1) admissions are assumed to occur only among those in the most and the second most privileged SES quartiles. According to ELSA, 52.5% of all new LTC admissions occurred among individuals in these quartiles which is a higher number of admissions than category (1) admissions alone (43.6% of all new admissions). Hence, category (2) admissions were assumed to make up the shortfall. If so, category (2) admissions account for 17.0% of all LTC admissions in the upper-half quartiles. Hence, in Table 5.47, 17.0% of LTC residents in the 1st and 2nd SES quartiles require NHS-funded nursing care under category (2) admission. For the other 83.0%, all residential care costs are self-funded and no nursing care costs are incurred.

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| **Table 5.47** Cost and health outcomes in long-term care admission. | | | |
| **Social quartile** | **Publicly funded care component** | **Expected public sector (self-funded) cost1** | **Remaining QALY2** |
| Most privileged | 17.0% need NHS nursing care; 0% of residential care cost | £2,809 (£81,138) | 0.958 |
| 2nd quartile | 17.0% need NHS nursing care; 0% of residential care cost | £2,809 (£81,138) | 0.958 |
| 3rd quartile | 67.2% need NHS nursing care; 50% of residential care cost | £51,673 (£40,569) | 0.958 |
| Most deprived | 67.2% need NHS nursing care; 100% of residential care cost | £92,242 (£0) | 0.958 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; LTC: long-term care; PW: per week; QALY: quality-adjusted life year  1 As in the Public Health England model, the aggregate care cost in LTC is estimated under the assumption that the average life expectancy in LTC is 2.5 years or 130 weeks [216]. The unit costs of nursing and residential care are also taken from Public Health England model: £127.11 per week for nursing care and £624.14 per week for residential care. The 2015/16 prices was updated to 2021/22 prices using the annual NHS pay and price inflation rate of 1.98% for nursing care and social care inflation rate of 2.13% for residential care [401].  2 The aggregate remaining QALY in LTC is estimated under the assumption that the average life expectancy in LTC is 2.5 years. The life-years are weighted by factor 0.383 which is the median EQ-5D of institutionalised respondents in ELSA Wave 4 (see Section 5.2.3.1 for EQ-5D estimation). | | | |

According to the PHE model, the cost of nursing care was £127.11 per week (in 2021/22 price), while the average length of stay at LTC (of all categories) was 2.5 years or 130 weeks. Hence, the expected total nursing care cost for 1st and 2nd social quartile individuals was £2,809 per person. For this subgroup, the total self-funded residential cost is £81,138 per person. ELSA data was used to obtain the median EQ-5D estimate of 0.383 among institutionalised persons. It was assumed that this EQ-5D value applied to all individuals regardless of SES and LTC category. Hence, given the average life expectancy of 2.5 years at LTC entry, the expected remaining QALY is 0.958 for all individuals.

For individuals in the 3rd and 4th (‘bottom-half’) SES quartiles, their LTC admissions are assumed to be of category (2) or (3), with varying level of public support for residential care cost. As mentioned, the PHE model used the empirical finding that around two-thirds of the costs incurred by category (2) and (3) admissions are borne by local authorities. According to ELSA, of all new LTC admissions that occurred for individuals in the bottom-half quartiles, those in the 3rd SES quartile accounted for around 70%, while those in the 4th quartile accounted for the other 30%. If it is assumed that the local authorities on average supported 50% of the residential costs for those in the 3rd quartile and 100% for those in the 4th quartile, then the average level of public funding support is 65%, i.e., close to two-thirds. Based on the ELSA estimate that individuals in the bottom-half quartiles accounted for 47.5% of all new LTC admissions and on the assumption this subgroup accounted for all category (3) admissions and the remaining category (2) admissions not accounted by individuals in the upper-half quartiles, it can be calculated that 67.2% of admissions in the bottom-half quartiles are category (2), while the other 32.8% are category (3). Under these assumptions, the expected cost of LTC stay borne by the public sector is £51,673 for those in the 3rd quartile and £92,242 for the 4th quartile. Those in the 3rd social quartile would self-fund 50% of their residential costs amounting to £40,569.

#### 5.2.6.3 Updated covariates and outcomes

The model incorporates several covariates that change over time. Age and falls history change in certain patterns: age increases by one year, while falls incidence for the cycle becomes falls history for the next. Frailty progression has already been estimated above. Other covariates and outcomes which have significant ‘memories’ (i.e., where its current value strongly influences the value taken in the next cycle) should similarly be estimated prospectively using the longitudinal information contained in ELSA. For illustration, this section reports the results of prospective estimations for: (i) high physical activity; (ii) self-referred exercise demand (under RC); and (iii) change in EQ-5D. Estimations for the following covariates are presented in Appendix E (Tables E13-E21): (1) cognitive impairment; (2) abnormal gait and balance; (3) GP routine contact; (4) paid employment; (5) unpaid work status; (6) change in CASP-19; (7) out-of-pocket care receipt; and (8) informal care receipt.

It would have been feasible to include Wave 5 variables already predicted by the model as explanatory variables in subsequent equations for other Wave 5 variables. However, this would create a strong linear association between Wave 4 and Wave 5 values of the same covariate (i.e., those with significant ‘memories’) included as explanatory variables. The resulting multicollinearity may inflate the standard errors of the affected coefficients. Therefore, explanatory variables were restricted to Wave 4 values (except for Waves 4-5 fall incidence and frailty change). The two-year interim between Waves 4-5 may overestimate the dynamic change occurring for the one-year model cycle. That said, assigning the estimated coefficients to modelled individuals with *annualised* frailty change (a key explanatory variable for all prospective estimations) reduced the extent of overestimation.

##### High physical activity

In ELSA, the proportion of the population engaged in high physical activity fell slightly from 17.3% in Wave 4 to 16.8% in Wave 5. Table 5.48 shows the coefficient estimates from the best-fit logistic regression for high physical activity in Wave 5.

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| **Table 5.48** Logistic regression coefficients for high physical activity in ELSA Wave 5. | | |
| ***Dependent variable: High physical activity in Wave 5 (N=6,205)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | 2.123 (0.453) | <0.001 |
| Age W4 | -0.047 (0.007) | <0.001 |
| Female | -0.226 (0.079) | 0.004 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | -0.065 (0.110) | 0.558 |
| *3rd quartile* | -0.188 (0.096) | 0.051 |
| *Most deprived quartile* | -0.455 (0.130) | <0.001 |
| Frailty W4 (0-100) | -0.051 (0.008) | <0.001 |
| Change in frailty1 | -0.070 (0.009) | <0.001 |
| High physical activity W4 | 2.029 (0.082) | <0.001 |
| Informal care receipt W4 | -0.444 (0.142) | 0.002 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; Ref: reference; SE: standard error; SES: socioeconomic status; W4: ELSA Wave 4; W5: ELSA Wave 5  1 Covariate included in logistic regression is two-year change in frailty measured in ELSA. In model simulation, the annualised change in frailty is used instead to predict dependent variable. | | |

Older age was associated with reduced probability of engaging in high physical activity. Women were less likely to engage in high physical activity, as were those in the most deprived SES quartile. Both Wave 4 frailty score and the change in frailty were associated with the probability. As expected, those who engaged in high physical activity in Wave 4 were likelier to be engaged in Wave 5. Informal care recipients were in vulnerable states that reduced their chance of engaging in high physical activity.

##### Self-referred exercise demand

Demand for self-referred exercise increased from 8.2% in Wave 4 to 10.6% in Wave 5. This may be attributed to the higher proportion of women in Wave 5 (since the cohort is two years older) who are likelier to attend exercise sessions. Table 5.49 shows the coefficient estimates from the best-fit logistic regression for self-referred exercise demand.

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| **Table 5.49** Logistic regression coefficients for self-referred exercise demand in ELSA Wave 5. | | |
| ***Dependent variable: Self-referred exercise demand in Wave 5 (N=6,094)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | -3.211 (0.464) | <0.001 |
| Age W4 | -0.017 (0.006) | 0.010 |
| Female | 0.627 (0.096) | <0.001 |
| Falls incidence W5 (ref: No fall incidence) |  |  |
| *Single non-MA fall* | 0.184 (0.137) | 0.179 |
| *Recurrent non-MA falls* | 0.264 (0.148) | 0.075 |
| *Single MA fall* | 0.371 (0.191) | 0.052 |
| *Recurrent falls with MA* | 0.490 (0.212) | 0.021 |
| Frailty W4 (0-100) | 0.069 (0.015) | <0.001 |
| Frailty^2 W4 | -0.0008 (0.0003) | 0.013 |
| Change in frailty1 | 0.040 (0.007) | <0.001 |
| High physical activity W4 | 0.590 (0.115) | <0.001 |
| Abnormal gait/balance W4 | -0.253 (0.129) | 0.050 |
| OOP care receipt W4 | 0.480 (0.208) | 0.021 |
| Exercise receipt W4 | 1.812 (0.107) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; OOP: out-of-pocket; Ref: reference; SE: standard error; W4: ELSA Wave 4; W5: ELSA Wave 5  1 Covariate included in logistic regression is two-year change in frailty measured in ELSA. In model simulation, the annualised change in frailty is used instead to predict dependent variable. | | |

Older age was associated with lower exercise demand. Women were likelier to demand exercise. Falls incidence types appeared to induce demand, though only the coefficient for recurrent falls with one or more MA fall was statistically significant at 95% confidence level. There was a significant nonlinear association between baseline frailty and demand, while change in frailty was also significantly associated. As in cross-sectional analysis, those already engaged in high physical activity were likelier to demand exercise sessions. Those with abnormal gait/balance were less likely to demand exercise. Those receiving OOP care were likelier to demand exercise, which may suggest that more socially privileged individuals demand self-referred exercise. Finally, those who received it in Wave 4 likelier to receive it again in Wave 5.

##### Change in EQ-5D

The average change in EQ-5D between ELSA Waves 4-5 was -0.014 (95% CInt: -0.020 to -0.008). Table 5.50 shows the coefficient estimates from the best-fit linear regression for between-wave EQ-5D change.

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| **Table 5.50** Linear regression coefficients for change in EQ-5D between ELSA Waves 4 and 5. | | |
| ***Dependent variable: Change in EQ-5D (N=6,205)*** | | |
| **Explanatory variables** | **Coefficient (SE)** | **P-value** |
| Constant | 0.500 (0.025) | <0.001 |
| Age W4 | 0.002 (0.0003) | <0.001 |
| Female | -0.019 (0.005) | <0.001 |
| SES (ref: Most privileged quartile) |  |  |
| *2nd quartile* | -0.019 (0.007) | 0.008 |
| *3rd quartile* | -0.009 (0.006) | 0.162 |
| *Most deprived quartile* | -0.023 (0.007) | 0.002 |
| Falls incidence W5 (ref: No fall incidence) |  |  |
| *Single non-MA fall* | -0.013 (0.008) | 0.081 |
| *Recurrent non-MA falls* | -0.040 (0.009) | <0.001 |
| *Single MA fall* | -0.022 (0.012) | 0.056 |
| *Recurrent falls with MA* | -0.0001 (0.014) | 0.943 |
| Frailty W4 (0-100) | -0.010 (0.0004) | <0.001 |
| Change in frailty1 | -0.014 (0.0004) | <0.001 |
| Abnormal gait/balance W4 | -0.017 (0.007) | 0.016 |
| EQ-5D W4 | -0.739 (0.034) | <0.001 |
| EQ-5D^2 W4 | 0.136 (0.029) | <0.001 |
| **Abbreviation:** ELSA: English Longitudinal Study of Ageing; MA fall: fall requiring medical attention; Ref: reference; SE: standard error; SES: socioeconomic status; W4: ELSA Wave 4; W5: ELSA Wave 5  1 Covariate included in logistic regression is two-year change in frailty measured in ELSA. In model simulation, the annualized change in frailty is used instead to predict dependent variable. | | |

As found for the cross-sectional analysis of EQ-5D level in Table 5.14, older age was in fact significantly associated with a *higher* change in EQ-5D. Women were likelier to experience a lower EQ-5D increase than men. Persons in the second most privileged quartile and the most deprived quartile were likelier to experience lower EQ-5D change than the most privileged. Only the incidence of recurrent non-MA falls was significantly associated with a negative EQ-5D change due to the closer association between more serious fall types and frailty progression. Both baseline frailty and rate of frailty change were associated with EQ-5D change. Abnormal gait/balance had a significant effect on EQ-5D. There was a non-linear relationship between baseline EQ-5D and EQ-5D change.

The estimated EQ-5D changes were not halved in the same way that the estimate change in frailty was halved for annualisation. Instead, estimated coefficients were applied to a one-year increase in age and annualised change in frailty to obtain a ‘quasi-annualised’ EQ-5D change. This assumes that the magnitudes of association between other covariates and EQ-5D change remain the same whether the period is annual or two-year. The change estimates were then added to individuals’ EQ-5D values to update them for the next cycle.

## 5.3 Model validation

According to the 2012 International Society for Pharmacoeconomics and Outcomes Research (ISPOR) guideline on model validation [173], recommended validation practices include the assessments of face, internal, external and cross validities. This section explores three validities of the parameterised falls prevention model: face (Section 5.3.1); internal (Section 5.3.2); and external (Section 5.3.3). Cross validity is assessed in Chapter 6 where results are compared to those of previous models.

### 5.3.1 Face validity

Face validity assessment involves expert assessment of model structure/assumptions, data sources, problem formulation (e.g., model interventions and outcomes), and results [173]. The validator should be independent from the model development and decision-making. In this study, these model aspects were presented to three independent health economic expert modellers in May 2021. The PhD researcher gave an hour-long presentation on the evaluation framework, model overview (Figure 5.1), key parameterisation methods (Section 5.2), and preliminary base case results. Section 5.2 was subsequently reviewed by the expert modellers and both oral and written feedback was received.

The two most substantive issues raised by modellers were: (i) whether annually incoming cohorts are necessary; and (ii) whether more locally sourced and individual-level data are available for all-cause healthcare costs (Table 5.18). Written responses were given to the issues before the face validity was confirmed. First, incoming cohorts are necessary to accurately characterise the resource and cost implications for decision-makers overseeing a geographically defined jurisdiction (rather than a specific cohort), which is the case for Sheffield CCG and SCC. Second, it was acknowledged that there may be nontrivial variation in parameters between national and local settings; the use of nationally representative ELSA data may hence produce locally non-transferable results. But the PhD researcher explained the current unavailability of CCG routine data and how the use of ELSA had been discussed and approved by stakeholders (Section 5.2.1.4). This was accepted as a methodological caveat.

### 5.3.2 Internal validity

Internal validity assessment concerns the accuracy of coding and its consistency with the model’s specifications [173]. For transparency, this study kept the complete documentation of the Simul8 Visual Logic and features alongside written explanations of their purpose (Appendix E). The assessments were independently conducted by another researcher proficient in Simul8 coding. First, each line of model code was verified. Second, coding outputs generated onto an Excel spreadsheet were verified: e.g., prevalence rates of baseline covariates including cognitive impairment should match the rates reported in ELSA. Third, simulation stop commands were placed at activity entry points to ensure that only eligible simulated entities entered. Finally, several scenario analyses verified whether model outcomes varied in a credible fashion in response to parameter changes: e.g., impact of increasing the baseline prevalence of cognitive impairment on other baseline covariates, comorbidity care costs, EQ-5D, productivity and GP routine contact. After these steps, the model’s internal validity was confirmed.

### 5.3.3 External validity

External validity assessment involves the comparison of simulated model outcomes to real-world data [173]. Four outcomes were used for validation: (1) annual falls incidence after 20 model cycles; (2) annual all-cause healthcare cost after 20 model cycles; (3) total fall-related healthcare cost; and (4) life expectancy at age 65. The outcomes were chosen because they are central to the final evaluation outcomes and because comparable external data exist (e.g., UK-based RCTs for falls incidence). For (1)-(2), 20 model cycles were incorporated to allow for long-term dynamic progressions of variables within the model; in the case of less credible dynamic trajectories, the deviations between model and external data would increase with the number of cycles. Twenty rather than 40 cycles also created a balanced mix between initial and incoming cohorts.

Concerning (1), the second column of Table 5.51 describes the characteristics (falls history, cognitive status, and mean age) of control groups of several UK-based RCTs. Comparable model subgroups in the 20th cycle of UC were then identified. The model closely tracked the RCT incidence rates or underpredicted them which would generate a conservative cost-effectiveness estimate of RC versus UC.

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| **Table 5.51** Comparison of falls incidence rates between model simulation and UK falls prevention randomised controlled trial data. | | | | | |
| **#** | **RCT control group characteristics** | **Reference** | **Model subgroup under usual care** | **Falls incidence** | |
| **RCT1** | **Model** |
| 1 | MA falls history; cognitively intact; mean age 78 | [62] | Cohort 2 in 20th model cycle with MA falls history; cognitively intact; mean age 78 | 52.0% | 55.1% |
| 2 | Recurrent non-MA or MA falls history; cognitively intact; mean age 73 | [136] | Cohort 7 in 20th model cycle with recurrent non-MA or MA falls history; cognitively intact; mean age 73 | 85.1% | 53.4% |
| 3 | Non-MA falls history; cognitively intact; mean age 83 | [385] | Cohort 1 in 20th model cycle with non-MA falls history; cognitively intact; mean age 83 | 82.4% | 67.1% |
| 4 | All falls histories; cognitively intact; mean age 78 | [25] | Cohort 2 in 20th model cycle; cognitively intact; mean age 78 | 52.9% | 40.8% |
| 5 | No recurrent non-MA or MA falls history; cognitively intact; mean age 73 | [135] | Cohort 7 in 20th model cycle without recurrent non-MA or MA falls history; cognitively intact; mean age 73 | 31.2% | 34.2% |
| 6 | MA falls history; cognitively impaired; mean age 84 | [384] | Cohort 1 in 20th model cycle with MA falls history; cognitively impaired; mean age 85 | 79.9% | 60.5% |
| 7 | All falls histories; cognitively impaired; mean age 78 | [235] | Cohort 2 in 20th model cycle; cognitively impaired; mean age 78 | 47.0% | 42.0% |
| **Abbreviation:** MA fall: fall requiring medical attention; RCT: randomised controlled trial  1 Falls data for the control group were recorded prospectively at high frequency (e.g., weekly). | | | | | |

Concerning (2), Hazra and colleagues reported the average annual all-cause cost of primary and secondary healthcare in the UK for persons aged 80+ [258]. Inflated to 2021/22 prices, the costs were £4,115 per person for ages 80-84, £4,609 for age 85-89 and £4,475 for ages 90+ years. The corresponding model predictions for the 20th cycle (fall-related and comorbidity primary and secondary healthcare cost without discounting) were £4,137, £4,390 and £4,977. Hence, the model underpredicted the healthcare costs for those aged 85-89 and overpredicted them by around 10% for those aged 90+. The total annual healthcare cost (for primary, secondary, community and NHS-funded nursing home care) for the model population aged 60+ in the 20th cycle was around £431 million, which is around half of the £800 million annual budget of Sheffield CCG (personal communication with PHP). This figure, whilst plausible, is hard to verify since the CCG spending decisions are not delineated by age groups.

Concerning (3), the PHE model had used HES data to estimate the primary and secondary healthcare costs of falls which were deemed representative of UK local health economies by the model’s Steering Group [216]. For Sheffield, the PHE model predicted a two-year fall-related primary and secondary healthcare cost of £7.9 million for 6,300 persons aged 65+ under usual care. The latter were a subgroup (20%) of fallers who would take up the prescribed exercise if offered; the fallers in turn comprised 34% of the Sheffield population aged 65+. Halving the £7.9 million to obtain the one-year cost and using the ELSA prevalence of falls among those aged 60-64, the estimated annual cost for Sheffield population aged 60+ was around £23.1 million. In comparison, the current model predicted total primary and secondary healthcare cost of £20.3 million in the first model cycle when the model population size is similar to that in the PHE model. Over the 40-year horizon under UC, the total discounted fall-related healthcare cost amounted to £658.5 million out of £10,058 million all-cause public sector cost, or 6.5%. It is difficult to verify this proportion, but it can be noted that according to GBD 2019, falls contributed 6.23% of total years lived with disability in England in 2019 for those aged 70+ [408]. If healthcare costs are proportional to the disability burden, the proportion of 6.5% is a high yet plausible figure.

Concerning (4), the average life expectancy for those aged 65 at model baseline was 16.8 years for men and 18.7 for women (including the average 2.5 years spent in LTC for those admitted). By comparison, the ONS estimates using 2017-19 data were 18.8 years for men and 21.1 for women [413]. Hence, the model underpredicts the life expectancy by around two years. This could be partly attributed to the use of ELSA Wave 4 (year 2008) data; between 2008 and 2019 the life expectancy from age 65 improved by around one year for men and women [413]. Nevertheless, the discrepancy motivates the analysis of an alternative scenario involving mortality risks to assess their impact on outcomes (see Section 5.4.2.2).

## 5.4 Model evaluation methods

The model evaluation methods are grouped under two categories: base case comparison between RC and UC, including related subgroup, sensitivity, and scenario analyses (Section 5.4.1); and evaluation of alternative falls prevention intervention scenarios/strategies, followed by commissioning recommendations based on their comparisons (Section 5.4.2).

### 5.4.1 Base case comparison

This section describes the methods for the base case comparison between RC and UC, commencing with the evaluation framework and outcomes (Section 5.4.1.1), then the methods for handling first-order uncertainty from variations in simulated experiences (Section 5.4.1.2). Methods for sensitivity analyses assessing parameter (second-order) uncertainty – probabilistic (Section 5.4.1.3) and deterministic (Section 5.4.1.4) – are described. Subgroup analysis plans are outlined (Section 5.4.1.5), embedded within which is the method for distributional cost-effectiveness analysis (DCEA) to assess the joint efficiency-equity result of base case comparison (Section 5.4.1.6). Scenarios concerning changes to key evaluation framework and falls epidemiology features are evaluated to assess their impact on the base case results (Section 5.4.1.7).

#### 5.4.1.1 Evaluation framework and outcomes

The types of analysis, perspectives, and time horizons were already noted in Section 5.2.1.2. In brief, the primary evaluation framework is CUA under the societal perspective and 40-year horizon. The secondary evaluation framework is ROI under the public sector perspective and five-year horizon. All cost and health outcomes were discounted at an annual rate of 3.5%. Distinction was made between all-cause and fall-related economic consequences as recommended by the expert guideline [105].

For the societal CUA, outcomes generated outside the public sector – productivity, OOP care expenditure, informal caregiver burden, and corresponding intervention costs (e.g., private co-payment) – were converted to net QALY equivalent using the £60,000 per QALY gained cost-effectiveness threshold [161], and then combined with public sector outcomes to derive the societal ICER.

Moreover, several wider outcomes, grouped under two categories, were reported:

1. Clinical and wellbeing endpoints for the whole target population (n=385,192):
   1. Number of fallers and person-years of fall experience of different fall types as recommended by the expert guideline [105];
   2. Number of other-cause mortalities;
   3. Number of LTC admissions;
   4. Aggregate CASP-adjusted life years (CALYs) as a measure of social wellbeing; and
   5. Number of person-years of social participation via volunteering and self-referred intervention uptake as a measure of community empowerment.
2. Individual-level lifetime outcomes tracked for a single group aged 65 at model baseline (n=5,399) who are all deceased or LTC admitted by the final model cycle:
   1. Number of persons achieving ‘fair health-related innings’ [232] – defined as 60% of the median lifetime QALY for this group under UC (the 60% of median threshold parallels the income poverty definition [414]);
   2. Number of persons achieving ‘fair wellbeing-related innings’ – defined as 60% of the median lifetime CALY for this group under UC;
   3. Number of persons achieving ‘productive ageing’ – defined as participating in paid or unpaid work for at least ten years from age 65;
   4. Number of persons in the 3rd and 4th SES quartiles experiencing ‘catastrophic’ private expenditure (including OOP care expenditure and intervention co-payment) – defined as accumulated expenditure exceeding 40% of individuals’ capacity to pay [415], equivalent to £9,300 for 3rd quartile individuals and £5,700 for 4th if they are assumed to have savings of £23,250 and £14,250 respectively (i.e., levels determining LTC public assistance in Section 5.2.6.2); and
   5. Number of persons whose informal caregiver(s) experience ‘excessive’ care burden – defined as accumulated value of informal caregiving exceeding £85,025 which is five times the annual income earned at the national living wage.

#### 5.4.1.2 Deterministic outcomes with first-order uncertainty

In individual-level models, first-order uncertainty arises from variability in the simulated experiences between individuals [416]. The model accounted for this type of uncertainty by re-running each analysis with 20 random number seeds and reporting the average outcome across the runs. The number of 20 was chosen due to constraints on the computational time imposed by the number of base case and scenario analyses. Overall, the deterministic model outcomes (as opposed to probabilistic outcomes) incorporated the impact of first-order uncertainty.

#### 5.4.1.3 Probabilistic sensitivity analysis

Parameter, or second-order, uncertainty arises from sampling errors associated with the parameter point estimates used in analysis [145, 416]. Probabilistic sensitivity analysis (PSA) can be used to assess the joint impact of second-order uncertainties of all incorporated parameters on outcomes [145]. Therefore, for the primary evaluation framework (40-year CUA under the societal perspective), PSA outcomes were presented as the main result. PSA was conducted on the random number seed (‘base seed’) that closely approached the 20-run average.

For the multivariate linear and logistic regressions, estimates were randomly sampled from the joint Normal distribution that had the point estimates reported in Section 5.2 tables as mean values and the estimated variance-covariance matrices as measures of variability (Tables E22.1-E24.14, Appendix E).

For the remaining parameters, Table 5.52 shows their distributional assumptions. Parameters constrained to be positive were assigned Gamma distributions, while those constrained to lie between zero and one were assigned Beta distributions [417]. Intervention efficacy RRs were assigned lognormal distributions [371]. The standard error (SE) expressed the extent of sampling-related uncertainty around a point estimate. Hence, the relative magnitude of SE as a proportion of the mean/point estimate was obtained from existing models identified in Chapter 4. For example, Sach (2007) reported the standard deviation of the annual cost of district nursing (i.e., community healthcare), from which the SE could be derived [349]; this SE was 8.2% of the mean cost of district nursing. The SE/mean proportion of 8.2% corresponded to the shape parameter *k* of value 148.7 for the Gamma distribution. As far as possible, such literature-based information was used to estimate the shape parameters of Gamma and Beta distributions. SEs for efficacy RRs were obtained directly from RCTs. In several cases, the best available information were assumptions made by previous models: e.g., Franklin (2019) assumed that SE for Gamma-distributed LTC cost was 10% of the mean [363].

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| **Table 5.52** Parameter distributions used for probabilistic sensitivity analysis. | | | | |
| **#** | **Parameter** | **Mean** | **Distribution** | **Reference** |
| ***Values and costs*** | | | | |
| 1 | Monetary value of being in paid employment | £24,192 | Gamma (*k* =26.6; ϑ =Mean/*k*)1,2 | [349] |
| 2 | Monetary value of engaging in unpaid work | £5,097 | Gamma (*k* =26.6; ϑ =Mean/*k*)2 | [349] |
| 3 | Comorbidity primary and secondary healthcare costs by frailty category | See Table 5.18 | Gamma (*k* =82.6; ϑ =Mean/*k*) | [349] |
| 4 | Community healthcare cost | £4,809.22 | Gamma (*k* =148.7; ϑ =Mean/*k*) | [349] |
| 5 | Short-term social care cost by frailty category and cognitive status | See Table 5.19 | Gamma (*k* =9.6; ϑ =Mean/*k*) | [349] |
| 6 | OOP care cost by frailty and SES categories | See Table 5.21 | Gamma (*k* =26.6; ϑ =Mean/*k*) | [349] |
| 7 | Informal care cost by single vs. multiple needs | See Table 5.24 | Gamma (*k* =26.6; ϑ =Mean/*k*) | [349] |
| 8 | Public sector cost in final year of life by cause | See Table 5.37 | Gamma (*k* =49.6; ϑ =Mean/*k*) | [363] |
| 9 | Acute QALY loss by fall type | See Table 5.43 | Beta (α for SE around 17% of mean; β derived)3,4 | [365] |
| 10 | Healthcare cost of MA falls by type | See Table 5.44 | Gamma (*k* =25; ϑ =Mean/*k*) | [345] |
| 11 | Long-term care cost by sector and SES | See Table 5.47 | Public sector cost: Gamma (*k* =100; ϑ =Mean/*k*); Societal cost: Gamma (*k* =26.6; ϑ =Mean/*k*) | [349, 363] |
| 12 | Long-term care remaining QALY | 0.958 | Gamma (*k* =50.3; ϑ =Mean/*k*) | [363] |
| ***Probabilities*** | | | | |
| 1 | Probability of accessing community healthcare by frailty category and cognitive status | 0.62% - 9.05% (see Section 5.2.3.4) | Beta (α for SE around 10% of mean; β derived)3 | Assumption |
| 2 | Probability of accessing short-term social care by frailty category and cognitive status | 5.37% - 30.65% (see Section 5.2.3.4) | Beta (α for SE around 10% of mean; β derived) | Assumption |
| 3 | Risk of recurrent MA fall | 42.6% | Beta (α =1.8 for SE around 11% of mean; β derived) | [363] |
| 4 | Probability of MA fall requiring hospitalisation by frailty category | 9.6% - 72.7% (see Section 5.2.5.2) | Beta (α for SE around 16% of mean; β derived) | [355] |
| ***Intervention access, cost and efficacy*** | | | | |
| 1 | Probability of accessing reactive intervention under usual care by frailty category | 9.58% - 72.73% (see Table 5.26) | Beta (α for SE around 16% of mean; β derived)3 | [355] |
| 2 | Demand rate for reactive intervention under recommended care by cognitive status | 53.8%, 49.6% (see Table 5.26) | Beta (α for SE around 10% of mean; β derived) | [361] |
| 3 | Proportion accessing bi-disciplinary (rather than multidisciplinary) reactive intervention | 75% | Beta (α =1.2 for SE around 10% of mean; β derived) | Assumption |
| 4 | Probability of accessing falls risk screening under usual care by frailty category | 23.9% - 43.9% (see Table 5.27) | Beta (α for SE around 10% of mean; β derived) | Assumption |
| 5 | Probability of accessing proactive intervention under usual care by frailty category | 10.9% - 100% (see Table 5.27) | Beta (α for SE around 10% of mean; β derived) | Assumption |
| 6 | Demand rate for proactive intervention under recommended care by cognitive status | 82.4%, 44.5% (see Table 5.27) | Beta (α for SE around 10% of mean; β derived) | [361] |
| 7 | Per-participant (variable) costs of multifactorial interventions | See Table 5.32 | Public sector cost: Gamma (*k* =100; ϑ =Mean/*k*); Societal cost: Gamma (*k* =25; ϑ =Mean/*k*) | [337, 363] |
| 8 | Fixed cost of operating falls clinic | See Table 5.32 | Gamma (*k* =100; ϑ =Mean/*k*) | [337, 363] |
| 9 | Per-participant (variable) costs of self-referred interventions | See Table 5.34 | Public sector cost: Gamma (*k* =100; ϑ =Mean/*k*); Societal cost: Gamma (*k* =25; ϑ =Mean/*k*) | [337, 363] |
| 10 | Intervention efficacies | See Table 5.35 | Lognormal (SE as reported by RCT or derived from 95% CInt) | See Table 5.35 |
| **Abbreviation:** CInt: confidence interval; MA fall: fall requiring medical attention; OOP: out-of-pocket; QALY: quality-adjusted life year; RCT: randomised controlled trial; SE: standard error; SES: socioeconomic status  1 *k* is the shape parameter, and its smaller value means greater skew for the Gamma distribution; ϑ is the scale parameter.  2 No distributional information was found for productivity values. Since Sach (2007)’s informal caregiving cost was estimated using human capital approach [349], its distributional information was assumed to apply to productivity.  3 Both α and β are positive shape parameters; .  4 According to Lee (2013) [365], the SE of utility decrement for MA fall was 17.1% of the mean value. Hence, α was set (and β subsequently derived) such that this SE to mean percentage is realised for all fall types. | | | | |

One thousand model runs were performed after verifying that the average PSA outcomes stabilised at a lower number of runs. For each run, a point estimate of each parameter was randomly drawn from the parameter distribution using Monte Carlo simulation. Evaluation outcomes were computed for each run and stored. The incremental cost and societal QALY estimates were plotted on a scatter graph. The percentage of model runs in which RC is cost-effective relative to UC at the £30,000 per QALY gained threshold was reported. How this percentage varies by threshold level was explored by plotting the cost-effectiveness acceptability curve (CEAC).

#### 5.4.1.4 Deterministic sensitivity analysis

Deterministic sensitivity analysis (DSA) was used to understand the largest drivers of model results. Each parameter was altered to their 2.5th or 97.5th centile values drawn from the distributions assigned for PSA whilst other parameters were kept at their mean values. Single parameter changes can also be employed in case of major non-linearity under parameter uncertainty, whereby the average outcome under PSA is substantially different from the deterministic outcome. In this case, each parameter would be altered to their 2.5th or 97.5th centile values whilst all other parameters are jointly varied under PSA.

#### 5.4.1.5 Subgroup analysis

For subgroup analyses under the base case analysis, the following delineating characteristics were considered: (a) initial cohort aged 60+ at baseline vs. new entry cohorts aged 60 at model entry; (b) five-year age group at entry; (c) sex; (d) SES quartile; (e) frailty category at entry; (f) physical activity status at entry; (g) cognitive status at entry; (h) fear of falling status at entry; (i) gait/balance status at entry; and (j) falls history type at entry. Further heterogeneity in model outcomes was explored under targeting strategies as alternative intervention scenarios (see Section 5.4.2.3).

#### 5.4.1.6 Distributional cost-effectiveness analysis

Outcome differences across two subgroup characteristics were deemed ‘unfair’: SES quartile and frailty category at entry. DCEA was used to jointly consider the efficiency and equity impacts of RC relative to UC [109], where equity is defined as reducing the relative or absolute outcome gap across SES quartiles and frailty categories. Here, the outcome of interest is the per-capita societal net health benefit (NHB) – i.e., QALY plus QALY-equivalent of net societal gains, net resource opportunity cost translated to QALY equivalent using the cost-effectiveness threshold – that accrue to each subgroup.

The equally distributed equivalent (EDE) level of societal NHB is calculated for each intervention strategy (e.g., UC, RC) using the following formulae (1) and (2) for relative and absolute inequality aversion, respectively [109]:

*NHBi* is the per-capita societal NHB for subgroup *i* amongst *n* = 4 subgroups for both SES and frailty category. Atkinson index *ε* and Kolm index *α* depict the strength of relative and absolute inequality aversions, respectively, where higher values denote greater aversion. A stylised example in conducting DCEA is shown in Table 5.53.

|  |  |  |  |
| --- | --- | --- | --- |
| **Table 5.53** Stylised example of distributional cost-effectiveness analysis. | | | |
| **Inequality aversion indices** | **Strategy A** | **Strategy B** | **Incremental (B-A)** |
| Societal mean NHB (no inequality aversion mean) | 4.00 | 4.25 | 0.25 |
| Societal Atkinson EDE NHB (ε=0) | 4.00 | 4.25 | 0.25 |
| Societal Atkinson EDE NHB (ε=3) | 3.90 | 4.10 | 0.20 |
| Societal Atkinson EDE NHB (ε=5) | 3.70 | 3.80 | 0.10 |
| Societal Atkinson EDE NHB (ε=11) | 3.30 | 3.30 | 0 |
| Societal Atkinson EDE NHB (ε=12) | 3.20 | 3.10 | -0.10 |
| Societal Atkinson EDE NHB (ε=30) | 3.10 | 2.90 | -0.20 |
| Societal Kolm EDE NHB (α=0.025) | 3.90 | 4.10 | 0.20 |
| Societal Kolm EDE NHB (α=0.05) | 3.80 | 3.90 | 0.10 |
| Societal Kolm EDE NHB (α=0.15) | 3.70 | 3.70 | 0 |
| Societal Kolm EDE NHB (α=0.5) | 3.50 | 3.40 | -0.10 |
| **Abbreviation:** EDE: equally distributed equivalent; NHB: net health benefit | | | |

Taking a simple average of the per-capita societal NHBs of subgroups (e.g., SES quartiles) produces a societal mean NHB of 4.00 under strategy A and 4.25 under strategy B. These are strategy-specific outcomes under no inequality aversion (or Atkinson index ε=0). They generate an incremental outcome of 0.25: i.e., strategy B is cost-effective relative to strategy A, producing an additional 0.25 societal NHB per capita (averaged across SES quartiles). This amount is referred henceforth as the ‘incremental no-aversion mean’. The decision-maker interested in efficiency alone would choose B over A.

Now suppose there exist unequal distributions of per-capita societal NHBs SES quartiles under both strategies. Under any inequality aversion parameter ε or α above zero, this results in EDE levels of societal NHB which are always *below* the societal mean NHB for both strategies and falling further as the inequality aversion parameter increases. Suppose also that strategy B *worsens* the inequality relative to A. This results in the EDE level falling below the societal mean NHB at a faster rate under strategy B than A as the inequality aversion parameter increases: e.g., from 4.00 to 3.30 at ε = 11 under strategy A (decline of 0.70) compared to from 4.25 to 3.30 under strategy B (decline of 0.95).

This also means that the *incremental* EDE level of NHB in the last column (referred henceforth as EDE INHB) falls below the incremental no-aversion mean of 0.25 as the inequality aversion parameters ε and α increase. The EDE INHB reaches zero at ε = 11 and α = 0.15. At any higher aversion levels, the decision-maker would choose strategy A over B due to the equity loss, despite the efficiency gain from B. At lower aversion levels, B would still be chosen despite the equity-efficiency trade-off.

Another possibility is that strategy B in fact *reduces* SES-delineated inequality relative to A, as well as improving efficiency; i.e., there is no equity-efficiency trade-off. This would be characterised by EDE INHBs being *higher* than the incremental no-aversion mean across the spectrum of inequality aversion parameters. Hence, when both the incremental no-aversion mean and the EDE INHB are above zero, a ratio or proportion of EDE INHB relative to incremental no-aversion mean can indicate the presence/absence of the trade-off: a proportion higher than one indicates its absence and below one its presence. Moreover, a greater magnitude of equity gain or loss produces a proportion further above or below one, respectively.

DCEA was also applied to scenario analyses around evaluation framework and falls epidemiology features and alternative falls prevention strategies, with a particular focus on SES-delineated health inequality. In the absence of Atkinson and Kolm index estimates representing the inequality aversion levels of Sheffield decision-makers, both indices were set by default at the top end of the ranges explored in the DCEA tutorial [109], namely Atkinson ε = 30 and Kolm α = 0.5, when interpreting the joint equity-efficiency impact. This approach estimates the maximum potential change in outcomes and decisions under the joint consideration of equity and efficiency. That said, outcomes under different indices are also presented graphically.

#### 5.4.1.7 Evaluation framework and falls epidemiology scenarios

The two evaluation framework scenarios most frequently considered by previous models were variations in time horizon and discount rates (Table D8 in Appendix D). Model outcomes were hence explored under 5-, 10-, 15-, 20- and 30-year horizons and under discount rates of 0% and 6%.

The following four falls epidemiology scenarios were explored:

(1) *Removing the falls-frailty feedback loop*. Here, the link between falls and frailty was removed in the dynamic frailty progression. This was done by re-estimating the multivariate linear regression for change in frailty in Table 5.45 without categorial falls incidence as an explanatory variable. The scenario removed the secondary effects of falls on model outcomes via frailty.

(2) *Frailty reduction*. This scenario encompassed two sub-scenarios where individuals’ frailty levels were reduced at different junctures: (i) initial frailty levels reduced by 20% at model entry; and (ii) the rate of frailty progression between cycles reduced by 20%. Sub-scenario (i) reduced individuals’ epidemiological risk factors (e.g., cognitive impairment, abnormal gait/balance) at model entry and may correspond to earlier life morbidity prevention, an important strategy for improving geriatric health (Section 1.3.2.3). Sub-scenario (ii) altered the epidemiological transition during old age and may correspond to the combined effects of other geriatric public health interventions. Overall, this scenario explored whether and how falls prevention integrates with other life-course and geriatric preventions that generate epidemiological changes.

(3) *Higher life expectancy*. Other-cause mortality risks across all subgroups (age, sex, and frailty category) were reduced by 20% to generate the higher life expectancy. This addressed the concern that the model underpredicts the life expectancy (Section 5.3.3) while exploring the impact of a continued rise in life expectancy among older populations.

(4) *Reduction in other-cause mortality risk gap across frailty categories*. The mortality hazard ratios delineated by frailty category were reduced by 20%. This did not alter the average mortality risk but its gradient across frailty category; it would correspond to improved general care for frailer individuals. Moreover, it reduced the life expectancy differential across subgroups, a key source of disadvantage for frailer subgroups (and socially vulnerable subgroups containing high proportions of frailer individuals). Therefore, the equity impact of this epidemiological change is of interest.

### 5.4.2 Alternative falls prevention strategies and commissioning recommendations

Potential alternative intervention scenarios/strategies informed by the conceptual model in Section 3.7.4 and practices of previous models (Section 4.5.4.3) are described (Section 5.4.2.1). Plan for conducting a full comparison of intervention strategies and formulating commissioning recommendations is outlined (Section 5.4.2.2).

#### 5.4.2.1 Falls prevention intervention scenarios

The following five falls prevention intervention scenarios were explored:

(1) *Pathway contributions*. The cost-effectiveness and wider benefits of individual pathways within RC – reactive, proactive, and self-referred – as well as combinations of two pathways were explored. This would inform which specific pathway(s) should be prioritised.

(2) *Capacity constraints and targeting*. There are concerns over the capacity implications of RC. As noted, RC requires seven falls clinics for 21,000 clients per year (Section 5.2.4.3). But it may be that no new venues and staff can be found besides the current falls clinic and two teaching hospitals in Sheffield. If so, a more feasible annual clinic client flow under ‘constrained recommended care’ (CRC) is 9,000, equivalent to operating the three venues full-time. This encompasses client flows from the reactive pathway (cognitively intact clients not receiving the bi-disciplinary intervention and cognitively impaired clients) and the proactive pathway (cognitively intact persons referred as high falls risk). No constraint is assumed for bi-disciplinary reactive intervention for cognitively intact clients. A potential limit to annual self-referred client number is 2,000, equivalent to operating 100 exercise sessions concurrently with 20 clients per session (according to personal communication with Dance to Health operator). Cognitively impaired clients referred to Tai Chi under the proactive pathway would face a similar venue constraint. It is assumed that this is limited to 500 clients per year.

Given the constraints, different targeting/rationing strategies are evaluated that determine the access to falls clinic and proactive Tai Chi: (1) random allocation; (2) no repeated intervention for clients with intervention history; (3) targeting the moderately and severely frail; and (4) targeting based on the predicted falls risk. For (3)-(4), the targeting mechanisms are added to the existing falls risk screening process at GP contact. The mechanisms are assumed to incur the same per-capita cost as the GP screening. Targeting under the self-referred pathway is assumed infeasible since the pathway relies on voluntary participation rather than professional screening and referral.

(3) *Economic value of community contributions*. Community assets play a key role in implementing geriatric public health interventions and their involvement was envisaged in Sheffield’s AS&R scheme. Value of implementation analyses can evaluate the economic value of hypothetical community involvement schemes. The QTUG pathway in Sheffield involved community organisations in falls risk screening (Section 3.7.1.2), while the qualitative research participants in Chapter 2 described the importance of community marketing in raising demand for self-referred exercise. Hence, additional investments in these two implementation areas are evaluated under three scenarios: (a) community falls risk screening to initiate the proactive pathway for 50% of persons not receiving GP contact; (b) community falls risk screening for persons in 3rd and 4th SES quartiles not receiving GP contact; and (c) increasing demand for self-referred intervention by 20%. The willingness to pay for each scheme is estimated by comparing the efficiency outcomes to the most favourable CRC scenario.

(4) *Double jeopardy problem*. This scenario explored the impact of a double jeopardy problem where societal intervention costs (time opportunity cost, private co-payment, and informal caregiver time opportunity cost) reduce the intervention demands of those in the 3rd and 4th SES quartiles and thereby further disadvantage these vulnerable subgroups. A follow-up scenario is where their demands are restored after the societal intervention costs for the 3rd and 4th SES quartiles are covered by the public sector. Thus, this scenario explores the integration between falls prevention and further public policies designed to remove extrinsic barriers to vulnerable older persons’ health promotion.

(5) *Environmental intervention*. The qualitative data in Chapter 2 highlighted the key influences of public environments on falls risk and prevention. Unsafe public environments have high levels of falls hazards, while age-friendly environments can promote physical activity. Two previous models showed that combined multifactorial and environmental interventions are highly cost-effective [127, 128], but did not investigate the interactions between the components. It is possible that highly successful environmental interventions make professional-led interventions less cost-effective or redundant. Hence, investigation of the synergy between environmental and clinical interventions is warranted.

#### 5.4.2.2 Strategy comparison and commissioning recommendations

The intervention scenario analyses will be followed by a full comparison of all intervention strategies (including RC) under both 40-year societal CUA and five-year public sector ROI. Optimal intervention strategies and associated commissioning recommendations will be formulated based on efficiency, equity (i.e., results of DCEA), aggregate impact on budget, feasibility (e.g., of environmental modifications), and wider individual-level outcomes. ‘No intervention’ (i.e., withdrawal of UC) was not considered as a strategy option based on the Sheffield falls specialist geriatrician’s opinion that the current therapy-based services are considered as routine care regardless of cost-effectiveness (Document 9 in Appendix B).

## 5.5 Chapter summary

This chapter parameterised the final implemented falls prevention model, validated it, and set out the methods for its analysis in Chapter 6. Methodological strengths and limitations of the model will be discussed in Chapter 6 after the model results are presented.

# Chapter 6. Falls Prevention Economic Model Results

## 6.1 Chapter outline

This chapter presents the results of the falls prevention model analysis then critically appraises the model’s strengths and limitations. Section 6.2 presents the base case comparison results that assess the performance of RC (representing the strategy recommended by UK guidelines) relative to UC (representing the current practice in Sheffield). The section includes the results of subgroup, sensitivity, and scenario analyses conducted around the base case comparison for robustness. Section 6.3 presents the evaluation results for alternative falls prevention strategies, followed by the results of a full comparison of all strategies including RC. It concludes with commissioning recommendations based on the full comparison. Section 6.4 discusses the implications of model results, including a comparison between the model’s commissioning recommendations and those derived from previous models identified by the systematic review in Chapter 4. The section also discusses the model’s strengths and limitations. Section 6.5 concludes the chapter.

## 6.2 Base case comparison results

For the base case comparison, deterministic outcomes that incorporate first-order uncertainty are presented (Section 6.2.1), followed by assessment of the impact of parameter uncertainty using probabilistic sensitivity analysis (Section 6.2.2) and deterministic sensitivity analysis (Section 6.2.3). The subgroup results are then presented, including the results of DCEA delineated by SES quartile and frailty category (Section 6.2.4). Results from scenario analyses around evaluation framework and falls epidemiology features are then reported (Section 6.2.5).

### 6.2.1 Deterministic outcomes with first-order uncertainty

Deterministic outcomes are presented as follows: societal CUA outcomes over 40-year horizon (Section 6.2.1.1), and wider outcomes (Section 6.2.1.2); and public sector ROI outcomes over five-year horizon (Section 6.2.1.3).

#### 6.2.1.1 Cost-utility analysis under societal perspective and 40-year horizon

Table 6.1 presents the societal CUA outcomes over 40-year horizon. The total target population size over the horizon was 385,192 individuals. To account for first-order uncertainty, all outcomes were averaged across 20 model trial runs with different random number seeds.

|  |  |  |  |
| --- | --- | --- | --- |
| **Table 6.1** Base case cost-utility analysis under societal perspective and 40-year horizon: deterministic outcomes with first-order uncertainty. | | | |
| N=385,192 | **Usual care** | **Recommended care** | **Incremental** |
| **Public sector outcomes1** | | | |
| Public sector costs |  |  |  |
| *(1) All-cause public sector economic costs2* | £10,054,093,186 | £9,926,870,581 | -£127,222,605 |
| *(2) Fall-related primary and secondary healthcare costs* | £658,423,877 | £553,040,517 | -£105,383,360 |
| *Public sector intervention costs* | £35,382,108 | £432,377,703 | £396,995,595 |
| *Net incremental cost with (1)* |  |  | £269,772,990 |
| *Net incremental cost with (2)* |  |  | £291,612,235 |
| QALY | 2,086,925 | 2,106,495 | 19,570 |
| Public sector ICER using net incremental cost with (1) |  |  | £13,785 per QALY gained |
| Public sector ICER using net incremental cost with (2) |  |  | £14,901 per QALY gained |
| **Societal outcomes** | | | |
| Productivity |  |  |  |
| *Productivity value3* | £12,898,045,513 | £12,950,951,021 | £52,905,508 |
| *Intervention TOC* | £1,246,430 | £42,481,862 | £41,235,432 |
| *Net productivity gain* |  |  | £11,670,076 |
| *Net productivity gain, QALY equivalent* |  |  | 195 QALYs |
| Personal finance |  |  |  |
| *OOP care expenditure4* | £2,459,655,286 | £2,416,466,801 | -£43,188,485 |
| *Intervention private co-payment* | £9,206,557 | £76,117,768 | £66,911,211 |
| *Net personal finance cost* |  |  | £23,722,726 |
| *Net personal finance cost, QALY equivalent* |  |  | -395 QALYs |
| Informal caregiver burden |  |  |  |
| *Informal caregiving cost* | £14,792,446,041 | £14,646,146,819 | -£146,299,222 |
| *Intervention caregiver TOC* | £354,099 | £51,827,969 | £51,473,870 |
| *Net informal caregiver cost* |  |  | -£94,825,352 |
| *Net informal caregiver cost, QALY equivalent* |  |  | 1,580 QALYs |
| Societal gain, QALY equivalent |  |  | 1,380 QALYs |
| **Societal ICER using (1)** |  |  | **£12,877 per QALY gained** |
| **Societal ICER using (2)** |  |  | **£13,920 per QALY gained** |
| **Societal INMB using (1)5** |  |  | **£358,708,621** |
| **Societal INMB using (2)** |  |  | **£336,869,376** |
| **Abbreviation:** ICER: incremental cost-effectiveness ratio; INMB: incremental net monetary benefit; LTC: long-term care; OOP: out-of-pocket; QALY: quality-adjusted life year; TOC: time opportunity cost  1 All outcomes were averaged across 20 model trial runs with different random number seeds.  2 Includes costs of fall-related primary and secondary healthcare, comorbidity primary and secondary healthcare, cost of dying, community healthcare, short-term social care, and all-cause long-term care funded by the public sector.  3 Includes paid employment and unpaid work/volunteering.  4 Includes OOP care expenditure and privately incurred LTC cost.  5 Incremental net monetary benefits are estimated using the cost-effectiveness threshold of £30,000 per QALY gained. | | | |

Over the 40-year horizon, the all-cause public sector care costs reduced by RC relative to UC amounted to £127.2 million, and the fall-related primary and secondary healthcare costs £105.4 million. The additional intervention cost amounted to £397.0 million, generating net incremental public sector costs of £269.8 million and £291.6 million when all-cause care costs and fall-related costs were used as cost outcomes, respectively. RC generated 19,570 additional QALYs relative to UC. Hence, the public sector ICERs were £13,785 and £14,901 per QALY gained when all-cause care costs and fall-related costs were used as cost outcomes, respectively.

Regarding societal outcomes, RC raised the total productivity value by £52.9 million; the additional intervention time opportunity cost (TOC) under RC relative to UC was worth £41.2 million. Hence, there was a net productivity gain of £11.7 million which was equivalent to 195 QALYs using the societal cost-effectiveness threshold of £60,000 per QALY gained. RC reduced OOP care expenditure by £43.2 million but this was outweighed by additional intervention private co-payment of £66.9 million relative to UC; the net personal finance impact was negative at £23.7 million, equivalent to 395 QALYs lost. By contrast, RC produced a net positive reduction in informal caregiver cost worth £94.8 million, equivalent to gain of 1,580 QALYs. The overall net societal outcome amounted to 1,380 QALYs gained. Accounting for this generated societal ICERs of £12,877 and £13,920 per QALY gained with all-cause care costs and fall-related costs, respectively.

Therefore, RC is cost-effective relative to UC over the 40-year horizon under public sector and societal perspectives if the NICE cost-effectiveness threshold of £30,000 per QALY gained is adopted. Under this threshold, the total societal INMB of RC relative to UC was around £358.7 million when all-cause costs were considered. In health-equivalent terms, the INHB was 11,957 QALYs. This was equivalent to £932.3 INMB and 0.031 INHB per person. The outcome variations across trial runs were modest, with the lowest societal ICER (accounting for all-cause care costs) of £12,084 per QALY gained and the highest of £15,196 per QALY gained, and standard deviation of £655.

#### 6.2.1.2 Wider outcomes under societal perspective

This section presents the wider outcomes from the base case 40-year societal analysis. Figure 6.1 shows the number and percentage change in the person-years of non-fatal fall episode by fall type under the base case analysis (averaged across 20 trial runs). Episodes of recurrent falls experienced the largest decrease of 18.3%, followed by the 14.7% decrease in the number of hospitalised fall episodes.

**Figure 6.1** Number and change in person-years of non-fatal fall episode by type under base case analysis. **Abbreviation:** MA fall: fall requiring medical attention.

The reduction in the number of fatal falls was limited, decreasing from 2,183 in UC to 2,174 in RC, constituting a 0.4% reduction. The number of other-cause deaths decreased from 198,072 in UC to 197,720 in RC (0.2% reduction), while the number of LTC admissions decreased from 51,701 to 51,134 (1.1% reduction). Regarding social wellbeing, the aggregate CASP-adjusted life year (CALY) gains increased from 2,046,857 in UC to 2,058,829 in RC (0.6% increase). Regarding social mobilisation, there were 1,454,734 person-years of participation in volunteering and/or self-referred intervention in UC, which increased to 1,974,535 person-years in RC (35.7% increase). The person-years of participation among those in the 3rd and 4th SES quartiles increased from 611,610 to 858,335 (40.3% increase), showing that the participatory benefit of RC relative to UC is proportionally higher among the socially deprived.

Table 6.2 compares the individual-level lifetime outcomes between UC and RC for the group aged 65 at model baseline (n=5,399). Overall, changes in individual-level lifetime outcomes had modest magnitudes. The numbers of persons achieving health- and wellbeing-related ‘fair innings’ in RC relative to UC increased by 0.8% and 0.5% respectively. The number of persons achieving productive ageing saw the largest change, increasing by 2.7%. The number of persons in the 3rd and 4th SES quartiles experiencing catastrophic private expenditure *increased* by 1.8%. But the number declined by 0.9% when intervention private co-payments were excluded, implying the net increase in the catastrophic expenditure incidence can be attributed to co-payments. This suggests that RC should be supplemented by policies reducing the co-payments of the socially vulnerable groups. The incidence of excessive informal caregiver burden declined slightly by 0.8%.

|  |  |  |  |
| --- | --- | --- | --- |
| **Table 6.2** Comparison of individual-level lifetime outcomes for the group aged 65 at baseline (n=5,399) under the base case 40-year societal cost-utility analysis. | | | |
| **Outcomes1,2** | **Usual care** | **Recommended care** | **Incremental (% change)** |
| Persons achieving ‘fair health-related innings’3 | 4,415 | 4,450 | 35 (0.8) |
| Persons achieving ‘fair wellbeing-related innings’4 | 4,482 | 4,504 | 22 (0.5) |
| Persons achieving ‘productive ageing’5 | 622 | 639 | 17 (2.7) |
| Catastrophic private expenditure (CPE)6 |  |  |  |
| *Persons experiencing CPE* | 553 | 563 | 10 (1.8) |
| *Persons experiencing CPE, excluding intervention private co-payment* | 550 | 545 | -5 (-0.9) |
| Excessive informal care burden7 |  |  |  |
| *Persons experiencing excessive informal care burden* | 1,753 | 1,738 | -14 (-0.8) |
| *Persons experiencing excessive informal care burden (excluding intervention caregiver TOC)* | 1,753 | 1,729 | -24 (-1.4) |
| **Abbreviation:** CALY: CASP-adjusted life year; LTC: long-term care; MA fall: fall requiring medical attention; OOP: out-of-pocket; QALY: quality-adjusted life year; SES: socioeconomic status; TOC: time opportunity cost.  1 All outcomes were averaged across 20 model trial runs with different random number seeds.  2 Comparison was restricted to those aged 65 at first model cycle to track their lifetime outcomes (all persons were deceased or LTC admitted by the 40th model cycle under both usual care and recommended care scenarios).  3 ‘Fair health-related innings’ is defined as 60% of the median lifetime QALY calculated from those aged 65 at baseline under usual care, which was 5.577.  4 ‘Fair wellbeing-related innings’ is defined as 60% of the median lifetime CALY calculated from those aged 65 at baseline under usual care, which was 5.559.  5 ‘Productive ageing’ is defined as participating in paid or unpaid work for at least ten years from age 65.  6 Private expenditure includes OOP care expenditure, private LTC cost and intervention private co-payments. ‘Catastrophic expenditure’ is defined as lifetime expenditure exceeding 40% of individuals’ capacity to pay, equivalent to £9,300 for 3rd SES quartile individuals and £5,700 for 4th if they are assumed to have savings of £23,250 and £14,250 respectively.  7 ‘Excessive informal care burden’ is defined as lifetime value of informal caregiving exceeding £85,025 which is five times the annual income earned at the national living wage. The burden includes informal caregiving cost and intervention time opportunity cost incurred by informal caregiver. | | | |

#### 6.2.1.3 Return on investment under public sector perspective and five-year horizon

Table 6.3 presents the public sector ROI outcomes over five-year horizon. The total target population size over the horizon was 152,138.

|  |  |  |  |
| --- | --- | --- | --- |
| **Table 6.3** Base case return on investment under public sector perspective and five-year horizon. | | | |
| N=152,138 | **Usual care** | **Recommended care** | **Incremental** |
| ***Total cost outcomes1*** |  |  |  |
| (1) All-cause public sector care costs2 | £1,849,611,631 | £1,829,897,263 | -£19,714,368 |
| (2) Fall-related primary and secondary healthcare costs | £101,303,106 | £85,069,262 | -£16,233,844 |
| Public sector intervention costs | £6,516,944 | £89,739,906 | £83,222,962 |
| **ROI using net cost with (1)** |  |  | (£) 1:0.24 |
| **ROI using net cost with (2)** |  |  | (£) 1:0.20 |
| **Abbreviation:** ROI: return on investment  1 All outcomes were averaged across 20 model trial runs with different random number seeds.  2 Includes costs of fall-related primary and secondary healthcare, comorbidity primary and secondary healthcare, cost of dying, community healthcare, short-term social care, all-cause long-term care | | | |

The public sector intervention cost was higher by £83.2 million under RC relative to UC. This investment generated all-cause care cost saving of £19.7 million and fall-related healthcare cost saving of £16.2 million. The ROI was hence around 1:0.24 when savings in terms of all-cause care costs were considered and 1:0.20 when only fall-related healthcare costs were; in other words, for every £1 spent on RC from initial UC, 24p and 20p would be returned depending on the costs considered. Therefore, RC does not produce a break-even public sector financial return relative to UC over five years.

### 6.2.2 Probabilistic sensitivity analysis

This section conducts PSA to assess the joint impact of uncertainty around all major model parameters, specifically the impact on 40-year societal CUA. To isolate the impact of second-order parameter uncertainty, PSA was conducted on the ‘base’ trial run (i.e., random number seed) that produced societal 40-year CUA outcomes closest to the average of the 20 trials. The average societal ICER (considering all-cause costs) stabilised after around 600 PSA runs (see Figure F1 in Appendix F), thus justifying the conduct of 1,000 PSA runs in total.

Table 6.4 shows the PSA results. Relative to the deterministic outcomes in Table 6.1, there was a decrease in the net societal gain equivalent to around 500 QALYs and a net loss in productivity. The jack-knife mean, used to account for bias in averaging ratios [418], of societal ICER considering all-cause costs was £14,067 (95% uncertainty interval: £12,011 to £15,923) per QALY gained.

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| **Table 6.4** Probabilistic outcomes of base case 40-year societal cost-utility analysis. | | | |
| N=385,192 | **Usual care** | **Recommended care** | **Incremental** |
| Public sector costs1 | Mean (SE) | Mean (SE) | Mean (SE) |
| *(1) All-cause public sector costs2* | £10,060,099,947 (£99,415,713) | £9,936,609,337  (£98,628,205) | -£123,490,610  (£5,909,603) |
| *(2) Fall-related healthcare costs* | £663,114,733  (£28,095,762) | £560,737,568  (£23,700,572) | -£102,377,165  (£5,504,016) |
| *Public sector intervention costs* | £33,992,444  (£2,186,958) | £430,663,194  (£8,281,037) | £396,670,750  (£7,888,734) |
| QALY | 2,091,707  (10,224) | 2,110,653  (10,238) | 18,946  (499) |
| Societal outcomes |  |  |  |
| *Net productivity3* |  |  | -£2,072,031  (£1,327,648) |
| *Net private expenditure4* |  |  | £21,821,270  (£1,543,638) |
| *Net informal caregiving cost5* |  |  | -£87,984,465  (£8,660,865) |
| Societal gain, QALY equivalent |  |  | 1,068 QALYs |
|  |  |  | **Jack-knife mean (95% UI)6** |
| **Societal ICER using (1)7** |  |  | £14,067 per QALY gained  (£12,011 - £15,923) |
| **Societal ICER using (2)** |  |  | £15,149 per QALY gained  (£13,193 - £17,006) |
|  |  |  | **Mean (95% UI)8** |
| **Societal INMB using (1)** |  |  | £327,260,886  (£286,031,713 - £368,490,059) |
| **Societal INMB using (2)** |  |  | £295,215,304  (£261,690,664 - £328,739,943) |
| **Abbreviation:** ICER: incremental cost-effectiveness ratio; INMB: incremental net monetary benefit; LTC: long-term care; OOP: out-of-pocket; QALY: quality-adjusted life year; SE: standard error; UI: uncertainty interval.  1 All outcomes were averaged across 20 model trial runs with different random number seeds.  2 Includes costs of fall-related primary and secondary healthcare, comorbidity primary and secondary healthcare, cost of dying, community healthcare, short-term social care, all-cause long-term care.  3 Includes values of paid and unpaid employment minus intervention time opportunity costs.  4 Includes OOP care expenditure and privately incurred LTC cost minus intervention private co-payments.  5 Includes informal caregiver burden/cost minus intervention caregiver time opportunity costs.  6 ICERs are computed using the jack-knife method to avoid bias associated with ratios (p. 550) [418].  7 The jack-knife means for public sector ICERs are £15,367 per QALY gained using (1) and £15,829 using (2).  8 The incremental net monetary benefits were estimated from the incremental outcomes rather than from jack-knife method using the cost-effectiveness threshold of £30,000 per QALY gained. | | | |

Figure 6.2 shows the scatter plot of outcomes – incremental societal QALY and incremental public sector all-cause cost of RC relative to UC – of the 1,000 probabilistic runs. See Figure F2 for the corresponding scatter plot under the public sector perspective. The scatter points for the probabilistic runs were uniformly placed in the north-east quadrant of the incremental QALY-cost graph and centred around the base seed run. All points lay below the line for the £30,000 per QALY gained cost-effectiveness threshold, while a minority of runs lay above the line for the £20,000 per QALY gained threshold.

Threshold: £20,000 per QALY gained

Threshold: £30,000 per QALY gained

**Figure 6.2** Scatter plot of probabilistic sensitivity analysis result for base case cost-utility analysis under societal perspective and 40-year horizon. **Abbreviation:** QALY: quality-adjusted life year.

Figure 6.3 shows the CEAC for the base case societal 40-year CUA. The probability of RC being cost-effective relative to UC crossed 50% at cost-effectiveness threshold of £13,700 per QALY gained. It was 93.4% at the threshold of £20,000 per QALY gained and 100% at £30,000 per QALY gained. See Figure F3 for the corresponding results under the public sector perspective.

**Figure 6.3** Cost-effectiveness acceptability curve for base case cost-utility analysis under societal perspective and 40-year horizon. **Abbreviation:** QALY: quality-adjusted life year; RC: recommended care; UC: usual care.

### 6.2.3 Deterministic sensitivity analysis

As noted, the jack-knife mean societal ICER across the probabilistic runs was £14,067 (95% uncertainty interval: £12,011 to £15,923) per QALY gained; in comparison, the deterministic base seed run produced a societal ICER of £12,800 per QALY gained. The latter was lower but lied within the 95% uncertainty interval. Thus, the level of non-linearity in the joint impact of parameter variations was deemed low. The deterministic alterations to individual parameters hence proceeded without jointly varying all other parameters. DSA was conducted on the base trial run as in PSA.

Table 6.5 shows the societal and public sector ICERs (considering all-cause costs) of variables with the top 20 highest impact on the base case societal ICER (there were 71 variables in total). The first column lists the variables in decreasing order of impact on the base case societal ICER, while the final column reports the rankings of the variables in terms of their impact on the base case public sector ICER. There was a close overlap in the top 20 variables that affected the societal and public sector ICERs.

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| **Table 6.5** Deterministic sensitivity analysis results: parameters with top 20 highest impact on incremental cost-effectiveness ratio considering all-cause costs over 40-year horizon. | | | | | |
| **Variable, by impact ranking on societal ICER** | **Societal ICER [£ per QALY gained]** | | **Public sector ICER [£ per QALY gained]** | | **Impact ranking on public sector ICER** |
| Low parameter value | High parameter value | Low parameter value | High parameter value |
| *Base case* | *12,800* | *12,800* | *13,897* | *13,897* |  |
| (1) Risk of any fall | 39,156 | 5,242 | 34,071 | 5,831 | 1 |
| (2) Risk of MA fall given recurrent falls | 21,893 | RC dominates | 23,434 | RC dominates | 2 |
| (3) Risk of recurrent falls given any fall | 25,766 | 8,988 | 24,159 | 9,849 | 3 |
| (4) Dynamic probability of GP routine contact | 4,637 | 14,537 | 5,162 | 15,108 | 4 |
| (5) Proactive int. demand under RC | 6,552 | 13,485 | 7,025 | 14,278 | 5 |
| (6) QALY loss from non-MA single/recurrent fall | 14,116 | 7,720 | 14,836 | 7,931 | 6 |
| (7) Dynamic probability of self-referred int. demand under RC | 16,145 | 10,015 | 16,168 | 10,571 | 7 |
| (8) Dynamic risk of LTC admission | 11,547 | 16,235 | 12,577 | 17,557 | 8 |
| (9) Dynamic risk of cognitive impairment | 10,877 | 15,548 | 11,910 | 15,677 | 12 |
| (10) Risk of recurrent MA fall | 14,530 | 10,613 | 15,215 | 11,087 | 9 |
| (11) Healthcare cost of hospitalised MA fall | 14,545 | 10,802 | 15,215 | 11,300 | 10 |
| (12) Initial risk of abnormal gait/balance | 13,708 | 15,340 | 14,221 | 15,829 | 14 |
| (13) Initial probability of self-referred int. demand under RC | 14,093 | 10,717 | 13,845 | 11,619 | 22 |
| (14) QALY loss from hospitalised MA fall | 14,185 | 10,849 | 14,912 | 11,270 | 13 |
| (15) Falls clinic fixed cost under RC | 11,307 | 14,374 | 11,828 | 15,036 | 15 |
| (16) Risk of MA fall given single fall | 11,715 | 14,770 | 12,587 | 16,377 | 11 |
| (17) Dynamic probability of high physical activity | 15,297 | 12,245 | 15,287 | 13,044 | 21 |
| (18) Proactive int. PS variable costs under RC | 11,399 | 14,277 | 11,924 | 14,935 | 16 |
| (19) RRs for proactive int. under RC | 11,727 | 14,460 | 12,309 | 15,221 | 17 |
| (20) Dynamic change in EQ-5D values | 13,985 | 11,596 | 14,692 | 12,078 | 18 |
| **Abbreviation:** AC: all-cause; ICER: incremental cost-effectiveness ratio; int.: intervention; LTC: long-term care; MA fall: fall requiring medical attention; QALY: quality-adjusted life year; RC: recommended care; RR: relative risk; PS: public sector. | | | | | |

All types of falls risks were in the top 20 impactful variables. Lower risks of falls reduced the extent of economic and health loss averted through falls prevention and thereby increased the societal and public sector ICERs (except for the risk of MA fall given single fall, ranked 16th). The dynamic probability of accessing the GP in the next cycle ranked 4th in terms of impact which was higher than all other intervention access parameters (e.g., proactive intervention demand 5th). Interestingly, the QALY loss from non-MA single/recurrent falls (6th) had a greater impact on ICERs than that from hospitalised MA falls (14th), while that from non-hospitalised MA falls ranked 25th. The dynamic risk of developing cognitive impairment was the epidemiological factor with the largest impact (9th). Amongst intervention cost and efficacy parameters, those for the proactive pathway had the largest impacts on ICERs (falls clinic cost 15th, public sector variable costs 18th, and RRs 19th).

### 6.2.4 Subgroup analysis

Section 6.2.4.1 reports the subgroup outcomes for the base case comparison. In the interest of conciseness, only the 40-year societal CUA outcomes are reported. The five-year public sector ROI outcomes delineated by SES quartile are reported for all intervention strategies in Section 6.3.2.2. Section 6.2.4.2 explores the variation in the intervention user profiles across pathways.

#### 6.2.4.1 Cost-utility analysis outcomes by subgroup

Subgroup analyses were conducted by the following characteristics: initial vs. new entry cohort; age group at model entry; sex; SES quartile; frailty category at model entry; and other covariates at model entry. Outcomes were averaged across 20 trial runs.

##### Outcomes by cohort

Table F1 in Appendix F shows the subgroup outcomes for the initial cohort aged 60+ at baseline and for the new cohorts entering as 60-year-olds at subsequent cycles. The societal ICERs were higher for the new cohorts (£13,918 vs. £11,619 per QALY gained, considering all-cause costs), but these remained below the commonly accepted thresholds of cost-effectiveness (e.g., £20,000 to £30,000 per QALY gained). The per-capita societal gain was higher for the new cohorts (1,199 vs. 181 QALYs), particularly due to the marked reduction in informal caregiving costs. Overall, accounting for the needs of older persons who newly become eligible during the intervention horizon determines the intervention use over time but does not majorly affect the cost-effectiveness profile of RC relative to UC.

##### Outcomes by age group at model entry

Table F2 shows the subgroup outcomes by five-year age group at model entry. For the subgroup aged 60-64 at entry, results for only the initial cohort members were evaluated since later cohorts (aged 60 at entry) spent varying durations in the model. The societal ICERs for RC relative to UC were below the commonly accepted threshold of £30,000 per QALY gained except for those aged 90+ when considering fall-related costs only (£31,681 per QALY gained). The cost-effectiveness profile improved with younger age at entry. The net societal gains were concentrated among those aged 60-64. Those aged 70+ incurred net societal loss, while those aged 85+ experienced net productivity loss, net private expenditure increase, and net informal caregiving cost increase. This should motivate supplementary policies to reduce these societal costs; improved intervention attributes (e.g., convenient location, attention on caregiver experience) could contribute. In all, the inclusion of younger subgroups in the target population is critical for improving the overall cost-effectiveness of RC relative to UC.

##### Outcomes by sex

Table F3 shows the subgroup outcomes by sex. There was a marked difference in the cost-effectiveness outcomes across sex, with men’s societal ICERs nearly double those of women (£18,641 vs. £9,659 per QALY gained, considering all-cause costs). The latter generated much greater all-cause and fall-related care cost savings and societal gains per capita. Hence, RC is particularly cost-effective for women and raises female societal contributions.

##### Outcomes by socioeconomic status

Table F4 shows the subgroup outcomes by SES quartile. The trends in the societal ICERs across the quartiles were non-linear, with the lowest ICER (considering all-cause costs) for the most deprived 4th quartile (£11,844 per QALY gained) and highest for the 2nd quartile (£14,450 per QALY gained). By contrast, the per-capita net societal gain was lowest for the 4th (0.0005 QALYs) and highest for the 1st (0.0058 QALYs). For the 3rd and 4th quartiles, there were marked increases in net private expenditure, driven mostly by intervention private co-payments. This should motivate schemes to reduce the co-payments; otherwise, they would increase the number of persons experiencing catastrophic private care expenditure, as already shown in Table 6.2.

Figure 6.4 shows the per-capita incremental health gain metrics delineated by SES quartiles for the base case analysis. The societal and public sector INHBs incorporate the health opportunity cost of resource use when all-cause costs are considered; the latter excludes the net societal gain. The 4th quartile enjoyed the most favourable outcome across all metrics; that said, the per-capita societal INHBs were near identical for the 1st and 4th quartiles. This differs from the societal ICER gradient in Table F4 which was lowest for the 4th quartile and highest for the 1st.

**Figure 6.4** Incremental health gain per capita by SES quartile of recommended care relative to usual care considering all-cause costs and cost-effectiveness threshold of £30,000 per QALY gained. **Abbreviation:** INHB: incremental net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status.

Table 6.6 reports the results of DCEA delineated by SES quartile. It shows the EDE levels of NHB for UC and RC under various relative and absolute inequality aversion indices (Atkinson ε and Kolm α, respectively) and where health differences across SES quartiles are deemed inequitable. As in the stylised example in Section 5.4.1.6, the societal EDE NHBs for both UC and RC decline relative to the no inequality aversion mean as the aversion parameters increase.

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| **Table 6.6** Equally distributed equivalent net health benefit across SES quartiles for base case comparison. | | | |
| **Inequality aversion indices** | **Usual care** | **Recommended care** | **Incremental** |
| Societal mean NHB (no inequality aversion mean)1 | 4.1774 | 4.2081 | 0.0307 |
| Societal Atkinson EDE NHB (ε=3)2 | 3.9184 | 3.9521 | 0.0337 |
| Societal Atkinson EDE NHB (ε=5) | 3.7365 | 3.7722 | 0.0357 |
| Societal Atkinson EDE NHB (ε=11) | 3.3627 | 3.3994 | 0.0367 |
| Societal Atkinson EDE NHB (ε=30) | 3.0846 | 3.1189 | 0.0343 |
| Societal Kolm EDE NHB (α=0.025)3 | 4.1698 | 4.2005 | 0.0307 |
| Societal Kolm EDE NHB (α=0.05) | 4.1622 | 4.1929 | 0.0307 |
| Societal Kolm EDE NHB (α=0.15) | 4.1311 | 4.1618 | 0.0308 |
| Societal Kolm EDE NHB (α=0.5) | 4.0167 | 4.0478 | 0.0311 |
| **Abbreviation:** EDE: equally distributed equivalent; NHB: net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status  1 The societal NHB incorporates QALY gain and QALY-equivalent net societal gain minus public sector opportunity costs (translated to QALY-equivalent using cost-effectiveness threshold of £30,000 per QALY gained) for each SES quartile. To account for the differing sizes of SES subgroups, per-capita (i.e., average) societal NHBs were computed for each subgroup. The unweighted mean of the subgroup averages was then computed, effectively treating the subgroups as of equal size. When the Atkinson ε relative inequality aversion parameter is set to zero, the Atkinson EDE NHB equals the NHB [109].  2 Atkinson index evaluates the distribution of health in terms of relative inequality [109].  3 Kolm index evaluates the distribution of health in terms of absolute inequality [109]. | | | |

Regarding incremental outcomes, the positive incremental no-aversion mean of 0.0307 shows that RC is cost-effective relative to UC at the £30,000 per QALY gained threshold. Moreover, the incremental EDE NHBs (EDE INHBs) of RC relative to UC (e.g., 0.0343 when Atkinson ε=30 and 0.0311 when Kolm α=0.5) remain higher than the incremental no-aversion mean (0.0307) across the ranges of relative and absolute inequality aversion parameters. This shows that RC also improved equity relative to UC. Figures F4(a) and (b) show the change in EDE INHBs across the ranges of relative and absolute inequality aversion parameters. Overall, there is some evidence that RC improved both efficiency and SES-delineated equity relative to UC. The equity improvement was experienced in terms of reductions in both relative and absolute inequalities in societal NHBs.

##### Outcomes by frailty category at model entry

Table F5 shows the subgroup outcomes by frailty category at model entry. RC was cost-effective relative to UC across all initial frailty categories. The societal ICERs were lowest for the moderate frailty category and highest for the severe category (£9,017 and £14,959 per QALY gained, respectively). The societal gains were concentrated among those initially fit and net negative for the severe category. The latter experienced a net increase in informal caregiving cost, mainly due to the greater prevalence of cognitively impaired persons in this category who required informal caregiver accompaniment at interventions.

Figure 6.5 shows the per-capita incremental health gain metrics delineated by initial frailty category. The moderately frail enjoyed the highest per-capita health gains by all metrics, followed by the mildly frail. The severely frail had higher gains than the fit in terms of public sector INHB and incremental QALY but not in terms of societal INHB that incorporated the net societal gain.

**Figure 6.5** Incremental health gain per capita by initial frailty category of recommended care relative to usual care considering all-cause costs and cost-effectiveness threshold of £30,000 per QALY gained. **Abbreviation:** INHB: incremental net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status.

Table 6.7 reports the EDE NHBs for UC and RC where health differences across frailty categories are deemed inequitable. The EDE INHBs of RC relative to UC remained above zero for diverse relative and absolute inequality aversion parameters; hence, RC is to be preferred over UC when efficiency and frailty-delineated equity are considered jointly. However, the Kolm EDE INHB (e.g., 0.0277 at α=0.5) remained below the incremental no-aversion mean (0.0325), suggesting that the absolute inequality worsened. Therefore, there is some evidence of an equity-efficiency trade-off in implementing RC.

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| **Table 6.7** Equally distributed equivalent net health benefit across initial frailty categories for base case comparison. | | | |
| **Inequality aversion indices** | **Usual care** | **Recommended care** | **Incremental** |
| Societal mean NHB (no inequality aversion mean)1 | 2.0433 | 2.0758 | 0.0325 |
| Societal Atkinson EDE NHB (ε=3)2 | 1.0719 | 1.1207 | 0.0488 |
| Societal Atkinson EDE NHB (ε=5) | 0.8671 | 0.9195 | 0.0524 |
| Societal Atkinson EDE NHB (ε=11) | 0.7223 | 0.7731 | 0.0508 |
| Societal Atkinson EDE NHB (ε=30) | 0.6598 | 0.7066 | 0.0468 |
| Societal Kolm EDE NHB (α=0.025)3 | 1.9660 | 1.9984 | 0.0324 |
| Societal Kolm EDE NHB (α=0.05) | 1.8894 | 1.9217 | 0.0323 |
| Societal Kolm EDE NHB (α=0.15) | 1.5924 | 1.6240 | 0.0316 |
| Societal Kolm EDE NHB (α=0.5) | 0.7622 | 0.7899 | 0.0277 |
| **Abbreviation:** EDE: equally distributed equivalent; NHB: net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status  1 The societal NHB incorporates QALY gain and QALY-equivalent net societal gain minus public sector opportunity costs (translated to QALY-equivalent using cost-effectiveness threshold of £30,000 per QALY gained) for each SES quartile. To account for the differing sizes of SES subgroups, per-capita (i.e., average) societal NHBs were computed for each subgroup. The unweighted mean of the subgroup averages was then computed, effectively treating the subgroups as of equal size. When the Atkinson ε relative inequality aversion parameter is set to zero, the Atkinson EDE NHB equals the NHB [109].  2 Atkinson index evaluates the distribution of health in terms of relative inequality [109].  3 Kolm index evaluates the distribution of health in terms of absolute inequality [109]. | | | |

##### Outcomes by other covariates at model entry

The results of further subgroup analyses are presented in Appendix F: Table F6 for outcomes by initial physical activity status; Table F7 by initial cognitive status; Table F8 by initial fear of falling status; Table F9 by initial gait/balance status; Table F10 by initial falls history type.

For the subgroups delineated by initial physical activity, the societal ICERs ranged between £12,570 and £14,145 per QALY gained and hence were below the commonly accepted thresholds of cost-effectiveness. The similar ICERs suggested that those without high physical activity at entry were not significantly disadvantaged by RC. It also suggested that RC can be supplemented by earlier-life physical activity promotion without having a major impact on the cost-effectiveness of RC vs. UC.

The societal ICERs delineated by initial cognitive status were higher for the cognitively impaired than intact, but they ranged between £12,571 and £15,786 per QALY gained and hence were below the commonly accepted thresholds of cost-effectiveness. The per-capita QALY gains were in fact comparable across initial cognitive status (0.051 for intact vs. 0.047 for impaired). By contrast, the societal gains were concentrated among the intact. In all, RC remains cost-effective relative to UC across initial cognitive status but increases the gap in societal benefits between subgroups.

The societal ICERs ranged between £9,940 and £14,098 per QALY gained for subgroups delineated by initial fear of falling. They were markedly lower for those with initial fear than those without; the per-capita QALY gain was likewise higher for those with fear (0.069 vs. 0.050). The societal gains were net negative for those with fear and net positive for those without. Therefore, RC is cost-effective relative to UC across initial fear of falling status and particularly favours those with initial fear of falling.

The societal ICERs ranged between £12,248 and £14,276 per QALY gained for subgroups delineated by initial gait/balance. The societal ICER considering all-cause care costs was lower for those with initial abnormal gait/balance, suggesting that prioritising those with abnormal gait/balance under the proactive pathway of RC is a cost-effective strategy.

There were noticeable variations in the societal ICERs across initial fall history types. Those with histories of recurrent non-MA falls or recurrent falls with one or more MA fall had markedly lower ICERs than those with other falls history types. These suggest that prioritising those with falls history under the reactive and proactive pathways of RC is a highly cost-effective strategy. The societal gains were net positive for all subgroups, though concentrated among those without initial falls history.

#### 6.2.4.2 Intervention user profile by pathway

This section explores the variation in the intervention user profile by pathway. Table F11 describes the characteristics of intervention users by pathway under UC and RC over the 40-year horizon. The total person-years of intervention use across all pathways increased by over tenfold from 159,169 under UC to 1,710,424 under RC; the annual average usage increased from 3,979 to 42,761. The self-referred pathway experienced the largest proportional expansion, increasing 272-fold from 47 users per year to 12,793. The proactive pathway use increased around 18-fold from 1,517 users per year to 26,928. Under RC, there were 21,131 annual falls clinic clients, consistent with the total capacity of seven clinics and 3,000 clients per clinic. This number encompassed a mix of reactive and proactive clients.

Comparing the characteristics of reactive pathway users between UC and RC, the proportions of users in their sixties and in the fit and mild frailty categories were markedly higher under RC than UC: e.g., 14.9% of reactive pathway users were aged 60-64 at use under RC compared to 8.1% under UC. The proportions delineated by sex and SES quartile were similar between UC and RC, though the proportion of users in the 4th SES quartile declined from 19.0% in UC to 16.7% in RC. The proportion of users who are cognitively impaired declined under RC relative to UC, though their absolute number increased.

For the proactive pathway, there was an increase in the proportion of users in the fit and mild frailty categories under RC than UC. The proportion of male users increased from 40.1% under UC to 45.9% under RC. The proportions by SES quartiles remained constant across UC and RC, though with a slight decline in the proportion of users in the 4th SES quartile. Cognitively impaired persons were ineligible for proactive intervention under UC; by contrast, they made up 26.8% of proactive intervention users under RC. Due to the use of abnormal gait/balance as a criterion of proactive referral, the proportion of users with this characteristic increased from 62.1% under UC to 79.8% under RC.

For the self-referred pathway, the simple assumption used to characterise its access under UC resulted in less credible access patterns: e.g., 100% of users were from the 1st SES quartile. But the very small number of users under UC likely minimises its impact on results. The ELSA-derived access pattern for RC is more credible. Comparing this pattern to those of reactive and proactive pathways under RC, the self-referred pathway users were younger (e.g., 45.0% aged 60-69 compared to 29.1% in reactive and 33.0% in proactive pathways), had higher proportion of women, were less frail (e.g., 70.9% in fit or mild frailty categories compared to 52.3% in reactive and 65.2% in proactive), and had higher proportions of persons with high physical activity, intact cognitive status, no fear of falling, no abnormal gait/balance and no falls history. The SES of users was similar across pathways: 52.7% of self-referred users were in the 1st and 2nd SES quartiles compared to 51.3% of reactive and 50.5% of proactive.

### 6.2.5 Evaluation framework and falls epidemiology scenarios

The scenarios regarding key evaluation framework and falls epidemiology features were informed by the conceptual model and are applied to the base case comparison. In the interest of space, this section focuses on the 40-year societal CUA outcomes. Results from two types of evaluation framework scenarios are presented: changes to time horizon (Section 6.2.5.1); and changes to discount rates (Section 6.2.5.2). These are followed by results from falls epidemiology scenarios: removing the falls-frailty feedback loop (Section 6.2.5.3); frailty reduction (Section 6.2.5.4); higher life expectancy (Section 6.2.5.5); and reduced other-cause mortality risk gap between frailty categories (Section 6.2.5.6).

#### 6.2.5.1 Changes to time horizon

Table F12 presents the societal CUA outcomes comparing RC to UC under the time horizons of five, 10, 15, 20 and 30 years. Figure 6.6 shows the societal and public sector ICERs (considering all-cause costs) across time horizon range from five to 40 years. There is a non-linear decline in the ICERs under both perspectives as the horizon increases. There were net societal losses under five- and 10-year horizons such that the societal ICERs were higher than the public sector ICERs. The threshold of £30,000 per QALY gained is crossed between five- and 10-year horizons (though not if only fall-related costs are considered). From the aggregate societal INMBs in Table F12, the additional amount that can be spent by the decision-maker to enable a longer horizon (e.g., establishing new training centres to secure long-term supply of professionals) can be estimated. Hence, £110.9 million may be spent to extend the horizon from five to 15 years and the RC would remain cost-effective relative to UC under the £30,000 per QALY gained threshold.

**Figure 6.6** Societal and public sector incremental cost-effectiveness ratios by time horizon. **Abbreviation:** ICER: incremental cost-effectiveness ratio; QALY: quality-adjusted life year.

Another consideration is the equity implication of differing time horizons. Figure F5 shows the societal INHBs for all-cause costs delineated by SES quartiles under five- to 40-year horizons. The ‘U-shaped’ SES gradients were present for all time horizons. Figure 6.7 shows the societal EDE INHBs per capita under (i) no inequality aversion, (ii) high relative inequality aversion (Atkinson ε=30), and (iii) high absolute inequality aversion (Kolm α=0.5); INHB difference across SES quartiles is deemed unfair. The incremental EDE INHBs of (ii) and (iii) were consistently above incremental no-aversion mean of (i), meaning that RC improved SES-delineated equity vs. UC under all time horizons.

**Figure 6.7** SES-delineated equity analysis: incremental societal EDE INHBs by inequality aversion level and time horizon. **Abbreviation:** EDE: equally distributed equivalent; INHB: incremental net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status.

In discussing model time horizons, a distinction can be made between evaluation and intervention horizons. In the above analyses, these two horizons were equal at five to 40 years. Hence, under the base case analysis, evaluation was conducted for 40 years while the interventions operated for the same period. The 40-year horizon corresponded to a lifetime horizon for the initial cohort but not for the new incoming cohorts. To understand the impact of this methodological feature, a further analysis was conducted with 80-year evaluation horizon and 40-year intervention horizon. This allows the same 40-year exposure to the interventions as the base case while tracking the lifetime outcomes of all cohorts.

The result of this analysis is shown in Table F13. The societal ICER considering all-cause costs was £11,871 per QALY gained, lower but comparable to the base case ICER of £12,877 per QALY gained. The proportional sizes of EDE INHBs relative to incremental no-aversion mean were 1.1411 and 1.0206 (measuring the strength of equity impact) under relative and absolute inequality aversion parameters of ε=30 and α=0.5, respectively. These were higher but comparable to the base case proportions of 1.1169 and 1.0121. Overall, the tracking of all cohorts’ lifetime outcomes did not have a major impact on outcomes, likely due to the lack of access to RC after the 40th year.

If the intervention horizon was also extended to 80 years so that all incoming cohorts faced 80-year evaluation *and* intervention horizons, there would be more substantial improvements to the outcomes. It would likely approach the outcomes reported in Table F2 for the subgroup aged 60-64 at entry: the societal ICER considering all-cause costs for this subgroup was £9,085 per QALY gained.

#### 6.2.5.2 Changes to discount rates

Table F14 presents the 40-year societal CUA outcomes under the discount rates of 0% and 6% for both health and cost outcomes. The rate variations had large impacts on the present values of costs and outcomes (e.g., total societal INMB increased from £356.3 million under 3.5% discount rates to £841.4 million under 0%) but a moderate impact on the societal ICERs.

The U-shaped SES gradients in societal per-capita INHBs were similar across discount rate scenarios (Figure F6), though the 4th SES quartile derived greater per-capita INHBs than the 1st under 0% discount rates. For 0% discount rates, the EDE INHBs of RC vs. UC were 0.0799 and 0.0730 under Atkinson ε=30 and Kolm α=0.5, respectively. These were higher than the incremental no-aversion mean of 0.0710, implying joint improvements in equity and efficiency. The proportions between EDE INHB and incremental no-aversion mean were 1.1254 and 1.0282, respectively. The corresponding figures for 6% discount rates were 0.0189, 0.0172 and 0.0170, with proportions of 1.1118 and 1.0118. The proportions were 1.1169 and 1.0121 for the base case. Hence, compared to the base case, the equity gain increased under 0% discount rate and decreased under 6%. Nevertheless, the dual equity-efficiency improvements of RC relative to UC were maintained under both discount rate scenarios.

#### 6.2.5.3 Removing the falls-frailty feedback loop

Table F15 shows the 40-year societal CUA outcomes after the falls-frailty feedback loop is removed. The impact was large, with societal and public sector ICERs increasing above the commonly accepted threshold of £30,000 per QALY gained. The QALY gain saw the most significant decline from 19,570 gain under base case to 6,895. The majority of QALY gain from RC vs. UC can thus be attributed to the prevention of secondary effects of falls via frailty progression. The societal outcomes likewise saw a significant shift from net gain of 1,380 QALYs to net loss of 1,587.

Figure 6.8 compares the societal per-capita INHBs (considering all-cause costs) delineated by SES quartile in base case and in this scenario. The U-shaped SES gradient in the INHBs disappears under the latter; the 4th quartile now derives the lowest INHBs. The societal EDE INHBs were -0.015 and -0.013 under Atkinson ε=30 and Kolm α=0.5, respectively, which were lower than the incremental no-aversion mean of -0.012. This confirms that RC worsened health inequity vs. UC. Overall, the falls-frailty feedback is a key causal mechanism for the efficient and equitable impacts of RC vs. UC.

**Figure 6.8** Societal per-capita INHBs for all-cause care costs by SES quartile in base case and in falls-frailty feedback removal scenario. **Abbreviation:** INHB: incremental net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status.

#### 6.2.5.4 Frailty reduction

Table F16 shows the 40-year societal CUA outcomes under scenarios of 20% reduction in: (i) initial frailty levels at model entry; and (ii) the rate of frailty progression during model simulation. Under (i), the initial cohort aged 60+ and subsequent cohorts aged 60 entered the model with much improved health status: e.g., the prevalence of high physical activity in the initial cohort was 33.9% vs. 16.2% under base case. Under both scenarios, the societal and public sector ICERs increased relative to base case but remained below the commonly accepted threshold of £30,000 per QALY gained.

Figure F7 compares the societal per-capita INHBs (considering all-cause costs) delineated by SES quartile in base case and the two scenarios. The U-shaped gradient is apparent in all. Table 6.8 shows the SES-delineated societal EDE INHBs of RC vs. UC under the two scenarios. Compared to the base case, initial frailty reduction magnified the equity improvement of RC vs. UC, while frailty progression rate reduction dampened it. Nevertheless, the dual equity-efficiency improvements of RC vs. UC were maintained under the two scenarios. There is hence scope for integration between RC and frailty reduction both at earlier life stages and contemporaneously in old age.

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| **Table 6.8** SES-delineated EDE INHBs for recommended care relative to usual care under two frailty reduction scenarios. | | | |
|  | **RC vs. UC** | | |
| **Societal INHB1** | **Initial frailty reduction** | **Frailty progression rate reduction** | **Base case** |
| (1) Incremental no-aversion mean2 | 0.0276 | 0.0225 | 0.0307 |
| (2) Atkinson EDE INHB (ε=30) | 0.0312 | 0.0241 | 0.0343 |
| *Proportion of (2) relative to (1)* | *1.1304* | *1.0684* | *1.1169* |
| (3) Kolm EDE INHB (α=0.5) | 0.0281 | 0.0225 | 0.0311 |
| *Proportion of (3) relative to (1)* | *1.0181* | *1.0004* | *1.0121* |
| **Abbreviation:** EDE: equally distributed equivalent; INHB: incremental net health benefit; QALY: quality-adjusted life year; RC: recommended care; SES: socioeconomic status; UC: usual care.  1 The societal NHB incorporates QALY gain and QALY-equivalent net societal gain minus public sector opportunity costs (translated to QALY-equivalent using cost-effectiveness threshold of £30,000 per QALY gained) for each SES quartile. The incremental NHB (INHB) is measured relative to UC.  2 This is the EDE INHB when Atkinson ε=0 [109]. | | | |

#### 6.2.5.5 Higher life expectancy

Table F17 shows the 40-year societal CUA outcomes when other-cause mortality risks were reduced by 20%. Compared to base case, the societal and public sector ICERs were all lower due to the higher total QALY gains and public sector cost savings, though the net societal gain was lower. Therefore, policies improving the geriatric life expectancy complement RC, improving its cost-effectiveness vs. UC. The lower life expectancy generated by the model relative to the ONS data (Section 5.3.3) hence produced a conservative estimate of cost-effectiveness.

Figure F8 shows the SES gradient to the societal INHBs under the scenario and base case. Relative to base case, the SES gradient was more pro-poor under the scenario, with the 3rd and 4th quartiles now deriving greater per-capita INHBs than the 1st. Interestingly, the 1st quartile derived less INHBs under the scenario than the base case due to the lower net societal gain for the quartile (571 vs. 769 QALYs).

For the higher life expectancy scenario, the EDE INHBs were 0.0376 and 0.0336 under Atkinson ε=30 and Kolm α=0.5, respectively, which were higher than the incremental no-aversion mean of 0.0328. The proportions of the EDE INHBs relative to the latter were 1.1483 and 1.0249 respectively, which were higher than the proportions under the base case (1.1169 and 1.0121). Hence, the higher life expectancy magnified the equity improvement of RC.

#### 6.2.5.6 Reduced other-cause mortality risk gap between frailty categories

Table F18 shows the 40-year societal CUA outcomes from scenario with 20% reduction in the hazard ratios across frailty categories (relative to the fit category) for the other-cause mortality risk. Under UC in base case, the gap in life expectancy from age 60 between those who are initially fit and those who are severely frail is 6.4 years; this gap is reduced to 4.8 years under the scenario. There were modest increases in the societal ICERs relative to base case; RC remained cost-effective vs. UC. There was a modest decrease in the net societal gain from 1,380 to 1,197 QALYs, primarily due to the lower net productivity gain among frailer persons with extended life years.

Figure F9 compares the societal per-capita INHBs delineated by initial frailty category in base case and the scenario. Despite the reduction in the life expectancy differential between frailty subgroups, the frailty gradient to the INHBs remained similar between base case and scenario. For the latter, the EDE INHBs were 0.0436 and 0.0269 under Atkinson ε=30 and Kolm α=0.5, respectively, while the incremental no-aversion mean was 0.0314. Hence, as in the base case, RC improved equity relative to UC in terms of relative but not absolute societal INHB inequality (Table 6.7). The proportional size of the EDE INHBs relative to incremental no-aversion mean were 1.3870 and 0.8560 respectively; the corresponding figures under base case were 1.4385 and 0.8519. Thus, the mortality risk gap reduction did not improve the frailty-delineated equity gains.

Figure F10 shows the social per-capita INHBs delineated by SES quartile. For the scenario, the EDE INHBs were 0.0327 and 0.0300 under Atkinson ε=30 and Kolm α=0.5, respectively, while the incremental no-aversion mean was 0.0294. The proportional size of the EDE INHBs relative to the latter were 1.1115 and 1.0192, respectively. In comparison, the proportions were 1.1169 and 1.0121 under the base case. Hence, relative to base case, this scenario magnified the equity improvement in terms of absolute SES-delineated inequality but not in terms of relative inequality. The corresponding proportions were 1.1483 and 1.0249 under the higher life expectancy scenario above. Thus, life expectancy increases for the whole population brought greater equity improvements than the narrowing of mortality risk gap across frailty categories. This finding should be considered by decision-makers seeking to integrate falls prevention with wider life-extending geriatric public health strategies.

### 6.2.6 Summary of results under base case comparison

Under the 40-year societal CUA, RC had a 93.4% probability of being cost-effective relative to UC at the cost-effectiveness threshold of £20,000 per QALY gained and 100% at £30,000 per QALY gained. It increased productivity and reduced private care expenditure and informal caregiving cost, but the productivity gain and the private expenditure reduction were outstripped by increases in intervention time opportunity costs and co-payments, respectively. There was no equity-efficiency trade-off in terms of relative and absolute inequality delineated by SES quartile. The epidemiological scenarios showed that falls prevention is highly integrative with other geriatric public health interventions that reduce baseline and contemporaneous frailty and improve life expectancy.

However, gains in terms of individual-level lifetime outcomes were more muted and no positive financial return was feasible under the five-year public sector perspective. Even under the 40-year societal CUA, a 10-year time horizon was required to be cost-effective under the £30,000 per QALY gained threshold. ICER increased with initial age and crossed the £30,000 per QALY gained threshold for those aged 90+. This suggests that younger age groups should be included to cross-subsidise RC for older peers.

## 6.3 Alternative falls prevention strategies and commissioning recommendations

Falls prevention intervention scenarios described in Section 5.4.2.1 are first evaluated individually (Section 6.3.1), followed by a full comparison (Section 6.3.2). The latter informs the commissioning recommendations subsequently formulated (Section 6.3.3).

### 6.3.1 Evaluation of alternative falls prevention strategies

Evaluation of individual scenarios are presented as follows: estimating the contributions of individual pathways (Section 6.3.1.1); incorporating capacity constraints to RC with different targeting strategies (Section 6.3.1.2); value of implementation analyses of community contributions (Section 6.3.1.3); estimating the impact of removing the double jeopardy problem (Section 6.3.1.4); and incorporating supplementary environmental interventions to RC (Section 6.3.1.5).

#### 6.3.1.1 Pathway contributions

This section explores the contributions relative to UC of: (i) individual pathways in their respective RC configurations; and (ii) combinations of two pathways in their respective RC configurations.

##### Individual pathways

Table F19 shows the cost-effectiveness of the contributions of individual pathways in their RC configurations vs. UC. It also reports the total intervention users by pathway over 40 years. The reactive pathway produced the lowest societal ICER (considering all-cause costs) of £1,937 per QALY gained, followed by the self-referred pathway with £4,818 per QALY gained. But the latter produced a much higher aggregate INMB of £255.3 million vs. £79.2 million for the reactive pathway. The proactive pathway produced the highest societal ICER of £20,622 per QALY gained. There were diminishing returns to pathway addition, whereby the sum of the societal INMBs of pathways (£440.2 million) was greater than the base case level (£358.7 million). This is likely due to the reduction in falls risk from one pathway reducing the cost-effectiveness of others.

Figure 6.9 shows the SES gradients to the societal per-capita INHBs (considering all-cause costs) of individual pathways vs. UC. The proactive pathway was the most pro-poor option, with the 4th SES quartile deriving the greatest per-capita INHB. The self-referred pathway was the least pro-poor option, with the 4th quartile deriving the smallest per-capita INHB.

**Figure 6.9** Societal per-capita INHBs for all-cause care costs by SES quartile in individual pathway implementation scenarios. **Abbreviation:** INHB: incremental net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status

Table 6.9 compares the EDE INHBs of pathways vs. UC under high relative and absolute inequality aversions. All pathways produced positive EDE INHBs relative to UC, meaning that they are preferable to UC under joint equity-efficiency consideration. The proactive pathway improved both equity and efficiency; the reactive improved equity in terms of absolute but not relative inequality; while the self-referred improved equity in terms of relative but not absolute. Nevertheless, under both Atkinson ε=30 and Kolm α=0.5, the self-referred pathway generated higher EDE INHBs than others.

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| **Table 6.9** SES-delineated EDE INHBs for individual prevention pathways relative to usual care. | | | |
| **Societal INHB1** | **Reactive pathway vs. UC** | **Proactive pathway vs. UC** | **Self-referred pathway vs. UC** |
| (1) Incremental no-aversion mean2 | 0.0072 | 0.0096 | 0.0221 |
| (2) Atkinson EDE INHB (ε=30) | 0.0068 | 0.0121 | 0.0223 |
| *Proportion of (2) relative to (1)* | *0.9471* | *1.2659* | *1.0085* |
| (3) Kolm EDE INHB (α=0.5) | 0.0072 | 0.0101 | 0.0219 |
| *Proportion of (3) relative to (1)* | *1.0022* | *1.0550* | *0.9898* |
| **Abbreviation:** EDE: equally distributed equivalent; INHB: incremental net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status; UC: usual care.  1 The societal NHB incorporates QALY gain and QALY-equivalent net societal gain minus public sector opportunity costs (translated to QALY-equivalent using cost-effectiveness threshold of £30,000 per QALY gained) for each SES quartile. The incremental NHB (INHB) is measured relative to UC.  2 This is the EDE INHB when Atkinson ε=0 [109]. | | | |

##### Combinations of two pathways

Table F20 shows the cost-effectiveness of the combinations of two pathways in their RC configurations vs. UC. The combination of reactive and self-referred pathways produced the lowest societal ICER (£4,270 per QALY gained, considering all-cause costs) and the highest aggregate societal INMB (£329.0 million) despite having the lowest number of users; the latter nearly reached the level under the base case (£358.7 million). Moreover, its net societal gain of 1,457 QALYs was greater than that under the base case (1,380 QALYs). Adding the proactive pathway to this configuration would have yielded small additional INMB and a *loss* in net societal gain, showing evidence of diminishing return.

Figure F11 shows the SES gradients to the societal per-capita INHBs (considering all-cause costs) of pathway combinations vs. UC. Combinations with the self-referred pathway produced less pro-poor gradients that the one without. Table 6.10 compares the EDE INHBs of pathway combinations relative to UC under high relative and absolute inequality aversions. All three combinations improved efficiency and equity in terms of relative inequality, but only the reactive-proactive combination improved equity in terms of absolute inequality. Nevertheless, the reactive-self-referred combination generated the highest EDE INHB under both Atkinson ε=30 and Kolm α=0.5 compared to others.

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| **Table 6.10** SES-delineated EDE INHBs for combinations of two prevention pathways relative to usual care. | | | |
| **Societal INHB1** | **Reactive-Proactive pathways vs. UC** | **Reactive-Self-referred pathways vs. UC** | **Proactive-Self-referred pathways vs. UC** |
| (1) Incremental no-aversion mean2 | 0.0151 | 0.0282 | 0.0258 |
| (2) Atkinson EDE INHB (ε=30) | 0.0188 | 0.0284 | 0.0259 |
| *Proportion of (2) relative to (1)* | *1.2446* | *1.0056* | *1.0047* |
| (3) Kolm EDE INHB (α=0.5) | 0.0159 | 0.0280 | 0.0256 |
| *Proportion of (3) relative to (1)* | *1.0526* | *0.9918* | *0.9943* |
| **Abbreviation:** EDE: equally distributed equivalent; INHB: incremental net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status; UC: usual care.  1 The societal NHB incorporates QALY gain and QALY-equivalent net societal gain minus public sector opportunity costs (translated to QALY-equivalent using cost-effectiveness threshold of £30,000 per QALY gained) for each SES quartile. The incremental NHB (INHB) is measured relative to UC.  2 This is the EDE INHB when Atkinson ε=0 [109]. | | | |

#### 6.3.1.2 Capacity constraint and targeting strategies

Table 6.11 shows the results of 40-year societal CUA where different targeting/allocation mechanisms under constrained recommended care (CRC) are compared to UC. The annual intervention use figures show that the capacity constraints were binding in all cases except for falls clinic use under scenario (2). In (4), the predicted falls risk level at which persons were referred to intervention (≥60%) was deliberately set such that the falls clinic use remained just below the 9,000 annual capacity.

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| **Table 6.11** Scenarios of constrained recommended care with different targeting strategies relative to usual care for 40-year societal cost-utility analysis. | | | | |
| N=385,192 | **Targeting/allocation strategies under constrained recommended care** | | | |
| **(1) Random allocation** | **(2) No repeated intervention** | **(3) Target moderate & severe frailty** | **(4) Target highest predicted falls risk (≥60%)** |
| Constrained service annual use1,2 |  |  |  |  |
| *Falls clinic* | 9,000 | 7,332 | 9,000 | 8,962 |
| *Proactive Tai Chi* | 500 | 500 | 500 | 500 |
| *Self-referred interventions* | 2,000 | 2,000 | 2,000 | 2,000 |
| Pathway annual use3 |  |  |  |  |
| *Reactive* | 3,182 | 2,577 | 3,227 | 2,969 |
| *Proactive* | 8,047 | 6,994 | 7,995 | 8,198 |
| *Self-referred* | 2,000 | 2,000 | 2,000 | 2,000 |
| Total | 13,229 | 11,571 | 13,248 | 13,167 |
|  | **Incremental outcomes relative to usual care** | | | |
| Public sector costs |  |  |  |  |
| *(1) All-cause PS costs4* | -£57,066,208 | -£43,622,063 | -£61,839,683 | -£69,811,771 |
| *(2) Fall-related HC costs* | -£49,696,650 | -£36,752,916 | -£58,952,362 | -£61,888,647 |
| *PS intervention costs* | £137,393,185 | £150,625,685 | £145,246,289 | £147,222,044 |
| QALY | 5,994 | 6,041 | 6,311 | 8,644 |
| Societal outcomes |  |  |  |  |
| *Net productivity5* | £12,264,692 | £12,872,752 | £11,764,657 | £21,733,042 |
| *Net private expenditure6* | £5,143,640 | £12,275,670 | £2,241,392 | £3,137,833 |
| *Net informal care cost7* | -£21,891,439 | -£40,304,980 | -£15,241,467 | -£45,646,938 |
| Societal gain, QALY equivalent | 484 QALYs | 682 QALYs | 413 QALYs | 1,071 QALYs |
| Societal ICER using (1) | £12,401 per QALY gained8 | £15,917 per QALY9 | £12,405 per QALY gained10 | £7,969 per QALY gained11 |
| Societal ICER using (2) | £13,539 per QALY gained | £16,939 per QALY gained | £12,834 per QALY gained | £8,784 per QALY gained |
| Societal INMB using (1)12 | £113,990,748 | £94,669,816 | £118,309,448 | £214,019,285 |
| Societal INMB using (2) | £106,621,191 | £87,800,668 | £115,422,127 | £206,096,160 |
| **Abbreviation:** HC: healthcare; ICER: incremental cost-effectiveness ratio; INMB: incremental net monetary benefit; LTC: long-term care; OOP: out-of-pocket; PS: public sector; QALY: quality-adjusted life year.  1 All outcomes were averaged across 20 model trial runs with different random number seeds.  2 Intervention annual uses under recommended care are 21,131, 7,225 and 12,793 for bi-disciplinary reactive intervention, falls clinic, proactive Tai Chi and self-referred intervention, respectively.  3 Pathway annual uses under recommended care are 3,040, 26,928, 12,793 and 42,761 for reactive, proactive and self-referred pathways and the total, respectively (see Table F11).  4 Includes costs of fall-related primary and secondary healthcare, comorbidity primary and secondary healthcare, cost of dying, community healthcare, short-term social care, all-cause long-term care.  5 Includes values of paid and unpaid employment minus intervention time opportunity costs.  6 Includes OOP care expenditure and privately incurred LTC cost minus intervention private co-payments.  7 Includes informal caregiver burden/cost minus intervention caregiver time opportunity costs.  8 The public sector ICERs are £13,402 per QALY gained using (1) and £14,631 using (2).  9 The public sector ICERs are £17,714 per QALY gained using (1) and £18,851 using (2).  10 The public sector ICERs are £13,216 per QALY gained using (1) and £13,673 using (2).  11 The public sector ICERs are £8,956 per QALY gained using (1) and £9,872 using (2).  12 Incremental net monetary benefits are estimated using the cost-effectiveness threshold of £30,000 per QALY gained. | | | | |

Random allocation in (1) produced ICERs comparable to those under base case; thus, capacity constraints in themselves had little impact on cost-effectiveness beyond reducing the aggregate INMB. No repeated intervention provision in (2) produced higher ICERs than (1), mainly because the under-utilisation of the third falls clinic raised the per-capita intervention cost. Frailty targeting in (3) also produced ICERs comparable to the base case. The most significant change in cost-effectiveness was produced by falls risk targeting in (4). This significantly reduced the ICER relative to base case.

The constraints significantly reduced the aggregate societal INMB (considering all-cause costs) from £358.7 million under base case to £214.0 million under (4); but the INMB per intervention user increased from £210 in base case to £406 in (4). Comparing the INMBs across targeting scenarios allowed the estimation of decision-maker’s WTP for the targeting tools: for example, the additional societal INMB (considering all-cause costs) of £100.0 million for (4) relative to (1) was the maximum amount that can be invested in multivariate falls risk targeting system under the £30,000 per QALY gained threshold *after* accounting for the per-capita targeting cost. Hence, the amount can cover any additional costs involved in the system set-up.

Figure F12 shows the SES gradients to societal per-capita INHBs (considering all-cause costs) under the scenarios. Table 6.12 compares the EDE INHBs of the targeting strategies relative to UC under high relative and absolute inequality aversions. All strategies improved both equity and efficiency. Scenario (4) had the highest proportional increases in EDE INHBs relative to incremental no-aversion mean under both relative and absolute inequality aversions.

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| **Table 6.12** SES-delineated EDE INHBs for targeting strategies under constrained recommended care relative to usual care. | | | | |
| **Societal INHB1** | **(1) Random allocation vs. UC** | **(2) No repeated intervention vs. UC** | **(3) Targeting frailty vs. UC** | **(4) Targeting falls risk vs. UC** |
| (1) Incremental no-aversion mean2 | 0.0103 | 0.0086 | 0.0108 | 0.0191 |
| (2) Atkinson EDE INHB (ε=30) | 0.0110 | 0.0092 | 0.0122 | 0.0221 |
| *Proportion of (2) relative to (1)* | *1.0643* | *1.0774* | *1.1297* | *1.1604* |
| (3) Kolm EDE INHB (α=0.5) | 0.0104 | 0.0087 | 0.0111 | 0.0197 |
| *Proportion of (3) relative to (1)* | *1.0067* | *1.0167* | *1.0314* | *1.0339* |
| **Abbreviation:** EDE: equally distributed equivalent; INHB: incremental net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status; UC: usual care.  1 The societal NHB incorporates QALY gain and QALY-equivalent net societal gain minus public sector opportunity costs (translated to QALY-equivalent using cost-effectiveness threshold of £30,000 per QALY gained) for each SES quartile. The incremental NHB (INHB) is measured relative to UC.  2 This is the EDE INHB when Atkinson ε=0 [109]. | | | | |

#### 6.3.1.3 Economic value of community contributions

Table 6.13 shows the intervention use figures and the cost-effectiveness vs. CRC scenario (4) of three community involvement schemes that supplement CRC scenario (4): (a) community falls risk screening (for the proactive pathway) for 50% of persons not receiving GP contact; (b) community falls risk screening for persons in 3rd and 4th SES quartiles not receiving GP contact; and (c) increasing demand for self-referred intervention by 20%. The per-capita cost of community screening was assumed to be the same as that at GP contact (£10.83). The marketing cost for (c) was incorporated in the per-participant cost of self-referred exercise (Table 5.34). Schemes (a) and (b) resulted in community organisations conducting 6.7% and 6.0% of the total annual screenings, respectively. Due to binding capacity constraints, there were no major changes to pathway annual use rates under all schemes.

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| **Table 6.13** Economic value of community involvement schemes supplementing constrained recommended care with falls risk targeting under 40-year societal cost-utility analysis. | | | |
| N=385,192 | **(a) Community falls risk screening for 50% without GP contact** | **(b) Community falls risk screening for 3rd and 4th SES quartiles without GP contact** | **(c) 20% increase in self-referred intervention demand** |
| Constrained service annual use1 |  |  |  |
| *Falls clinic* | 9,000 | 9,000 | 8,985 |
| *Proactive Tai Chi* | 500 | 500 | 500 |
| *Self-referred interventions* | 2,000 | 2,000 | 2,000 |
| Pathway annual use |  |  |  |
| *Reactive* | 2,965 | 2,955 | 2,972 |
| *Proactive* | 8,241 | 8,245 | 8,217 |
| *Self-referred* | 2,000 | 2,000 | 2,000 |
| Total |  |  |  |
| Annual screening count |  |  |  |
| *GP routine contact* | 117,726 | 117,715 | 117,638 |
| *Community screening* | 8,512 | 7,490 | 0 |
|  | **Incremental outcomes relative to constrained recommended care with falls risk targeting (CRC scenario (4))** | | |
| Public sector costs |  |  |  |
| *(1) All-cause public sector costs2* | -£882,213 | -£4,548,389 | £1,438,692 |
| *(2) Fall-related healthcare costs* | -£1,807,139 | -£1,424,989 | -£854,358 |
| *Public sector intervention costs* | £3,080,746 | £2,677,635 | £19,146 |
| QALY | 430 | 235 | -93 |
| Societal outcomes |  |  |  |
| *Net productivity3* | -£1,499,589 | -£1,226,249 | -£6,194,390 |
| *Net private expenditure4* | -£3,137,032 | £193,387 | -£3,380,540 |
| *Net informal caregiving cost5* | £4,237,719 | -£7,712,359 | -£1,409,700 |
| Societal gain, QALY equivalent | -43 QALYs | 105 QALYs | -23 QALYs |
| Societal ICER using (1) | £5,690 per QALY gained6 | Dominated comparator7,8 | Dominated by comparator9,10 |
| Societal ICER using (2) | £3,296 per QALY gained | £3,681 per QALY gained | £7,167 per QALY gained11 |
| Societal INMB using (1)12 | £9,393,141 | £12,078,855 | -£4,953,702 |
| Societal INMB using (2) | £10,318,067 | £8,955,455 | -£2,660,653 |
| **Abbreviation:** CRC: constrained recommended care; ICER: incremental cost-effectiveness ratio; INMB: incremental net monetary benefit; LTC: long-term care; OOP: out-of-pocket; QALY: quality-adjusted life year; SES: socioeconomic status.  1 All outcomes were averaged across 20 model trial runs with different random number seeds.  2 Includes costs of fall-related primary and secondary healthcare, comorbidity primary and secondary healthcare, cost of dying, community healthcare, short-term social care, all-cause long-term care.  3 Includes values of paid and unpaid employment minus intervention time opportunity costs.  4 Includes OOP care expenditure and privately incurred LTC cost minus intervention private co-payments.  5 Includes informal caregiver burden/cost minus intervention caregiver time opportunity costs.  6 The public sector ICERs are £5,116 per QALY gained using (1) and £2,964 using (2).  7 The societal ICER using (1) is -£5,498 per QALY gained in the south-east quadrant of the cost-effectiveness plane.  8 The public sector ICERs are -£7,947 per QALY gained using (1) and £5,322 using (2).  9 The societal ICER using (1) is -£12,511 per QALY gained in the north-west quadrant of the cost-effectiveness plane.  10 The public sector ICERs are -£15,654 per QALY gained using (1) and £8,969 using (2).  11 This is positive due to QALY loss and net cost reduction, in the south-west quadrant of the cost-effectiveness plane.  12 Incremental net monetary benefits are estimated using the cost-effectiveness threshold of £30,000 per QALY gained. | | | |

There was nevertheless a marked contrast in result between the community falls risk screening schemes and the self-referred demand promotion scheme: the former were highly cost-effective vs. CRC scenario (4), while the latter generated efficiency losses. This finding can be attributed to the change generated by the community screening schemes in the client flows across the proactive and self-referred pathways. Under capacity constraints, high-risk individuals were more likely to access falls prevention in the proactive rather than the self-referred pathway. This was because the proactive interventions were risk-targeted, while the self-referred exercise was self-initiated; the average predicted falls risks were 68.8% for falls clinic clients and 40.5% for self-referred clients. Moreover, the constraints affected a smaller proportion of persons under the proactive than the self-referred pathway: the proactive client flow under constraint was 30.5% of the unconstrained flow in RC, while the proportion was 15.6% for the self-referred client flow. The community screening schemes hence transferred to the proactive pathway high-risk persons who otherwise would have had a smaller chance of accessing intervention in the self-referred pathway. Although the overall client numbers in the proactive and self-referred pathways did not vary greatly between CRC scenario (4) and the above schemes (due to binding capacity constraints), the change in the risk profile of clients generated significant outcome differences.

The societal INMBs in Table 6.13 were estimates of the decision-maker’s WTP on each scheme under the £30,000 per QALY gained threshold. Hence, for example, the decision-maker could spend £12.1 million over the 40-year horizon to fund a falls risk screening scheme operated by community organisations that targets the 3rd and 4th SES quartiles and processes around 7,500 screenings per year. Note that the per-capita cost of screening (£10.83) was already costed; the £12.1 million is an additional amount that can be invested for set-up.

Figure F13 compares the societal per-capita INHBs of community involvement schemes relative to CRC scenario (4). Table 6.14 compares the EDE INHBs of the community involvement schemes supplementing CRC scenario (4) vs. no supplementation under high relative and absolute inequality aversions. Only scheme (b) improved both equity and efficiency. Scheme (a) would be accepted over no supplementation but introduced equity-efficiency trade-offs. Scheme (c) produced EDE INHBs lower than the negative incremental no-aversion mean, implying that it worsened equity and efficiency.

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| **Table 6.14** SES-delineated EDE INHBs for community involvement schemes supplementing CRC with falls risk targeting relative to no supplementation. | | | |
| **Societal INHB1** | **Community FRS for 50% without GP contact in CRC(4) vs. CRC(4) alone** | **Community FRS for 3rd and 4th SES quartiles without GP contact in CRC(4) vs. CRC(4) alone** | **20% increase in self-referred demand in CRC(4) vs. CRC(4) alone** |
| (1) Incremental no-aversion mean2 | 0.0008 | 0.0017 | -0.0005 |
| (2) Atkinson EDE INHB (ε=30) | 0.0004 | 0.0026 | -0.0015 |
| *Proportion of (2) relative to (1)* | *0.4623* | *1.4884* | *2.8916* |
| (3) Kolm EDE INHB (α=0.5) | 0.0007 | 0.0018 | -0.0007 |
| *Proportion of (3) relative to (1)* | *0.9201* | *1.0383* | *1.3944* |
| **Abbreviation:** CRC(4): constrained recommended care scenario (4); EDE: equally distributed equivalent; FRS: falls risk screening; INHB: incremental net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status.  1 The societal NHB incorporates QALY gain and QALY-equivalent net societal gain minus public sector opportunity costs (translated to QALY-equivalent using cost-effectiveness threshold of £30,000 per QALY gained) for each SES quartile.  2 This is the EDE INHB when Atkinson ε=0 [109]. | | | |

#### 6.3.1.4 Double jeopardy problem

This section explores the impact of: (I) the double jeopardy (DJ) problem where societal intervention costs reduce the intervention demands of those in the 3rd and 4th SES quartiles by 50%; and (II) a policy where the demands are restored after the societal intervention costs for the 3rd and 4th SES quartiles are covered by the public sector, with the opportunity cost of this coverage falling on the 1st and 2nd SES quartiles (e.g., coverage via funds originally earmarked for more prosperous areas of Sheffield). Both scenarios were implemented on CRC scenario (4). Table 6.15 first evaluates these two scenarios relative to UC and then relative to each other; the intervention use figures for the two scenarios are also shown.

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| **Table 6.15** Impacts of (I) double jeopardy reducing intervention demands of 3rd and 4th SES quartile individuals and (II) public sector coverage of societal intervention costs under 40-year societal cost-utility analysis. | | | |
| N=385,192 | **(I) Double jeopardy: 50% reduction in intervention demands1** | **(II) Public sector coverage of societal intervention costs1,2** |  |
| Constrained service annual use3 |  |  |  |
| *Falls clinic* | 6,938 | 8,962 |  |
| *Proactive Tai Chi* | 500 | 500 |  |
| *Self-referred interventions* | 2,000 | 2,000 |  |
| Pathway annual use |  |  |  |
| *Reactive* | 2,200 | 2,969 |  |
| *Proactive* | 6,536 | 8,198 |  |
| *Self-referred* | 2,000 | 2,000 |  |
| Total | 10,736 | 13,167 |  |
|  |  |  |  |
|  | **Incremental outcomes relative to usual care** | | **(II) – (I) incremental** |
| Public sector costs |  |  |  |
| *(1) All-cause public sector costs4* | -£54,788,392 | -£69,811,771 | -£15,023,380 |
| *(2) Fall-related healthcare costs* | -£48,815,863 | -£61,888,647 | -£13,072,785 |
| *Public sector intervention costs* | £134,546,649 | £170,489,227 | £35,942,578 |
| QALY | 6,550 | 8,644 | 2,094 |
| Societal outcomes |  |  |  |
| *Net productivity5* | £10,679,302 | £25,946,460 | £15,267,158 |
| *Net private expenditure6* | -£2,902,928 | -£12,412,617 | -£9,509,689 |
| *Net informal caregiving cost7* | -£30,917,714 | -£49,148,209 | -£18,230,494 |
| Societal gain, QALY equivalent | 742 QALYs | 1,458 QALYs | 717 QALYs |
| Societal ICER using (1) | £10,939 per QALY gained8 | £9,966 per QALY gained9 | £7,443 per QALY gained10 |
| Societal ICER using (2) | £11,758 per QALY gained | £10,750 per QALY gained | £8,137 per QALY gained |
| Societal INMB using (1)11 | £138,985,110 | £202,384,670 | £63,399,560 |
| Societal INMB using (2) | £133,012,581 | £194,461,546 | £61,448,965 |
| **Abbreviation:** ICER: incremental cost-effectiveness ratio; INMB: incremental net monetary benefit; LTC: long-term care; OOP: out-of-pocket; QALY: quality-adjusted life year; SES: socioeconomic status  1 The scenarios are implemented on capacity constrained recommended care with falls risk targeting.  2 The public sector covers the societal intervention costs of 3rd and 4th SES quartiles; this restores the intervention demands to the base case levels (prior to double jeopardy scenario).  3 All outcomes were averaged across 20 model trial runs with different random number seeds.  4 Includes costs of fall-related primary and secondary healthcare, comorbidity primary and secondary healthcare, cost of dying, community healthcare, short-term social care, all-cause long-term care.  5 Includes values of paid and unpaid employment minus intervention time opportunity costs.  6 Includes OOP care expenditure and privately incurred LTC cost minus intervention private co-payments.  7 Includes informal caregiver burden/cost minus intervention caregiver time opportunity costs.  8 The public sector ICERs are £12,177 per QALY gained using (1) and £13,089 using (2).  9 The public sector ICERs are £11,648 per QALY gained using (1) and £12,564 using (2).  10 The public sector ICERs are £9,991 per QALY gained using (1) and £10,922 using (2).  11 Incremental net monetary benefits are estimated using the cost-effectiveness threshold of £30,000 per QALY gained. | | | |

The societal ICERs considering all-cause costs relative to UC were higher under both scenarios than when CRC scenario (4) was evaluated against UC (Table 6.11), but they remained below £30,000 per QALY gained threshold. The societal ICER of scenario (II) relative to (I) was £7,443 per QALY gained, suggesting that it would be highly cost-effective for the public sector to reimburse the societal intervention costs of socially vulnerable persons if there is a substantial DJ problem.

The decision-maker may also consider implementing scenario (II) even in the absence of any DJ problem. This would reduce societal intervention costs incurred by the 3rd and 4th SES quartiles by £23.3 million, equivalent to 388 QALYs at the £60,000 per QALY gained threshold, and increase the public sector costs by the same amount, i.e., equivalent to 776 QALYs at the £30,000 per QALY gained threshold. Hence, there would be an efficiency loss of 388 QALYs, equivalent to £11.6 million; the societal ICER would be £60,000 per QALY gained (£23.3 million divided by 388 QALYs). Therefore, it would not be cost-effective to implement scenario (II) in the absence of a major DJ problem as in scenario (I).

Table 6.16 compares the EDE INHBs of scenarios (I) and (II) relative to UC, scenario (II) relative to (I), and scenario (II) relative to CRC scenario (4) under high relative and absolute inequality aversions. Scenario (I) introduced an equity-efficiency trade-off relative to UC. Scenario (II) improved both equity and efficiency relative to UC and scenario (I). Interestingly, scenario (II) reduced efficiency relative to CRC scenario (4) as discussed, but improved equity to an extent that it would be preferred over CRC scenario (4) under high relative and absolute inequality aversions. The incremental EDE INHB of scenario (II) relative to CRC scenario (4) became positive when Atkinson ε=2 and Kolm α=0.45.

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| **Table 6.16** SES-delineated EDE INHBs for double jeopardy problem and public sector coverage scenarios relative to different comparators. | | | | |
| **Societal INHB1** | **DJ problem scenario (I) vs. UC** | **PS coverage scenario (II) vs. UC** | **Scenario (II) vs. (I)** | **Scenario (II) vs. CRC(4)** |
| (1) Incremental no-aversion mean2 | 0.0120 | 0.0182 | 0.0062 | -0.0008 |
| (2) Atkinson EDE INHB (ε=30) | 0.0083 | 0.0244 | 0.0161 | 0.0023 |
| *Proportion of (2) relative to (1)* | *0.6918* | *1.3393* | *2.5949* | *-2.8535* |
| (3) Kolm EDE INHB (α=0.5) | 0.0108 | 0.0198 | 0.0090 | 0.0001 |
| *Proportion of (3) relative to (1)* | *0.8982* | *1.0858* | *1.4496* | *-0.1311* |
| **Abbreviation:** CRC(4): constrained recommended care scenario (4); DJ: double jeopardy; EDE: equally distributed equivalent; INHB: incremental net health benefit; QALY: quality-adjusted life year; SES: socioeconomic status; UC: usual care.  1 The societal NHB incorporates QALY gain and QALY-equivalent net societal gain minus public sector opportunity costs (translated to QALY-equivalent using cost-effectiveness threshold of £30,000 per QALY gained) for each SES quartile.  2 This is the EDE INHB when Atkinson ε=0 [109]. | | | | |

#### 6.3.1.5 Environmental intervention

Table F21 shows the impact of four environmental intervention scenarios: (i) physical activity (PA) promotion that increases the probability of engaging in high physical activity by 5%; (ii) PA promotion with the same efficacy targeting the 3rd and 4th SES quartiles; (iii) falls hazard (FH) removal that reduces the falls risk by 5%; and (iv) FH removal with the same efficacy targeting the 3rd and 4th SES quartiles. The environmental interventions supplemented: (A) UC; and (B) CRC scenario (4). They were then compared to UC alone. The environmental interventions were costed based on previous modelling evidence. Nshimyumukiza (2013) reported that PA promotion cost CAD$3 (around £3 in 2021 price) per person annually [336]. Johansson (2008) reported that a combined programme of multifactorial and environmental (addressing falls hazards) interventions cost SEK6,451,149 (£729,988) for 5,500 residents in one year [128]; if the environmental intervention comprised half of the total cost, this amounted to £66.36 per person annually.

PA promotion, implemented universally or targeted at 3rd and 4th SES quartiles, was highly cost-effective vs. UC with societal ICERs (considering all-cause costs) of £2,110 and £1,692 per QALY gained, respectively. When supplemented to CRC scenario (4), the combined programme improved the cost-effectiveness vs. UC when compared to non-supplemented CRC scenario (4). The targeted PA promotion generated similar QALY gains to universal promotion (9,452 and 10,506 QALYs, respectively) when supplementing CRC but not when implemented singly (998 and 2,321 QALYs).

FH removal produced societal ICERs (considering all-cause costs) of £9,783 and £8,240 per QALY gained relative to UC when implemented universally and targeted, respectively. When supplemented to CRC scenario (4), the combined programme reduced the cost-effectiveness vs. UC when compared to non-supplemented CRC scenario (4). But the aggregate societal INMBs considering all-cause costs (£404.7 million universal, £320.5 million targeted) were higher for the combined programme than CRC alone (£214.0 million), indicating the higher reach of the programme.

Table F22 compared the four scenarios vs. UC supplemented with the same respective environmental interventions. For all four interventions, the cost-effectiveness of CRC scenario (4) vs. UC worsened when compared to no supplementary environmental intervention. Hence, there was a diminishing return to CRC when implemented in the context of an environmental intervention.

Figure F14 shows the societal per-capita INHBs (considering all-cause costs) by SES quartile of the four environmental interventions supplementing UC vs. UC alone. Figure F15 shows the same outcomes for the four interventions supplementing CRC scenario (4) vs. UC alone. The pro-poor gradient to the INHBs was visible for targeted, but not universal, environmental interventions.

Table 6.17 compares the EDE INHBs of the four environmental interventions (supplementing usual care or CRC scenario (4)) relative to UC alone under high relative and absolute inequality aversions. Universal PA promotion and FH removal, when supplementing UC, worsened relative and absolute inequities vs. UC alone. Targeting the 3rd and 4th SES quartiles improved the equity gains. Even so, PA promotion worsened relative inequity when supplementing UC. Overall, the environmental interventions should be targeted and supplement CRC scenario (4) to improve equity and efficiency.

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| **Table 6.17** SES-delineated EDE INHBs for environmental interventions relative to usual care. | | | | |
| **Societal INHB1** | **(i) Universal PA promotion vs. UC** | **(ii) 3rd/4th SES quartile PA promotion vs. UC** | **(iii) Universal FH removal vs. UC** | **(iv) 3rd/4th SES quartile FH removal vs. UC** |
|  | **(A) Environmental interventions supplementing UC** | | | |
| (1) Incremental no-aversion mean2 | 0.0072 | 0.0032 | 0.0214 | 0.0133 |
| (2) Atkinson EDE INHB (ε=30) | 0.0036 | 0.0030 | 0.0178 | 0.0384 |
| *Proportion of (2) relative to (1)* | *0.4983* | *0.9286* | *0.8333* | *2.8747* |
| (3) Kolm EDE INHB (α=0.5) | 0.0062 | 0.0033 | 0.0203 | 0.0207 |
| *Proportion of (3) relative to (1)* | *0.8552* | *1.0249* | *0.9490* | *1.5496* |
|  | **(B) Environmental interventions supplementing CRC(4)** | | | |
| (1) Incremental no-aversion mean | 0.0252 | 0.0213 | 0.0351 | 0.0298 |
| (2) Atkinson EDE INHB (ε=30) | 0.0243 | 0.0250 | 0.0353 | 0.0591 |
| *Proportion of (2) relative to (1)* | *0.9640* | *1.1745* | *1.0051* | *1.9866* |
| (3) Kolm EDE INHB (α=0.5) | 0.0248 | 0.0223 | 0.0349 | 0.0377 |
| *Proportion of (3) relative to (1)* | *0.9827* | *1.0459* | *0.9920* | *1.2660* |
| **Abbreviation:** CRC(4): constrained recommended care scenario (4); DJ: double jeopardy; EDE: equally distributed equivalent; FH: falls hazard; INHB: incremental net health benefit; PA: physical activity; QALY: quality-adjusted life year; SES: socioeconomic status; UC: usual care.  1 The societal NHB incorporates QALY gain and QALY-equivalent net societal gain minus public sector opportunity costs (translated to QALY-equivalent using cost-effectiveness threshold of £30,000 per QALY gained) for each SES quartile.  2 This is the EDE INHB when Atkinson ε=0 [109]. | | | | |

### 6.3.2 Comparison of intervention strategies

This section compares the 23 intervention strategies, including RC and the alternative scenarios. The comparison is first conducted under the primary evaluation framework of 40-year societal CUA (Section 6.3.2.1), then under the secondary framework of five-year public sector ROI (Section 6.3.2.2).

#### 6.3.2.1 Comparison under 40-year societal cost-utility analysis

Table 6.18 arranges the strategies by public sector all-cause cost in increasing order. Strategies with lower societal QALYs than any strategy in a row above were strongly dominated by the latter; rows for these strategies are shaded in dark grey. For example, strategy [6] of reactive-self-referred pathway combination strongly dominated strategies [7]-[17]. Strategy [4] was extendedly dominated by strategies [3] and [6], and strategy [18] by strategies [6] and [19]. They are shaded in light grey. Hence, there were six non-dominated strategies (other than UC): [1] PA promotion targeting the 3rd and 4th SES quartiles supplementing UC; [2] RC reactive pathway only; [3] universal PA promotion supplementing UC; [6] RC reactive-self-referred pathways; [19] universal FH removal supplementing CRC scenario (4); and [22] RC. The ICERs between these strategies are shown in the penultimate column. Table 6.18 also shows the aggregate INMBs vs. UC in the final column.

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| **Table 6.18** Comparison of intervention strategies under 40-year societal cost-utility analysis. | | | | | | | | |
| **[#]** | **Strategy1,2** | **Societal QALY** | **Public sector all-cause cost (£ million)** | **Incremental societal QALY vs. UC** | **Incremental public sector all-cause cost vs. UC** | **ICER vs. UC** | **ICER vs. next best alternative** | **Aggregate INMB vs. UC** |
| [0] | UC | 2,014,177 | £10,089.48 |  |  |  |  |  |
| [1] | UC + 3rd/4th SES PA promotion | 2,015,587 | £10,091.86 | 1410 | £2,384,663 | £1,692 | £1,692 | £39,907,265 |
| [2] | RC reactive pathway only | 2,017,000 | £10,094.94 | 2823 | £5,468,709 | £1,937 | £2,182 | £79,222,621 |
| [3] | UC + universal PA promotion | 2,017,365 | £10,096.20 | 3188 | £6,725,948 | £2,110 | £3,445 | £88,912,151 |
| [4] | RC SR pathway only3 | 2,024,314 | £10,138.32 | 10137 | £48,844,062 | £4,818 |  | £255,262,807 |
| [5] | UC + 3rd/4th SES FH removal | 2,020,495 | £10,141.53 | 6318 | £52,059,168 | £8,240 |  | £137,477,404 |
| [6] | RC reactive & SR pathways | 2,026,965 | £10,144.08 | 12788 | £54,599,917 | £4,270 | £4,987 | £329,027,507 |
| [7] | CRC(4) + 3rd/4th SES FRS | 2,024,232 | £10,165.01 | 10055 | £75,539,518 | £7,513 |  | £226,098,140 |
| [8] | CRC(4): falls risk targeting | 2,023,891 | £10,166.89 | 9714 | £77,410,272 | £7,969 |  | £214,019,285 |
| [9] | CRC(4) + 3rd/4th SES PA promote | 2,024,900 | £10,167.93 | 10723 | £78,454,739 | £7,316 |  | £243,241,891 |
| [10] | CRC(4) + SR demand 20% increase | 2,023,775 | £10,168.34 | 9598 | £78,868,110 | £8,217 |  | £209,065,582 |
| [11] | CRC(4) + FRS for 50% | 2,024,278 | £10,169.08 | 10101 | £79,608,805 | £7,882 |  | £223,412,425 |
| [12] | CRC(1): random allocation | 2,020,654 | £10,169.80 | 6477 | £80,326,978 | £12,401 |  | £113,990,748 |
| [13] | CRC(4) + universal PA promotion | 2,026,541 | £10,170.78 | 12364 | £81,305,259 | £6,576 |  | £289,618,874 |
| [14] | CRC(3): frailty targeting | 2,020,901 | £10,172.88 | 6724 | £83,406,606 | £12,405 |  | £118,309,448 |
| [15] | CRC(4) + PS societal costs | 2,024,279 | £10,190.15 | 10102 | £100,677,456 | £9,966 |  | £202,384,670 |
| [16] | CRC(2): no repeated provision | 2,020,899 | £10,196.48 | 6722 | £107,003,622 | £15,917 |  | £94,669,816 |
| [17] | UC + universal FH removal | 2,026,880 | £10,213.75 | 12703 | £124,271,326 | £9,783 |  | £256,830,286 |
| [18] | CRC(4) + 3rd/4th SES FH removal4 | 2,029,194 | £10,219.49 | 15016 | £130,019,256 | £8,658 |  | £320,475,176 |
| [19] | CRC(4) + universal FH removal | 2,035,091 | £10,312.22 | 20914 | £222,747,128 | £10,651 | £20,691 | £404,679,723 |
| [20] | RC proactive pathway only | 2,025,448 | £10,321.90 | 11271 | £232,429,283 | £20,622 |  | £105,706,657 |
| [21] | RC reactive & proactive pathways | 2,027,687 | £10,325.96 | 13510 | £236,483,262 | £17,505 |  | £168,808,598 |
| [22] | RC | 2,035,126 | £10,359.25 | 20949 | £269,772,990 | £12,877 | £1,337,595 | £358,708,621 |
| [23] | RC proactive & SR pathways | 2,032,901 | £10,361.90 | 18724 | £272,423,328 | £14,550 |  | £289,283,028 |
| **Abbreviation:** CRC(#): constrained recommended care scenario (#); FH: falls hazard; FRS: falls risk screening; ICER: incremental cost-effectiveness ratio; INMB: incremental net monetary benefit; PA: physical activity; PS: public sector; QALY: quality-adjusted life year; RC: recommended care; SES: socioeconomic status; SR: self-referred; UC: usual care.  1 All outcomes were averaged across 20 model trial runs with different random number seeds.  2 Strongly dominated strategies are highlighted in dark grey; extendedly dominated strategies in light grey.  3 The ICER of this strategy relative to strategy [3] is £6,061 per QALY gained; the ICER of strategy [6] relative to this strategy is £2,171 per QALY gained. Hence, this strategy is extendedly dominated by strategies [3] and [6].  4 The ICER of this strategy relative to strategy [6] is £33,837 per QALY gained; the ICER of strategy [19] relative to this strategy is £15,723 per QALY gained. Hence, this strategy is extendedly dominated by strategies [6] and [19]. | | | | | | | | |

Figure 6.10 displays the incremental societal QALYs (x-axis) and the incremental public sector all-cause costs (y-axis) vs. UC of the 23 strategies, labelled by the number in Table 6.18. The comparison of the incremental outcomes vs. UC was justified because ‘no intervention’ was not considered as a strategy option (Section 5.4.3). All strategies lay in the north-east quadrant of the cost-effectiveness plane since no strategy dominated UC. The six non-dominated strategies have coloured diamonds. If the commonly accepted cost-effectiveness threshold of £30,000 per QALY gained is adopted without any budget constraint, then strategy [19] would be the optimal strategy with ICER of £10,651 per QALY gained and aggregate INMB of £404.7 million vs. UC.

Threshold: £30,000 per QALY gained

Threshold: £20,000 per QALY gained

**Figure 6.10** Incremental societal QALYs and public sector all-cause costs of intervention strategies relative to usual care under 40-year societal cost-utility analysis. **Note:** See Table 6.18 for strategy label by [#]; non-dominated strategies are shown in filled, coloured diamonds. **Abbreviation:** QALY: quality-adjusted life year; UC: usual care.

A further factor to consider is the aggregate budget impact. Table 6.18 had shown the public sector budget impact of each strategy in the form of incremental public sector all-cause costs vs. UC. If the commissioner cannot incur a net cost above, say, £100 million over the 40-year horizon, then this would rule out strategies [19] and [22]. In this case, strategy [6] would be the optimal strategy.

Regarding the equity-efficiency impacts, Table 6.19 shows the EDE INHBs of all strategies vs. UC under: no SES-delineated inequality aversion; high relative inequality aversion (Atkinson ε=30); and high absolute inequality aversion (Kolm α=0.5). All benefits were estimated under the £30,000 per QALY gained threshold. The strategies were arranged by increasing incremental no-aversion mean.

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| **Table 6.19** Incremental equally distributed equivalent societal net health benefits across SES quartiles of intervention strategies relative to usual care. | | | | | | |
| **[#]1** | **Strategy2** | **(1) Incremental no-aversion mean3** | **(2) Atkinson EDE INHB (ε=30)** | *Proportion of (2) relative to (1)* | **(3) Kolm EDE INHB (α=0.5)** | *Proportion of (3) relative to (1)* |
| [1] | UC + 3rd/4th SES PA promotion | 0.0032 | 0.0030 | *0.9286* | 0.0033 | *1.0249* |
| [2] | RC reactive pathway | 0.0072 | 0.0068 | *0.9471* | 0.0072 | *1.0022* |
| [3] | UC + universal PA promotion | 0.0072 | 0.0036 | *0.4983* | 0.0062 | *0.8552* |
| [16] | CRC(2): no repeated provision | 0.0086 | 0.0092 | *1.0774* | 0.0087 | *1.0167* |
| [20] | RC proactive pathway | 0.0096 | 0.0121 | *1.2659* | 0.0101 | *1.0550* |
| [12] | CRC(1): random allocation | 0.0103 | 0.0110 | *1.0643* | 0.0104 | *1.0067* |
| [14] | CRC(3): frailty targeting | 0.0108 | 0.0122 | *1.1297* | 0.0111 | *1.0314* |
| [5] | UC + 3rd/4th SES FH removal | 0.0133 | 0.0384 | *2.8747* | 0.0207 | *1.5496* |
| [21] | RC reactive & proactive pathways | 0.0151 | 0.0188 | *1.2446* | 0.0159 | *1.0526* |
| [15] | CRC(4) + PS societal costs | 0.0182 | 0.0244 | *1.3393* | 0.0198 | *1.0858* |
| [10] | CRC(4) + SR demand 20% increase | 0.0185 | 0.0206 | *1.1112* | 0.0190 | *1.0237* |
| [8] | CRC(4): falls risk targeting | 0.0191 | 0.0221 | *1.1604* | 0.0197 | *1.0339* |
| [11] | CRC(4) + FRS for 50% | 0.0199 | 0.0225 | *1.1314* | 0.0205 | *1.0292* |
| [7] | CRC(4) + 3rd/4th SES FRS | 0.0208 | 0.0247 | *1.1875* | 0.0215 | *1.0343* |
| [9] | CRC(4) + 3rd/4th SES PA promote | 0.0213 | 0.0250 | *1.1745* | 0.0223 | *1.0459* |
| [17] | UC + universal FH removal | 0.0214 | 0.0178 | *0.8333* | 0.0203 | *0.9490* |
| [4] | RC SR pathway | 0.0221 | 0.0223 | *1.0085* | 0.0219 | *0.9898* |
| [13] | CRC(4) + universal PA promotion | 0.0252 | 0.0243 | *0.9640* | 0.0248 | *0.9827* |
| [23] | RC proactive & SR pathways | 0.0258 | 0.0259 | *1.0047* | 0.0256 | *0.9943* |
| [6] | RC reactive & SR pathways | 0.0282 | 0.0284 | *1.0056* | 0.0280 | *0.9918* |
| [18] | CRC(4) + 3rd/4th SES FH removal | 0.0298 | 0.0591 | *1.9866* | 0.0377 | *1.2660* |
| [22] | RC | 0.0307 | 0.0343 | *1.1169* | 0.0311 | *1.0121* |
| [19] | CRC(4) + universal FH removal | 0.0352 | 0.0353 | *1.0052* | 0.0349 | *0.9921* |
| **Abbreviation:** CRC(#): constrained recommended care scenario (#); EDE: equally distributed equivalent; FH: falls hazard; FRS: falls risk screening; INHB: incremental net health benefit; PA: physical activity; PS: public sector; RC: recommended care; SES: socioeconomic status; SR: self-referred; UC: usual care.  1 Assigned in Table 6.18 according to increasing incremental public sector all-cause cost.  2 All outcomes were averaged across 20 model trial runs with different random number seeds.  3 This is the EDE INHB when Atkinson ε=0 [109]. All INHBs were estimated using the cost-effectiveness threshold of £30,000 per QALY gained. | | | | | | |

Strategy [19] generated the highest incremental no-aversion mean vs. UC; this concurs with the outcome above that [19] would be the optimal strategy when considering efficiency alone. However, strategy [18], which had been extendedly dominated by [6] and [19] above, generated the highest EDE INHBs under both relative and absolute inequality aversions. Thus, the added consideration of equity changed the strategy rankings: the environmental FH removal supplementing CRC scenario (4) should be targeted at 3rd and 4th SES quartiles (strategy [18]) rather than universal (strategy [19]). Figures F16 and F17 show that these results are robust at lower Atkinson and Kolm indices, respectively. For relative inequality aversion, strategy [19] has the highest EDE INHB of all strategies when the Atkinson index ε ranges from 0 to around 2; thereafter, strategy [18] has the highest EDE INHB. Likewise for absolute inequality aversion, strategy [19] had the highest EDE INHB up to Kolm index α=0.35, after which strategy [18] had the highest.

The budget impact should again be considered. Strategies [18], [19] and [22] all generated high budget impacts (Table 6.18) and may thus be ruled out. In this case, [6] would again be the optimal strategy. Strategies [1] to [3], which were three non-dominated strategies with modest budget impacts, ranked lowest in terms of both incremental no-aversion mean and EDE INHBs due to their low aggregate efficiency gains and adverse impacts on (relative) SES-delineated equity.

Table 6.20 compares the incremental individual-level lifetime outcomes of all 23 strategies vs. UC. The top three strategies with the largest impact varied by outcome. Table 6.20 also constructs a combined score across outcomes (1)-(4) and (6). Strategy [19] ranked highest according to this score, followed by [22] then [23]. Strategy [18] ranked joint ninth according to this score. Therefore, strategy [19] performed best in terms of efficiency and individual-level lifetime outcomes.

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| **Table 6.20** Incremental individual-level lifetime outcomes of intervention strategies relative to usual care. | | | | | | | | | |
| **[#]1** | **Strategy2** | **Incremental outcome relative to usual care (top three rank #)** | | | | | | | **Combined score3 (rank #)** |
| **(1) Fair health-related innings** | **(2) Fair wellbeing-related innings** | **(3) Productive ageing** | **(4) CPE** | **(5) CPE without int. cost** | **(6) EICB** | **(7) EICB without int. cost** |
| [1] | UC + 3rd/4th SES PA promotion | 0 | 2 | 5 | 5 | 5 | -11 | -11 | 13 (19) |
| [2] | RC reactive pathway only | 1 | 0 | 3 | 0 | -2 | -19 | -21 | 23 (=17) |
| [3] | UC + universal PA promotion | 0 | 1 | 3 | 2 | 2 | -20 | -20 | 23 (=17) |
| [4] | RC SR pathway only | 4 | 2 | 12 | 1 | -6 | -19 | -22 | 37 (=11) |
| [5] | UC + 3rd/4th SES FH removal | 9 | 3 | 0 | -5 | -5 | -12 | -12 | 30 (14) |
| [6] | RC reactive & SR pathways | 11 | 2 | 0 | -4 | -11 | -20 | -24 | 37 (=11) |
| [7] | CRC(4) + 3rd/4th SES FRS | 14 | 5 | 7 | 1 | -6 | -7 | -9 | 32 (13) |
| [8] | CRC(4): falls risk targeting | 5 | 1 | 9 | 2 | -6 | -25 | -27 | 38 (10) |
| [9] | CRC(4) + 3rd/4th SES PA promote | 18 | 11 (2) | 7 | -5 | -12 (=3) | -22 | -24 | 63 (5) |
| [10] | CRC(4) + SR demand 20% increase | 6 | 1 | 4 | -5 | -12 (=3) | -20 | -22 | 35 (=12) |
| [11] | CRC(4) + FRS for 50% | 9 | 1 | 16 (=3) | -10 (1) | -19 (1) | -18 | -21 | 54 (7) |
| [12] | CRC(1): random allocation | 6 | 2 | 10 | 11 | 1 | -22 | -23 | 29 (15) |
| [13] | CRC(4) + universal PA promotion | 12 | 2 | 8 | 5 | -2 | -29 | -30 | 46 (=9) |
| [14] | CRC(3): frailty targeting | 8 | 2 | 5 | 6 | -4 | -10 | -12 | 18 (18) |
| [15] | CRC(4) + PS societal costs | 5 | 1 | 9 | -9 (2) | -9 | -26 | -27 | 50 (8) |
| [16] | CRC(2): no repeated provision | 0 | 1 | 6 | 3 | -2 | -23 | -25 | 27 (16) |
| [17] | UC + universal FH removal | 22 (3) | 7 (3) | 14 | -6 (3) | -6 | -19 | -19 | 68 (4) |
| [18] | CRC(4) + 3rd/4th SES FH removal | 8 | 1 | 0 | -4 | -12 (=3) | -32 (2) | -35 (2) | 46 (=9) |
| [19] | CRC(4) + universal FH removal | 23 (2) | 6 | 21 (1) | -5 | -13 (2) | -31 (3) | -33 (=3) | 86 (1) |
| [20] | RC proactive pathway only | 6 | 0 | 6 | 4 | -4 | -27 | -32 | 35 (=12) |
| [21] | RC reactive & proactive pathways | 13 | 2 | 16 (=3) | 0 | -11 | -26 | -33 (=3) | 57 (6) |
| [22] | RC | 35 (1) | 25 (1) | 17 (2) | 10 | -5 | -15 | -24 | 82 (2) |
| [23] | RC proactive & SR pathways | 21 | 6 | 6 | 3 | -10 | -40 (1) | -48 (1) | 70 (3) |
| **Abbreviation:** CPE: catastrophic private expenditure; CRC(#): constrained recommended care scenario (#); EICB: excessive informal caregiver burden; FH: falls hazard; FRS: falls risk screening; INHB: incremental net health benefit; PA: physical activity; PS: public sector; RC: recommended care; SES: socioeconomic status; SR: self-referred; UC: usual care.  1 Assigned in Table 6.18 according to increasing incremental public sector all-cause cost.  2 All outcomes were averaged across 20 model trial runs with different random number seeds.  3 Calculated by adding outcomes (1), (2) and (3), then subtracting (4) and (6). | | | | | | | | | |

#### 6.3.2.2 Comparison under five-year public sector return on investment analysis

Table 6.21 shows the public sector ROI over the five-year horizon of alternative intervention strategies vs. UC. It shows the ROIs considering all-cause and fall-related costs, the ROIs (considering all-cause costs) by SES quartile, and the net public sector budget impacts.

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| **Table 6.21** Public sector returns on investment considering all-cause costs of intervention strategies relative to usual care under five-year horizon. | | | | | | | | |
| **[#]1** | **Strategy2** | **Incremental PS AC cost** | **ROI (£ per £1 invested)** | | **ROI for AC cost by SES quartile** | | | |
| AC cost | Fall cost | **1st** | **2nd** | **3rd** | **4th** |
| [1] | UC + 3rd/4th SES PA promotion | -£1,034,767 | 1.121 | 0.306 | -0.051 | -0.015 | 1.465 | 3.429 |
| [2] | RC reactive pathway only | £1,063,538 | 0.799 | 0.609 | 0.627 | 0.244 | 1.023 | 1.652 |
| [3] | UC + universal PA promotion | £855,699 | 0.508 | 0.034 | 0.136 | 0.271 | 0.468 | 2.790 |
| [4] | RC SR pathway only | £10,368,413 | 0.312 | 0.223 | 0.276 | 0.176 | 0.406 | 0.410 |
| [5] | UC + 3rd/4th SES FH removal | £10,518,831 | 0.352 | 0.225 | -0.081 | -0.066 | 0.659 | 0.807 |
| [6] | RC reactive & SR pathways | £13,131,272 | 0.382 | 0.315 | 0.327 | 0.223 | 0.543 | 0.400 |
| [7] | CRC(4)+ 3rd/4th SES FRS | £16,087,595 | 0.398 | 0.329 | 0.374 | 0.308 | 0.411 | 0.526 |
| [8] | CRC(4): falls risk targeting | £15,694,175 | 0.388 | 0.325 | 0.374 | 0.236 | 0.444 | 0.495 |
| [9] | CRC(4)+ 3rd/4th SES PA promote | £16,572,821 | 0.372 | 0.327 | 0.307 | 0.275 | 0.517 | 0.440 |
| [10] | CRC(4)+ SR demand 20% increase | £15,857,234 | 0.381 | 0.333 | 0.356 | 0.251 | 0.452 | 0.452 |
| [11] | CRC(4)+ FRS for 50% | £16,243,173 | 0.396 | 0.329 | 0.315 | 0.324 | 0.442 | 0.569 |
| [12] | CRC(1): random allocation | £25,059,895 | 0.285 | 0.224 | 0.240 | 0.177 | 0.390 | 0.310 |
| [13] | CRC(4)+ universal PA promotion | £17,248,068 | 0.370 | 0.325 | 0.332 | 0.271 | 0.467 | 0.372 |
| [14] | CRC(3): frailty targeting | £19,740,029 | 0.344 | 0.309 | 0.332 | 0.267 | 0.387 | 0.367 |
| [15] | CRC(4)+ PS societal costs | £20,144,679 | 0.331 | 0.277 | 0.374 | 0.236 | 0.326 | 0.362 |
| [16] | CRC(2): no repeated provision | £28,788,180 | 0.246 | 0.203 | 0.207 | 0.182 | 0.310 | 0.293 |
| [17] | UC + universal FH removal | £9,997,232 | 0.472 | 0.381 | 0.434 | 0.450 | 0.506 | 0.493 |
| [18] | CRC(4)+ 3rd/4th SES FH removal | £27,122,495 | 0.347 | 0.275 | 0.154 | 0.128 | 0.852 | 0.902 |
| [19] | CRC(4)+ universal FH removal | £26,040,263 | 0.406 | 0.337 | 0.354 | 0.377 | 0.464 | 0.422 |
| [20] | RC proactive pathway only | £53,413,879 | 0.209 | 0.172 | 0.175 | 0.163 | 0.254 | 0.249 |
| [21] | RC reactive & proactive pathways | £54,209,118 | 0.243 | 0.202 | 0.207 | 0.193 | 0.268 | 0.333 |
| [22] | RC | £63,508,594 | 0.237 | 0.195 | 0.175 | 0.233 | 0.268 | 0.315 |
| [23] | RC proactive & SR pathways | £62,923,292 | 0.207 | 0.178 | 0.180 | 0.179 | 0.247 | 0.221 |
| **Abbreviation:** AC: all-cause; CRC(#): constrained recommended care scenario (#); FH: falls hazard; FRS: falls risk screening; PA: physical activity; PS: public sector; RC: recommended care; ROI: return on investment; SES: socioeconomic status; SR: self-referred; UC: usual care.  1 Assigned in Table 6.18 according to increasing incremental public sector all-cause cost.  2 All outcomes were averaged across 20 model trial runs with different random number seeds. | | | | | | | | |

Strategy [1] of PA promotion targeting the 3rd and 4th SES quartiles was the only strategy generating a break-even return (ROI above one). There was a clear pro-poor gradient to the strategy’s ROIs, with those for the 1st and 2nd SES quartiles being negative due to their incurring the opportunity cost of PA promotion while deriving no efficacy. However, strategy [1]’s return worsens over longer time horizons: the overall ROI considering all-cause cost is 0.841 for the 20-year horizon and 0.391 for 40-year. This can be attributed to the greater longevity increases under longer time horizons which in turn accrue greater comorbidity care costs. Under the 40-year horizon, strategy [1] increased the average life expectancy for those aged 65 at baseline by 0.1 years and all-cause comorbidity care cost by £180 per person (total £1.03 million). The relatively small intervention cost of the strategy – £3.9 million under the 40-year horizon, compared to £397.0 million for RC – makes its ROI highly sensitive to changes in comorbidity care costs. This ROI trajectory is significant for environmental interventions since they would typically plan over a longer time horizon to accommodate long-term environmental changes.

Strategies [2] and [3] produced break-even returns for 3rd and/or 4th SES quartiles but not so for the whole population. These findings could motivate SES-based targeting, but feasibility may be an issue: it may not be feasible, for example, to discriminate clients by SES when implementing the reactive interventions under [2]. As for [3], the SES-based targeting would produce strategy [1]. Strategies [5] and [18] involving targeted FH removal produced returns close to break-even for the 4th SES quartile.

### 6.3.3 Commissioning recommendations

This section formulates recommendations for Sheffield commissioners. Table 6.22 lists the candidate strategies and the rationale under the primary and secondary evaluation frameworks.

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| **Table 6.22** Candidate intervention strategies for commissioning. | | | |
| **[#]1** | **Strategy** | **Rationale** | |
| **40-year horizon, societal CUA** | **5-year horizon, PS ROI** |
| [1] | UC + 3rd/4th SES PA promotion | Non-dominated strategy; ICER (AC cost) £1,692 per QALY vs. UC; small PS budget impact (£2.4m). | ROI (AC cost) 1.121; pro-poor ROI gradient. |
| [2] | RC reactive pathway only | Non-dominated strategy; ICER (AC cost) £1,937 per QALY vs. UC; small PS budget impact (£5.5m). | ROI (AC cost) above one for 3rd & 4th SES quartiles; pro-poor ROI gradient. |
| [3] | UC + universal PA promotion | Non-dominated strategy; ICER (AC cost) £2,110 per QALY vs. UC; small PS budget impact (£6.7m). | ROI (AC cost) above one for 4th SES quartile; pro-poor ROI gradient. |
| [5] | UC + 3rd/4th SES FH removal | 2nd highest EDE INHB2 under Atkinson ε=30. | ROI (AC cost) approaching one for 4th SES quartile; pro-poor ROI gradient. |
| [6] | RC reactive & SR pathways | Non-dominated strategy; ICER (AC cost) £4,270 per QALY vs. UC; 3rd highest aggregate INMB (£329.0m) |  |
| [18] | CRC(4) + 3rd/4th SES FH removal | Highest EDE INHB under Atkinson ε=30 and Kolm α=0.5. | ROI (AC cost) approaching one for 4th SES quartile; pro-poor ROI gradient. |
| [19] | CRC(4) + universal FH removal | Non-dominated strategy; ICER (AC cost) £10,651 per QALY vs. UC; highest aggregate INMB (£404.7m); 2nd highest EDE INHB under Kolm α=0.5; highest impact on individual-level lifetime outcomes. |  |
| [22] | RC | 2nd highest impact on individual-level lifetime outcomes; 2nd highest aggregate INMB (£358.7m) |  |
| **Abbreviation:** AC: all-cause; CRC(#): constrained recommended care scenario (#); CUA: cost-utility analysis; EDE: equally distributed equivalent; FH: falls hazard; ICER: incremental cost-effectiveness ratio; INHB: incremental net health benefit; INMB: incremental net monetary benefit; PA: physical activity; PS: public sector; QALY: quality-adjusted life year; RC: recommended care; ROI: return on investment; SES: socioeconomic status; SR: self-referred; UC: usual care.  1 Assigned in Table 6.18 according to increasing incremental public sector all-cause cost.  2 All INHBs and INMBs calculated under the cost-effectiveness threshold of £30,000 per QALY gained. | | | |

Strategies [1], [2], [3], [5] and [18] were strong candidates under both frameworks, while [6], [19] and [22] provided some rationale under the 40-year societal CUA. As noted, strategy [19] performed best in terms of efficiency (if the decision-maker is willing to spend £20,691 per QALY gained) and individual-level lifetime outcomes, while [18] generated the highest EDE INHBs. But concern over the public sector budget impact may rule out [18], [19] and [22]. Nevertheless, strategies [1] to [3] with small budget impacts generated correspondingly small aggregate INMBs (£39.9 million, £79.2 million, and £88.9 million, respectively). Commissioners may hence consider strategy [6] that generated aggregate INMB of £329.0 million (third highest among strategies) at a modest budget impact of £54.6 million.

Significantly, five of eight candidate strategies involved environmental interventions. Hence, commissioning recommendation depends strongly on the feasibility of the environmental strategies: i.e., whether they lie within the decision space of the commissioning team. The Sheffield City Council commissioner confirmed that environmental interventions are within their purview (see Section 6.6.2). But the efficacy and cost assumptions for the environmental interventions are less credible than other intervention parameters sourced from RCTs. It is unclear, for example, whether the 5% efficacy of PA promotion and falls risk reduction would apply uniformly to all individuals in the target population.

If environmental interventions are ruled out, then strategies [18] and [19] would not be considered. Then strategy [22] of RC would generate a societal ICER of £26,366 per QALY vs. its next best alternative, strategy [6] (Table 6.18); strategy [21] would no longer be strongly dominated by [19] but extendedly dominated by [6] and [22]. Therefore, the guideline-recommended RC would be a strong option only when environmental interventions are not feasible and under a cost-effectiveness threshold higher than £26,366 per QALY gained. Though the latter is less than the commonly accepted threshold of £30,000 per QALY, the high budget impact of RC (£269.8 million) may invite a comparison to a lower threshold to account for the greater resource opportunity cost [145].

Interestingly, all capacity constrained strategies other than [18] and [19] were strongly dominated by [6] that encompassed unconstrained RC configurations of reactive and self-referred pathways. A key question, therefore, is whether Sheffield can accommodate the capacity requirements of these two pathways, and particularly that of the self-referred pathway which would see client flow expanding from 1,885 to 12,793 users per year (Table F11). If this is not feasible, then the recommendations would change greatly as shown in Table 6.23; the rows for dominated strategies are shaded in grey.

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| **Table 6.23** Comparison of capacity constrained, non-environmental intervention strategies under 40-year societal cost-utility analysis. | | | | | | |
| **Cost-effectiveness comparison** | | | | | | |
| **[#]1** | **Strategy2** | **Incremental societal QALY vs. UC** | **Incremental public sector all-cause cost vs. UC** | **ICER vs. UC** | **ICER vs. next best alternative** | **Aggregate INMB vs. UC** |
| [7] | CRC(4) + 3rd/4th SES FRS | 10055 | £75,539,518 | £7,513 | £7,513 | £226,098,140 |
| [8] | CRC(4): falls risk targeting | 9714 | £77,410,272 | £7,969 |  | £214,019,285 |
| [10] | CRC(4) + SR demand 20% increase | 9598 | £78,868,110 | £8,217 |  | £209,065,582 |
| [11] | CRC(4) + FRS for 50% | 10101 | £79,608,805 | £7,882 | £88,463 | £223,412,425 |
| [12] | CRC(1): random allocation | 6477 | £80,326,978 | £12,401 |  | £113,990,748 |
| [14] | CRC(3): frailty targeting | 6724 | £83,406,606 | £12,405 |  | £118,309,448 |
| [15] | CRC(4) + PS societal costs | 10102 | £100,677,456 | £9,966 | £534,850 | £202,384,670 |
| [16] | CRC(2): no repeated provision | 6722 | £107,003,622 | £15,917 |  | £94,669,816 |
| **Efficiency-equity joint consideration and individual-level lifetime outcomes (rank #)** | | | | | | |
| **[#]** | **Strategy** | **Inc. no-aversion mean3** | **Atkinson EDE (ε=30)** | **Kolm EDE (α=0.5)** | **Combined score for lifetime outcomes4** | |
| [7] | CRC(4) + 3rd/4th SES FRS | 0.0208 (1) | 0.0247 (1) | 0.0215 (1) | 32 | |
| [8] | CRC(4): falls risk targeting | 0.0191 (3) | 0.0221 | 0.0197 | 38 (3) | |
| [10] | CRC(4) + SR demand 20% increase | 0.0185 | 0.0206 | 0.0190 | 35 | |
| [11] | CRC(4) + FRS for 50% | 0.0199 (2) | 0.0225 (3) | 0.0205 (2) | 54 (1) | |
| [12] | CRC(1): random allocation | 0.0103 | 0.0110 | 0.0104 | 29 | |
| [14] | CRC(3): frailty targeting | 0.0108 | 0.0122 | 0.0111 | 18 | |
| [15] | CRC(4) + PS societal costs | 0.0182 | 0.0244 (2) | 0.0198 (3) | 50 (2) | |
| [16] | CRC(2): no repeated provision | 0.0086 | 0.0092 | 0.0087 | 27 | |
| **Abbreviation:** CRC(#): constrained recommended care scenario (#); EDE: equally distributed equivalent; FH: falls hazard; FRS: falls risk screening; ICER: incremental cost-effectiveness ratio; inc.: incremental; INHB: incremental net health benefit; INMB: incremental net monetary benefit; PA: physical activity; PS: public sector; QALY: quality-adjusted life year; RC: recommended care; SES: socioeconomic status; SR: self-referred; UC: usual care.  1 Assigned in Table 6.18 according to increasing incremental public sector all-cause cost.  2 Dominated strategies are shaded in grey. All outcomes were averaged across 20 model trial runs.  3 All INHBs were estimated under the cost-effectiveness threshold of £30,000 per QALY gained.  4 See Table 6.20 for component items within the combined score. | | | | | | |

All targeting strategies under CRC other than falls risk targeting (CRC scenario (4)) were strongly dominated. The CRC scenario (4) was in turn strongly dominated by strategy [7] that supplemented the scenario with targeted falls risk screening by community organisations for the 3rd and 4th SES quartiles. Strategy [11] that involved non-targeted community falls risk screening supplementing CRC scenario (4) produced an ICER of £88,463 per QALY gained vs. strategy [7] and hence would not be cost-effective under the threshold of £30,000 per QALY gained. Likewise, strategy [15] that involved public sector coverage of societal intervention costs of 3rd and 4th SES quartiles produced an ICER of £534,850 per QALY gained vs. strategy [11] and would not be cost-effective. In all, strategy [7] would be the optimal strategy under 40-year societal CUA with ICER of £7,513 per QALY vs. UC. None of the above strategies would be recommended under five-year public sector ROI.

If equity is also considered, strategy [7] would still rank first, followed by [11] or [15] depending on whether relative or absolute inequality is considered at Atkinson ε=30 and Kolm α=0.5, respectively. Figures F18 and F19 show that the top ranking of [7] remained throughout the ranges of Atkinson and Kolm indices, respectively. Public sector coverage of societal intervention costs in strategy [15] raised the EDE INHBs above those of CRC scenario (4) alone in [8] and hence should be considered even in the absence of any substantial double jeopardy problem. Interestingly, strategies [11], [15] and [8] ranked above [7] in terms of individual-level lifetime outcomes.

The comparisons in Table 6.23 highlight the importance of auxiliary implementation strategies for commissioning. Commissioners should invest in additional targeting infrastructure using multivariate falls risk scores under capacity constraints. This should be supplemented by community organisations reaching out to socially deprived individuals not already screened by their GPs, which would require data-sharing between primary care and community organisations. Alternatively, commissioners could invest in measures to reduce the intervention costs incurred by socially deprived individuals when accessing falls prevention. These include publicly funded means to reduce transport costs and participant- and caregiver-centred intervention setting and scheduling to reduce time opportunity costs.

A key caveat to the recommendations is the lack of sensitivity analyses. Specifically, subgroup analyses, PSA, DSA, and evaluation framework and epidemiological scenario analyses were applied only to the base case comparison. Parameter uncertainty would particularly affect the evaluation of environmental interventions. The next iteration of model analyses should conduct sensitivity analyses on intervention strategies, particularly those highlighted as candidates for commissioning.

Nevertheless, several implications can be drawn from the sensitivity analyses applied to the base case. First, the cost-effectiveness varied by age at intervention commencement, with younger age groups deriving superior outcomes (Table F2). But this should not motivate age-based rationing which would go against the principles of the NHS and NICE [259, 260]. Instead, the result should motivate the inclusion of younger seniors in falls prevention to cross-subsidise the older peers. Hence, commissioners should consider extending the falls prevention eligibility to those aged 60-64 who are currently not targeted by NICE CG161 [13]. Second, the cost-effectiveness of RC was most favourable for those who were moderately frail at entry (Table F5). This appears to support the practice of targeting the moderately frail under Sheffield Teaching Hospital’s QTUG pathway (Section 3.7.1.2) [209]. But frailty targeting under CRC scenario (3) produced worse outcomes than multivariate falls risk targeting. Thus, commissioners should invest in a screening system that utilises eFI (constructed from routine data) as a component of the multivariate falls risk score rather than eFI alone. Finally, the epidemiological scenarios showed that falls prevention is highly integrative with other geriatric public health interventions reducing baseline and contemporaneous frailty and improving life expectancy. Hence, falls prevention could be commissioned as part of an integrated geriatric care package.

Overall, the commissioning recommendations can be summarised as follows:

1. Commissioners should confirm the feasibility of environmental interventions and capacity expansions required by RC (see intervention user profiles by pathway in Table F11).
2. If environmental interventions and full capacity expansions are feasible, the eight intervention scenarios in Table 6.22 emerge as candidate strategies for commissioning. The optimal strategy should be chosen based on commissioners’ relative priority over cost-effectiveness, aggregate INMB, budget impact, equity impact and individual-level lifetime outcomes under 40-year societal CUA and/or five-year public sector ROI.
3. If not feasible, then strategy [7] involving capacity constrained pathways, targeting by multivariate falls risk score, and community falls risk screening targeted at 3rd and 4th SES quartiles would likely be the optimal strategy under 40-year societal CUA.
4. Physical activity promotion targeting 3rd and 4th SES quartiles produce a positive financial return under the five-year public sector ROI but is only tentatively recommended because the return is projected to drop below the break-even condition over a longer time horizon.
5. The above recommendations are accompanied by research recommendations. The optimal strategy should be subject to further sensitivity analyses, including subgroup analyses, PSA, DSA, and evaluations of further implementation strategies such as public sector coverage of societal intervention costs. Likewise, the impacts of supplementary geriatric public health interventions reducing frailty and mortality should be further evaluated.

## 6.4 Discussion

This section further discusses the model findings in the context of previous model results (Section 6.4.1) and preliminary, post-analysis conversations with Sheffield commissioners (Section 6.4.2). Sections 6.4.3 and 6.4.4 then discuss the model strengths and limitations, applying, respectively, the methodological checklist for falls prevention economic evaluation and comparison to the methodological recommendations formulated in Section 4.6.1.

### 6.4.1 Comparison to previous falls prevention model results

Several points of comparison can be noted between the results of the current model and those of previous models for cross-validation [173]. The systematic review in Chapter 4 identified (a) combined multifactorial and environmental (falls hazard removal) interventions in Johansson (2008) [128], (b) general physical activity promotion for women in Nshimyumukiza (2013) [336], and (c) targeted vitamin D supplementation in Zarca (2014) [368] as cost-effective interventions under lifetime horizon CUA conducted by validated models (Section 4.6.2). Comparisons can be drawn for interventions (a) and (b). A caveat is that the current model takes a 40-year horizon which limited the evaluation horizon for the incoming cohorts, although as noted in Section 6.2.5.1, extending the evaluation horizon to 80 years produced similar results to the base case. The results are nevertheless conservative relative to analyses with lifetime evaluation *and* intervention horizons for all cohorts.

Regarding intervention (a), Johansson (2008) found that it dominated usual care in the base case but produced an ICER of around £17,000 per QALY gained when costs of added life-years in the form of net productivity loss were included in scenario analysis. The latter is arguably closer to the analytic approach in this study since the current model incorporates comorbidity care costs as well as productivity level. The current model found that strategies [18] and [19] that involved combinations of universal or targeted environmental FH removal and CRC scenario (4) encompassing multifactorial intervention in its reactive and proactive pathways were two of eight commissioning candidates (Table 6.22). The societal ICERs relative to UC considering all-cause costs were £8,658 and £10,651 per QALY gained for strategies [18] and [19], respectively. They were hence markedly lower than the ICER of £17,000 per QALY gained in Johansson (2008). The divergence can be partially attributed to the characterisation of the costs of added life-years as unambiguous net productivity *loss* in Johansson (2008); the costs varied only by age group, meaning that the loss could not be reduced by falls prevention. By contrast, the current model allowed comorbidity care costs and productivity level to vary by frailty and thus by the intervention effect on frailty reduction. This generated net productivity gains worth £36.8 million and £25.6 million for strategies [18] and [19], respectively (Table F21).

Incidentally, another model that evaluated intervention (a) under a five-year horizon is Beard (2006) [127]. This study used data from quasi-experimental evaluation and found the intervention to dominate usual care; ROI under the ‘worst case scenario’ was 6.3. By contrast, the five-year ROI for strategy [19] was 0.337. A key difference was the intervention cost: Beard (2006) reports the annual intervention cost of AUS$213,161 in 1992, equivalent to £205,925 in 2021 price; the intervention targeted a community with 90,000 older persons, making the annual intervention cost just £2.29 per person. In comparison, the current model used cost data from Johansson (2008) which amounted to £66.36 per person (Section 6.3.1.5). Intervention effectiveness was also higher in Beard (2006): the intervention generated a statistically significant 20% reduction in the number of hospitalised falls, compared to 14.1% for strategy [19] vs. UC. Hence, the key question is whether the intervention configuration in Beard (2006) can be replicated. The substantially higher intervention cost in Johansson (2008), also from an internal intervention study, suggests that not all programmes can replicate the cost in Beard (2006). Nevertheless, it may be that the current model has underestimated the efficiency of strategy [19].

Regarding intervention (b), Nshimyumukiza (2013) found that it dominated ‘no intervention’. The current model found that both targeted and universal physical activity promotions, i.e., strategies [1] and [3], respectively, were highly cost-effective vs. UC with societal ICERs of £1,692 and £2,110 per QALY gained. The superior result of dominance in Nshimyumukiza (2013) can be attributed to the higher efficacy parameter: the current model conservatively assumed efficacy of 5% increase in the likelihood of engaging in high physical activity, while Nshimyumukiza (2013) incorporated efficacy of 38% reduction in hip fracture risk. The per-capita cost of PA promotion was the same in both models. However, the current model also estimated the equity impacts of PA promotions and found a regressive impact for universal PA promotion (Table 6.17). Hence, unlike Nshimyumukiza (2013), the current model would recommend PA promotion be targeted at socially vulnerable subgroups.

Other results from lifetime CUAs can be noted (Table 4.16). Eldridge (2005) estimated that the three-pathway strategy implemented in UK setting would have reduced the number of fallers by 11.3% over one year if the falls risk screening level reached 100% (from 6.5% in base case) [274]. In comparison, the current model (which incorporated 100% screening under RC) estimated 6.4% reduction in person-years of any fall over the 40-year horizon vs. UC (Figure 6.1). The divergence could partially be attributed to the higher efficacy estimate in Eldridge (2005) who incorporated an estimate of 36% reduction in number of fallers; by contrast, only one of the RCT-based estimates in the current model reached such efficacy (Table 5.35). RCN (2005) evaluated a multifactorial intervention in the UK setting and found it dominated ‘no intervention’ [146]. The much higher efficiency in RCN (2005) compared to RC or CRC in the current model can partially be attributed to the much lower intervention cost in RCN (2005): £239 per participant (in 2021/22 price) in RCN (2005) vs. £624 per participant in the current model when fixed cost is translated to per-participant rate (Table 5.32).

Deverall (2018) found single-component group exercise to be highly cost-effective relative to no intervention with ICER of £4,527 per QALY gained [361]. In comparison, the self-referred pathway alone in its RC configuration (strategy [4]) produced an ICER of £4,818 per QALY gained relative to UC. However, this strategy was extendedly dominated by universal PA promotion (strategy [3]) and combined reactive and self-referred pathways (strategy [6]) when considering cost-effectiveness alone (Table 6.18). Deverall (2018) also found that the group exercise would worsen the existing health inequity between Maori and non-Maori ethnic subgroups in New Zealand. In comparison, the current model found that strategy [4] generated equity improvement in terms of relative inequality but regression in terms of absolute inequality (Table 6.9). Yet strategy [6] also produced higher EDE INHBs than strategy [4]. Overall, single-component group exercise would not be recommended by this study and its cost-effectiveness under capacity constraints should be explored.

### 6.4.2 Informing commissioning in Sheffield

The Covid-19 pandemic afforded only brief opportunities for discussion with Sheffield CCG and City Council commissioners after completing the above analyses; see section titled ‘Preliminary, post-analysis feedback from commissioners’ in Appendix F. The CCG commissioner perceived the model results as the first step in incorporating falls prevention within a broader work on frailty and multimorbidity prevention and in recognising how health inequalities and wider determinants of health impact upon this work. Nevertheless, the pandemic had changed the decision-making context from the conceptualisation phase in Chapter 3 with the focus of falls prevention shifting to the care home setting. There were new concerns over social distancing at community-based group interventions.

The Council commissioner noted the significance of results on environmental interventions which are directly under the Council purview, and which meet the Council objective of addressing wider environmental determinants of health. Based on the model results, particularly the scarcity of break-even ROI over the five-year horizon, the Council commissioner commented that the most relevant audience for model results are likely social impact investors who seek a mix of financial and non-financial returns over a horizon longer than five years (and reimbursed by social impact bonds established by the central government [419]). Both CCG and Council commissioners raised various methodological points such as whether primary care screening has been adequately costed and how the SES variable matches the index of multiple deprivation used for local decision-making.

Overall, the current model results contribute to an ongoing discussion around geriatric public health strategy rather than finalise specific decisions for local commissioners. In fact, the understanding of who the most relevant local commissioners are changed from the preliminary, post-analysis discussions. If, for example, social impact investors become the main commissioning stakeholders, then the decision problem boundary would change accordingly. The focus would likely shift towards the self-referred pathway and environmental interventions, away from implementing the NICE CG161 within the reactive and proactive pathways. Further model analyses will then be warranted.

### 6.4.3 Methodological checklist score of the current model

The strengths and limitations of the model can be appraised using the methods applied to previous models by the Chapter 4 systematic review, namely: (i) application of the methodological checklist for falls prevention economic evaluation; and (ii) comparison to the 30 methodological recommendations formulated in Section 4.6.1. This section applies method (i), while the next section applies (ii).

Table F23 shows the checklist items, item-specific scores for the current model and justifications. The total score was 29 (of maximum 32) which is higher than the maximum (mean) score of 27 (21.2) among previous models (Section 4.4.3). The current model addressed the three most prevalent checklist issues, namely: (1) reporting all-cause/total health resource utilisation costs (item 15); (2) reporting intervention costs and all-cause/fall-related healthcare costs separately and reporting both aggregate and mean costs (item 21); and (3) justifying the comparator including the do-nothing alternative (item 8).

Checklist deficits arose for items 10 and 11 concerning the definitions of falls and fall injuries, although the model was constrained by the information in ELSA. This issue was similarly prevalent among previous models with only 41.3% providing an adequate definition of a fall. As noted in Section 5.2.4.4, the current model assumed that the efficacies of two RCTs with six-month follow-ups were durable for the year in which the interventions are accessed. This resulted in deficit for item 24. Sensitivity analyses were performed only for the base case, resulting in deficit for item 28.

It is unclear how well the checklist score discriminates models’ methodological quality. It was noted in Section 4.7.2 that among general population, lifetime models, the three most thoroughly validated also had the highest checklist scores [128, 336, 368], suggesting some level of construct validity. There is hence some evidence that the current model is the most methodologically robust falls prevention model to date. The score difference between the current model (score 29) and Nshimyumukiza (2013) with the next highest score (27) was not large, but it is unclear whether the magnitude of difference carries any methodological significance, i.e., whether the scores have cardinal property.

### 6.4.4 Appraisal of current model according to methodological recommendations

The section titled ‘Critical narrative appraisal of current model’ in Appendix F provides a thorough appraisal of how the current model handled the methodological recommendations formulated by the systematic review in Section 4.6.1. This includes Table F24 containing the key strengths and limitations by each recommendation, followed by commentary. The current section provides a summary of the salient appraisal results.

For the falls epidemiology features, the current model was highly transparent in describing the data sources and their strengths and limitations (e.g., for ELSA in Sections 5.2.1.4 and 5.2.5.2). The model distinguished between single and recurrent fallers and considered a broad range of falls risk factors, including the multivariate frailty index, and their longitudinal trajectories. The frailty index also helped capture diverse secondary effects, including mortality, LTC admission, EQ-5D progression and comorbidity care costs. The latter allowed the modelling of all-cause care costs, the methodological issue most neglected by previous models (Section 4.7.3). The lack of individual-level granularity to epidemiological parameters (e.g., frailty-delineated mortality rate, all-cause primary and secondary healthcare costs) and potential issues in the representativeness of ELSA to Sheffield for the period 2021-60 remain the key limitations.

For the falls prevention intervention features, the current model sought to accurately portray the falls prevention practice in Sheffield, the recommended practice, and alternative strategies. All strategies incorporated services within the reactive, proactive, and self-referred pathways operating in tandem. The abnormal gait/balance variable used for falls risk screening replicated the performance of TUG, a test recommended by NICE CG161 (p. 53) [13]. Targeting based on falls risk and frailty was explored as alternative strategies. Costing of intervention resources differentiated between fixed and variable costs. Heterogeneity in falls prevention efficacy by subgroups was considered. Long-term effectiveness of interventions beyond the receipt year depended on sustained access patterns rather than assumptions. Nevertheless, the key limitations included: assumption of 100% falls risk screening rate at GP contact; assumption that interventions can be set up and run without delay; and unbalanced sets of efficacy parameters across intervention subgroups depending on data availability. Further research should consider further fixed/sunk costs (e.g., data system upgrade to enable citywide risk screening) and a greater range of intervention health effects beyond falls prevention.

There were four key challenges for public health economic modelling. For the first challenge of capturing non-health outcomes and societal intervention costs, the current model incorporated a wider range than any previous model (Table 4.11) and balanced outcomes with their respective intervention costs. It also tracked individual-level lifetime outcomes; rankings of intervention strategies varied by whether individual- or population-level outcomes were used (Section 6.3.2.1). The future model could incorporate further impacts on social wellbeing (e.g., from intervention receipt and LTC admission) and health/wellbeing aspects of informal caregiving.

The current model incorporated several variables to address the second challenge of capturing heterogeneity and dynamic complexity in geriatric health and intervention need: e.g., SES quartiles, multivariate frailty index, physical activity level, and cognitive status. The frailty index captured the continuous and dynamic nature of geriatric health and improved upon the discrete/binary depiction (if at all) in previous models (Table 4.13). A limitation was that the variables were estimated sequentially rather than simultaneously at baseline and dynamic update. Further research could use simultaneous equations to estimate the joint probabilities of covariate incidence. Several causal mechanisms were under-represented relative to conceptualisation (Table 3.6), such as cognitive components of fear of falling and social community of older persons. The modelling of incoming cohorts enabled a more accurate portrayal of target population size over time and provides scope for incorporating cohort-level epidemiological and demographic transitions in future models.

For the challenge of considering theories of human behaviour and implementation, the current model parameterised the demand for self-referred exercise at individual-level granularity (Tables 5.30 and 5.49), though not for reactive and proactive intervention demand. Further research should seek to incorporate health and non-health psychological motives of older persons and the sociological mechanisms influencing demand, as well as factors impacting professional behaviour and competence. The model evaluated scenarios of community sector involvement through value of implementation analyses. These showed that not all modes of involvement result in efficiency and equity gains. The model was unique in incorporating capacity constraints in community-based falls prevention. Future models should characterise queuing mechanisms for those denied access to an intervention in a given year due to capacity constraints. Finally, a key limitation is that the model did not account for the impact of the Covid-19 pandemic on demand- and supply-side intervention factors.

To address the challenge of considering issues of equity, the current model incorporated a newly constructed SES variable as the social characteristic of equity relevance and the frailty category as the health severity characteristic of equity relevance. This approach improved upon previous models, only five of which incorporated social or health severity characteristic of equity relevance (Table 4.15). Having incorporated the mechanisms by which SES and frailty affected outcomes, the model evaluated scenarios of policies designed to address them (e.g., community involvement targeting the bottom two SES quartiles) within the DCEA framework. A form of ECEA was also conducted by tracking the number of individuals experiencing catastrophic private care expenditures over their lifetime. Both DCEA and ECEA have not been previously applied in the falls prevention context. Nevertheless, key limitations for this challenge include: the assumption of fixed SES over time; non-inclusion of further social and severity characteristics identified in qualitative research (Tables 2.3 and 2.4) and uncertainty over the relevance of ELSA-derived SES variable for local decision-making.

Regarding the evaluation methods, the current model was transparent about the sensitivity and scenario analyses conducted, deriving the latter from the conceptual model. A full comparison of all intervention strategies was conducted using a wide range of outcomes including cost-effectiveness, equity, individual-level lifetime outcomes, budget impact, capacity implication, and feasibility. However, the intervention scenarios did not exhaust the range of possible permutations. Moreover, further work could conduct PSA and alternative evaluation frameworks and epidemiological scenarios on the key intervention scenarios that emerge as commissioning candidates.

## 6.5 Chapter summary

This chapter analysed the developed falls prevention model, evaluated the performance of the guideline recommended vs. current practice in falls prevention, and formulated commissioning recommendations based on the comparison of alternative intervention strategies. The preliminary engagement with the Sheffield commissioners represents the start of a process of incorporating community-based falls prevention within the local geriatric public health strategy and practice. The chapter also conducted a comprehensive methodological appraisal of the model, using both the checklist and narrative synthesis. Several methodological limitations were highlighted as well as areas warranting further research. These methodological aspects and prospective research areas are further discussed in the next chapter.

# Chapter 7. Discussion, Further Research and Conclusion

## 7.1 Chapter outline

This chapter aims to summarise and recap the findings from the whole research and to bring the study to its conclusion. Section 7.2 discusses what this research contributes regarding the methodological and commissioning practices for community-based falls prevention. Section 7.3 explores the methodological and evaluative implications on the economic modelling of further geriatric public health interventions. Section 7.4 evaluates the strengths and limitations of the study as a whole, Section 7.5 suggests avenues for further research, and Section 7.6 concludes the chapter.

## 7.2 What this study contributes

This study aimed to seek methodological solutions in developing a credible economic model of community-based falls prevention interventions which assesses the health economic performance of the UK guideline-recommended falls prevention strategy relative to current practice and alternative intervention strategies at the local health economy level. The objectives were to: (1) develop a conceptual model of falls prevention; (2) conduct a methodologically rigorous systematic review of previous falls prevention models; and (3) develop a *de novo* model that incorporates methodological solutions and analyse it to inform commissioning at Sheffield as a representative local health economy. The key contributions made by this thesis to the literature are discussed under these objectives (Sections 7.2.1 to 7.2.3).

### 7.2.1 Developing a conceptual model of falls prevention

Chapter 3 developed a conceptual model of community-based falls prevention which subsequently informed the systematic review and the model development and evaluation. The study objective (1) was thus met. Three key contributions (KCs) to the literature can be highlighted.

***(KC1) A conceptual model of the falls prevention decision problem was transparently developed according to a published framework.***

The model conceptualisation in Chapter 3 proceeded according to the stages outlined in the published framework for public health model conceptualisation [1]. These stages involved asking key conceptual questions (e.g., what is the main decision problem and why is it a problem?) and documenting the corresponding answers obtained from local stakeholders and the literature. The improved understanding of the decision problem and its context prospectively reduced the model’s structural uncertainty. This is a novel contribution to the falls prevention literature: seven models in Chapter 4 involved experts and stakeholders in model development [167, 200, 216, 336, 346, 348, 368]; but none detailed the conceptualisation process or structured it according to a framework. Moreover, given that the framework is targeted at public health economic modelling in general [1], this contribution can be replicated in wider public health areas.

***(KC2) Qualitative data from current and eligible users of falls prevention interventions were used to directly inform the conceptual model development.***

Chapter 2 demonstrated that qualitative data on older persons’ views on facilitators and barriers to falls prevention can be mapped to frameworks informing commissioning and conceptual model development. This contrasts with the currently prevalent approach of conducting qualitative research separately from economic evaluation [146, 193, 194]. This is particularly relevant to falls prevention which has been the subject of numerous qualitative studies [141, 201, 243].

***(KC3) The conceptual model was used to appraise the strengths and limitations of the final falls prevention model.***

The conceptual model’s identifications of key causal links and relevant interventions in Sections 3.6 and 3.7 helped appraise the comprehensiveness of the final model structure by assessing which links and intervention features were incorporated in the final model. These conceptual details thus constituted a design-oriented conceptual model against which various simplifications and abstractions during the model parameterisation were compared and justified [211]. Accordingly, Section 6.4.4 detailed how the final model incorporated or omitted several key conceptualised features. This is again a novel contribution to the falls prevention literature: none of the previous models that engaged stakeholders prospectively described the key causal links and intervention features against which the final model can be compared. Their discussions of the model strengths and limitations were consequently unsystematic.

### 7.2.2 Conducting a systematic review of falls prevention models

Chapter 4 conducted a comprehensive systematic review of previous falls prevention models which subsequently informed the model development and evaluation. This was preceded by the systematic overview in Appendix C which informed the systematic review methodology. The study objective (2) to conduct a methodologically rigorous systematic review of previous falls prevention models was thus met. Two key contributions to the literature can be highlighted.

***(KC4) The systematic review was the most comprehensive review to date for community-based falls prevention models, covering all relevant methodological categories and issuing commissioning recommendations.***

The systematic review incorporated 46 models which was 26 more than those identified altogether by the seven previous reviews. The narrative synthesis was the most comprehensive to date, covering the following methodological categories for modelling: (1) falls epidemiology; (2) falls prevention intervention; (3) key public health modelling challenges; and (4) evaluation methods. This was complemented by the application of a reporting and methodological quality checklist designed by falls prevention experts [105]. The commissioning recommendations (based only on the review results) for general older populations over a lifetime horizon were likewise comprehensive, considering efficiency, equity, feasibility and transferability, and aggregate impact. The synthesised methodological features helped formulate commissioning decisions that accounted for methodological influences on the evaluation outcomes.

The four sub-categories under (3) corresponded to the key methodological challenges for public health economic modelling [18]: (a) capturing non-health outcomes and societal intervention costs; (b) considering heterogeneity and dynamic complexity; (c) considering theories of human behaviour and implementation; and (d) considering issues of equity. Therefore, the current review was the first to show that these challenges could together serve as thematic frameworks for narrative synthesis within any future systematic reviews of public health economic models, not limited to community-based falls prevention (as for qualitative research in Chapter 2).

As noted by the systematic overview, previous reviews in this topic area had focused on one or two of the challenges but not all four. The PHE review of community-based falls prevention, for example, focused on (d) [147], while the Huter review focused on (a) [331]. Outside falls prevention, Bates and colleagues focused on the dynamic complexity of weight progression and the psychosocial determinants of weight status, i.e., (b) and (c) [420], while Salleh and colleagues focused on methods for capacity modelling, i.e., (c) [221]. Yet concurrent consideration of all four categories is advisable given the likely interactions between the challenges (conceptualised in Section 3.8.2). The interactions were significant in the final model: the regressive SES gradient was acute for societal gains (Table F3); neglecting the feedback loop between falls and frailty removed the pro-poor equity impact (Section 6.2.5.3); and implementation strategies brought different equity impact depending on whether they were targeted at the vulnerable subgroups (Section 6.3.1.3).

***(KC5) The findings of the systematic review were proactively used to inform the model development and appraisal.***

This study successfully implemented the recommended practice that a systematic review of existing models should help develop and justify the public health model structure [1]. Two previous systematic reviews, the RCN and PHE reviews [146, 147], preceded the development of RCN and PHE models [146, 216]; but their findings had little impact on the model developments. The PHE model, for example, did not conduct any equity analysis despite the PHE review’s focus on this challenge. By contrast, the current review formulated 30 methodological recommendations which subsequently informed and appraised the model structure. The checklist similarly suggested important criteria for the model development and reporting (Section 6.4.3). Finally, the evaluation outcomes from previous models were used to cross-validate the current model in Section 6.4.1. No previous cross-validation effort was based on data from a systematic review.

### 7.2.3 Developing and analysing the falls prevention model

Chapters 5 and 6 developed the *de novo* community-based falls prevention model and issued commissioning recommendations according to the result of intervention strategy comparisons. The study objective (3) to develop and analyse a *de novo* model to inform local commissioning was thus met. This section highlights several key methodological developments, organised around the four public health modelling challenges (Sections 7.2.3.1 to 7.2.3.4).

#### 7.2.3.1 Capturing non-health outcomes and societal intervention costs

The current model achieved major methodological advances in capturing non-health outcomes and societal intervention costs. Two key contributions to the literature can be highlighted.

***(KC6) The current model incorporated most of the conceptualised non-health outcomes and corresponding societal intervention costs associated with falls using publicly available data and frailty as the mediating link.***

Most of the conceptualised non-health outcomes and societal intervention costs of falls and falls prevention shown in Table 3.4 were incorporated in the final model; the exceptions were direct effect of falls on social wellbeing, intervention process cost/benefit, and health/wellbeing effect of informal care provision and receipt. Importantly, this was done using publicly available data (from ELSA and previous models) such that the current approach is readily implementable in other models. Moreover, the high relevance of the above outcomes and costs to general geriatric health and wellbeing beyond falls and falls prevention makes the implementation a research priority.

The current approach also greatly improves the analytic scope within frailty modelling. The central mechanism of the current approach was the dynamic link between falls and frailty. Non-health outcomes associated with frailty progression were incorporated as secondary effects of falls (see, for example, Table E16 on the probability of being in paid employment in the next cycle). This reduced the need for identifying the direct impacts of falls on non-health outcomes. This approach can be used in other geriatric and non-geriatric areas by estimating the link between the disease/syndrome and the frailty index, then the societal outcomes/costs associated with frailty. This study hence makes a significant contribution to frailty modelling and can supplement existing conceptual frameworks [45].

***(KC7) The societal analyses generated important insights on the broader benefits and costs of falls prevention and complementary geriatric policies.***

The model’s incorporation of productivity, personal finance, and informal caregiving generated important findings. First, it was shown that falls prevention raised senior productivity; RC was particularly effective at raising female productivity relative to UC (Table F3). These corroborated the policy attention on raising senior productivity to address societal issues associated with ageing populations [92]. Second, falls prevention reduced the level of informal caregiver burden both at the population and individual levels. This similarly corroborated the policy attention on reducing the informal caregiver burden, particularly that placed on female family members (p. 12) [2]. Third, the model found that falls prevention *exacerbated* old age poverty by raising the level of private care expenditure. All intervention scenarios reduced OOP care expenditure but incurred significant private co-payments, resulting in net increases in private care expenditure. Twelve of 23 strategies in Table 6.20 increased the number of persons in the 3rd and 4th SES quartiles experiencing catastrophic private care expenditure when co-payments were included, although the model likely overestimated the intervention demand by these quartiles in the presence of co-payments. Even so, lower demand would have raised the double jeopardy problem and worsened the equity impacts. Falls prevention should thus be integrated with policies that reduce the co-payments (e.g., coordination between intervention and transport services [421]) and/or directly support the incomes of vulnerable persons. In all, the study was able to show how societal analyses can validate several areas of geriatric policy focus and highlight issues warranting interventions that complement falls prevention.

#### 7.2.3.2 Considering heterogeneity and dynamic complexity

Heterogeneity and dynamic complexity were carefully considered by the current model. Three key contributions to the literature can be highlighted.

***(KC8) The current model considered the distinct intervention experiences for two subgroups that received insufficient attention in the current UK guidelines and previous models: the cognitively impaired and those with prior intervention history.***

The current model characterised the different intervention type, access rate, cost, and efficacy experienced by the cognitively impaired subgroup (Table 5.25). This represents a major methodological advance relative to previous models, none of which considered variations in intervention characteristics by cognitive status, let alone incorporated relevant subgroups (Section 4.5.3.2). The NICE and Public Health England falls prevention guidelines contain no tailored intervention pathway for the cognitively impaired [13, 143], even when falls prevention RCTs are frequently delineated by cognitive status (Table 5.35). The current model hence offers the first economic evidence to date which can inform such pathway designs in updated editions of the UK guidelines. The latter also lacked protocols for those with intervention history despite the capacity implications. The current model again offers the first evidence on the impacts of alternative service protocols. Specifically, the RC scenario imposed a limit of three receipts of proactive multifactorial interventions to keep the annual client flow manageable for seven falls clinics. Section 6.3.1.2 evaluated the scenario of no repeated receipt under falls clinic capacity constraints and found this to be dominated by the scenario of targeting by multivariate falls risk.

***(KC9) The current model conducted comprehensive analyses of the heterogeneity of falls prevention impact, including the relative performance of the guideline-recommended proactive pathway.***

The current model greatly expanded the range of heterogeneity explored relative to previous models which frequently confined their delineating characteristics to age, sex, and falls history (Table 4.12). The subgroup analyses also provided the platform for DCEAs delineated by pre-specified variables equity relevance, namely SES quartile and initial frailty category. The model conducted targeting analyses under capacity constraints: targeting by frailty category and by multivariate falls risk (Section 6.3.1.2). The significant improvement in the efficiency of CRC under falls risk targeting was a major finding. It implies that an additional layer of triage before multifactorial intervention receipt is warranted to supplement the screening at routine care contact. Frailty targeting, meanwhile, failed to significantly change the efficiency profile of CRC relative to random allocation. This implies that while validating a frailty measure is important [422], further work is required to evaluate how the measure integrates within the best predictive equation for the risk of falling. A corollary finding is that a comprehensive upgrade to the clinical data system is required since factors such as abnormal gait, non-MA falls history, and fear of falling are not commonly observed in routine care data [44].

The heterogeneity in intervention need was delineated and evaluated by the three pathways: reactive, proactive, and self-referred. Only a single previous model incorporated all three pathways, and that was without evaluating their respective performances [274]. The current model provided important economic evidence regarding the relative performance of the proactive pathway which constitutes the main component of NICE CG161 and other normative falls prevention guidelines [219, 423]. The proactive pathway was the least cost-effective of the three pathways relative to UC (Table F18). It was part of three of the eight candidate strategies in Table 6.21, namely: strategy [18] – CRC scenario (4) plus falls hazard removal for 3rd and 4th SES quartiles; [19] – CRC scenario (4) plus universal falls hazard removal; and [22] – RC. If the falls hazard removal becomes infeasible, then only RC would contain the pathway, and the next best alternative would be strategy [6] that contains reactive and self-referred pathways only. If capacity constraints are binding and thus rule out strategies [6] and [22], then strategy [7] of CRC scenario (4) plus targeted community falls risk screening becomes the optimal strategy under all outcomes (Table 6.23). Overall, the key finding is that the guidelines’ emphasis on the proactive pathway warrants numerous qualifications when health economics evidence is comprehensively considered.

***(KC10) The current model incorporated several key dynamic propagators central to geriatric health.***

The current model parameterised the key dynamic link between falls and frailty which no previous model had done. Removing this link in Section 6.2.5.3 had substantial negative impacts on the RC’s efficiency and equity relative to UC. Most of QALY gain from RC relative to UC, the entirety of societal gains, and the dual efficiency-equity improvements can be attributed to the prevention of secondary effects of falls via frailty progression. This study hence identified the secondary effect propagation via frailty as a firm methodological requisite for future falls prevention models.

The current model incorporated further key dynamic propagators. For example, the progression of abnormal gait/balance within model simulation was affected by falls incidence independently of frailty change (Table E14). Abnormal gait/balance in turn affected: any falls risk (Table 5.39); recurrent falls risk (Table 5.40); progression of cognitive status (Table E13); EQ-5D progression (Table 5.50); probability of GP contact (Table E15); probability of self-referred exercise demand (Table 5.50); probability of engaging in unpaid work (Table E17); and probabilities of receiving informal care at different intensities (Tables E20 and E21). Similar dynamic links were simulated for fear of falling, cognitive impairment, and physical activity status. These rich portrayals of dynamic propagation contrast with previous models (of horizons of five years or longer), only two of which incorporated variables other than age, falls history, and specific biomarker as determinants of dynamic falls risk (Table 4.13) [274, 318]. The portrayals hence represent a significant methodological advance in falls prevention modelling.

#### 7.2.3.3 Considering theories of human behaviour and implementation

Three key contributions to the literature can be highlighted regarding the current model’s considerations of theories of human behaviour and implementation.

***(KC11) The current model characterised behavioural patterns that influenced falls risk and long-term intervention access.***

The current model parameterised several individual-level behavioural patterns that shaped falls risk and intervention access. The fear of falling variable, though not capturing the cognitive components [266, 270], could be perceived as a physio-behavioural factor shaping falls risk, gait/balance, and OOP care receipt in dynamic links. Its inclusion improved upon previous models, none of which incorporated behavioural factors (Section 4.5.3.3). The model likewise characterised individual-level dynamic patterns in intervention supply and demand under the proactive and self-referred pathways. Specifically, individuals who received routine GP contact in a cycle were more likely to receive it in the next (Table E15); likewise, those who demanded self-referred exercise were more likely to demand it again (Table 5.49). The patterns also informed potential intervention strategies: e.g., community falls risk screening and outreach may be commissioned to reach out to persons who do not have the recurring patterns of GP contact and self-referred exercise, respectively. By contrast, no previous model incorporated individual-level probabilities of GP contact and previous characterisations of intervention sustainability were simplistic (Table 4.14). Further work could parameterise the motives underlying the behavioural patterns. Quantitative surveys of older people’s health behaviours and their relationship to falls history and frailty are a research priority.

***(KC12) The current model highlighted implementation level and aggregate impact as key decisional criteria and conducted value of implementation analyses regarding community involvement.***

Since NICE CG161 was already normative for the English routine practice [139], the decision problem centred more around increasing the intervention reach relative to UC than evaluating new intervention types [424]. Accordingly, the current model was thorough in parameterising the supply and demand levels for each intervention scenario (Section 5.2.4.2). This contrasts with previous models, more than half (n=24) of which failed to clearly state and justify the comparator scenario, let alone characterise the implementation levels. Likewise, only a single previous model distinguished between supply- and demand-side determinants of intervention access [348].

The current model comprehensively reported the aggregate outcomes as recommended by the expert guideline on falls prevention economic evaluation [105], while only 26.1% of previous models had done so. In several cases, previous models misrepresented the intervention rankings by interpreting only the cost-per-unit ratios (Section 4.5.3.2). The ratios were also insensitive to changes in implementation levels and precluded value of implementation (VoIM) analyses (Section 4.5.3.3). By contrast, the current model assessed the aggregate outcomes, including the budget impact, when formulating commissioning recommendations (Section 6.3.3), and conducted several VoIM analyses of implementation strategies even under capacity constraints (Section 6.3.1.3). The latter strategies conceived of community asset involvement in implementation, even if the precise means of achieving the hypothetical access levels were unspecified. The current model is hence the first in this topic area to assess the economic case for community sector involvement which is advocated in key guidelines [93, 143]. There is ample scope for implementing the current approach in future falls prevention and other geriatric public health models.

***(KC13) The current model was the first falls prevention model to incorporate capacity constraints.***

The current model was unique amongst falls prevention models in incorporating capacity constraints. It demonstrated the modelling capability to evaluate the capacity implications and feasibility of clinical and public health guidelines when applied to the local setting. Current guidelines do refer to capacity implications but only as a peripheral criterion: NICE CG161 includes a disclaimer that the decision to adopt the recommendations would depend on available resources (p. 23) [13]; NICE PMG9 for HTA likewise states that the NICE Committee will receive evidence on local constraints and other implementation issues (points 4.5.3 and 6.1.6) [154]. The guideline credibility would nonetheless be enhanced by proactively evaluating the impact of capacity concerns on cost-effectiveness, rather than *ex-post*. This is particularly relevant to interventions that require long-term, professionally supervised participation for maximal impact such as falls prevention exercise [425].

Analysts interested in capacity modelling typically develop a discrete event simulation [221], which has been used to characterise the capacity use and waiting time for services including cancer screening and post-discharge geriatric care [215, 426]. This study has shown that it is equally feasible to develop a discrete individual simulation to capture the capacity implications. This model type offers an important option for analysts lacking time-to-event data on key parameters [168]. In operationalising the model, the inclusion of incoming cohorts is crucial to maintain the capacity pressure on services. This differs from the common modelling practice of targeting a single fixed cohort; only one previous model incorporated incoming cohorts, and only for the first 10 years of a lifetime horizon [336]. But it also provides the opportunity to model demographic and epidemiological transitions over time [56].

#### 7.2.3.4 Considering issues of equity

The current model achieved methodological advances in considering equity issues and conducting appropriate analyses. Two key contributions to the literature can be highlighted.

***(KC14) The current model incorporated a comprehensive set of equity criteria and assessed their impact on intervention strategy rankings.***

Issues of equity were central to the current model development and evaluation. The ‘Context’ component of the CICI framework in Chapter 2 included expert-highlighted equity criteria beyond cost-effectiveness [71]. The criteria emphasised the considerations of (i) vulnerable social groups, (ii) severity/extent of past health loss, and (iii) non-health consequences including financial protection, productivity, and caregiving. The current model incorporated all three considerations, conducting DCEAs delineated by SES quartile and frailty category for (i) and (ii), and tracking several non-health outcomes for (iii). It also tracked the number of individuals enjoying ‘fair innings’, an outcome prioritised by Williams as an indicator of health equity [232], and the intervention user profiles which can assess equity in healthcare access. The number of individuals experiencing catastrophic private care expenditure was emphasised by the ECEA framework [72]. Increases in this number in several intervention scenarios indicate the outcome’s relevance even in a developed country setting. Subgroup analyses identified further priority setting challenges, such as the decrease in the cost-effectiveness of RC vs. UC with age. That a single model incorporated multiple equity criteria represents a major methodological advance: no previous model in this area conducted equity analysis (Section 4.5.3.4).

***(KC15) The current model characterised causal mechanisms generating the equity-relevant outcomes and evaluated supplementary policies that address them.***

The current model explored and evaluated the causal mechanisms generating the equity-relevant outcomes, namely the life expectancy differential (LED) and the double jeopardy (DJ) problems that result in vulnerable groups’ reduced capacity to benefit from interventions. Reducing the LED problem across frailty categories in Section 6.2.5.6 produced only modest equity improvements relative to the base case. In fact, general life expectancy improvement across all frailty categories in Section 6.2.5.5 produced greater equity improvements. Meanwhile, removing the DJ problem in Section 6.3.1.4 through public sector coverage of societal intervention costs incurred by socially vulnerable groups brought marked equity improvements. These suggest that for falls prevention, the DJ problem is a more significant contributor to SES-delineated inequity than LED.

Given the equity-relevant outcomes, supplementary policies can be designed accordingly. Hence, a welfare policy that supports the income of socially vulnerable seniors should be prioritised to reduce the DJ problem. Earlier-life prevention that extends life expectancy universally would play an additional role. Evaluation of the causal mechanisms for equity-relevant outcomes and discussion around corresponding policy solutions constitute a major methodological advance: only one group of models from the same research team assessed the causal mechanism for differential outcomes across sex and ethnicity in New Zealand [206, 241, 337, 361], and this was unaccompanied by discussions on strategies that addressed the mechanism.

## 7.3 Implications for further geriatric public health economic modelling

Falls are not the only geriatric syndrome deserving policy attention [19], and geriatric public health interventions such as exercise have shown effectiveness in preventing many more adverse outcomes including frailty [320, 427], functional limitations [428-430], and mortality [431]. These reveal the scope for further economic modelling of geriatric public health interventions. This section explores what lessons can be drawn from this study for such modelling. Specifically, two themes are engaged with the aim of exploring how modelling could help resolve the issues involved. The first theme relates to a concern in the literature that economic evaluation may be biased against older populations relative to younger populations (Section 7.3.1). The second theme concerns the need for models to inform high integration of care (highlighted in Section 1.3.2.3 as a key characteristic of geriatric public health interventions) and assess the performance of integrated care schemes (Section 7.3.2).

### 7.3.1 Concern on bias in geriatric economic evaluation

A concern in the literature is that health economic evaluation produces results that are ‘ageist’, i.e., biased against older populations [83, 107]. Older populations have greater comorbidities and less remaining life expectancy which impair their ability to gain as much measurable health benefits from interventions as younger populations [107, 432]. This disadvantage is particularly acute under an evaluation framework that explicitly targets improvement in health, rather than in broader utility/wellbeing, since utility can still be improved (via intervention process benefits) amongst persons with smaller prospect of concrete health gain [148]. The unfavourable cost-per-health gain ratios would in turn shift healthcare resources away from geriatric interventions. This is a form of *indirect* ageism since the economic evaluation does not in itself make the value judgement that resources should be shifted away from older populations.

In response, it should be noted that worse cost-effectiveness outcomes are not inevitable for older populations. The results of the current model present a case in point. More generally, geriatric prevention, whilst not improving measurable health, could avert costly care utilisations, which may not be the case for younger populations. For example, social isolation among older populations has shown to be an independent risk factor for A&E admission [433], which is less likely to be the case for younger populations. This illustrates the need for *more* comparisons of high-quality evaluation results across interventions and age groups rather than less [434]. It also illustrates the need for decision modelling that can account for the full range of health and economic consequences of the geriatric syndrome/disease over an older person’s lifetime, e.g., by capturing the dynamic link between the syndrome and frailty. The current model also showed that a successful earlier-life prevention that reduced frailty by 20% at entry had a modest effect on the result of RC vs. UC (Tables F16 and 6.8).

Should, however, age-based disadvantage in cost-effectiveness outcomes be pronounced then this becomes a matter of broader social priorities beyond the efficiency of resource use [71]. A deontological case could be made that necessary service should not be denied to older persons (even at some loss of efficiency) since health is a fundamental right that should be enjoyed regardless of age [2, 435]. This commitment is echoed in the NHS Constitution Article 1 that rules out age-based restriction in healthcare [259]. The current model’s commissioning recommendations advocated extending the minimum target age from 65 to 60 so that the younger subgroups may cross-subsidise their older peers. Yet any discussion on social priorities and remedial policies is only possible with robust economic evidence that quantifies the associated opportunity costs [108, 232]. The risk of ageism hence calls for more transparent, evidence-based economic evaluations, not less.

Incidentally, Huter and colleagues suggested that the inclusion of wider outcomes and costs such as productivity would mitigate ageism in economic evaluation [83, 331]. However, inclusion of wider outcomes does not necessarily improve cost-effectiveness: in the current model, those aged 70+ at model entry incurred net societal loss which raised their societal ICERs (Table F1). Table F3 also showed that societal outcomes are generally pro-rich, raising a further set of equity issues. In all, discussions on priority setting challenges are likely unavoidable; expanding the modelled outcomes can assist these discussions but is unlikely to solve the problem by itself.

It should also be noted that several arguments have been advanced in the literature for *direct* ageism, namely the curtailment of healthcare resources for older populations until the health needs of younger age groups are satisfied. The three main reasons are [107]: (i) to ensure that those in earlier life stages are given the maximum chance of enjoying a ‘full’ lifespan or ‘fair innings’– termed ‘egalitarian ageism’; (ii) to assign lower priority on those who make smaller contributions to society – termed ‘productivity ageism’; and (iii) to cope with the resource pressures associated with an ageing population – termed ‘sustainability ageism’. These arguments do not invalidate the conduct of thorough geriatric economic evaluations but rather expands the discussion boundary on priority setting challenges. Economic modelling can again assist these discussions. For (i) and (ii), the model should incorporate the fair innings and productivity outcomes, respectively. For (iii), healthcare cost savings from geriatric interventions should be thoroughly documented. The current model has shown that these features can be readily incorporated. Beyond these, assigning more favourable weights to outcomes in younger age groups and groups with greater social roles – e.g., in the Global Burden of Disease measurement before 2010 [436] – has been ruled out by NICE [260].

Overall, economic modelling of geriatric public health interventions is a highly useful decision-making tool provided that the model fully accounts for: (1) the dynamic propagation of disease impact on outcomes; (2) the impact of earlier-life prevention that alters the baseline characteristics; (3) the variation in cost-effectiveness outcomes across age subgroups; (4) the number of persons achieving ‘fair innings’; and (5) the productivity gains and healthcare resource savings from prevention. These aspects set the benchmark for public health economic modelling such that the model can sufficiently inform the discussion on priority setting challenges.

### 7.3.2 High integration of care

The current study initially began with the aim of evaluating an integrated care scheme called Active Support & Recovery (AS&R) in Sheffield, a package of reactive and rehabilitation services including falls prevention (Table 3.3). At the preliminary discussion of model results, commissioners still conceptualised community-based falls prevention as a component within a broader geriatric prevention package (Section 6.4.2). This integrative conceptualisation necessarily applies to other geriatric interventions within the package. Therefore, geriatric public health models should possess the capacity to evaluate how their main intervention of interest interacts with other geriatric interventions. Fully parameterising the costs and efficacies of the latter would be optimal. But the evaluation could take the form of characterising the epidemiological effects generated by the other interventions.

The current model took the latter approach, evaluating the scenarios of initial and contemporaneous frailty reductions on the outcomes of base comparison (Section 6.2.5.4). These simulated the impacts of highly successful earlier-life and geriatric frailty preventions, respectively. Both scenarios showed that falls prevention remained cost-effective and equity-improving. The initial frailty reduction scenario evaluated the scope for *life-course* integration of falls prevention, while the contemporaneous frailty reduction evaluated the scope for *multi-need* integration (see Section 1.3.2.3 where these integration terms were defined). A key takeaway is the importance of incorporating a frailty variable (alongside other variables with key dynamic links) that captures the full impacts of further interventions.

Equally important for geriatric public health is *single-need* integration, namely the coordination of multiple assets, professional disciplines, and pathways to prevent a specific disease or syndrome such as falls. This first requires the model to distinguish between the individual components being integrated: e.g., in the current model between initial risk screening, risk-based triage under capacity constraints, therapeutics, and parallel prevention pathways. Scenarios on different permutations of components should then be evaluated to assess the component-specific contributions. The current model, for example, evaluated the unique efficiency-equity impacts of individual pathways and evaluated single pathway commissioning as alternative intervention strategies. The clinical parallel is the ‘whole disease model’ that characterises the interactions between detection, diagnosis, and therapeutics required to prevent and cure a single disease then fully compares the permutations [437].

Another important integration type is *intersectoral* integration in its different forms: (i) intersectoral environmental interventions; (ii) integration between public health and wider welfare (e.g., income support for vulnerable groups) policies; and (iii) non-clinical community asset involvement as implementation resources. Thorough conceptualisation of the decision problem is crucial for understanding the full scope for intersectoral integration and evaluating it in the final model. Specifically, the qualitative research in Chapter 2 found local older persons being highly sensitive towards factors influencing all above forms of intersectoral integration. Therefore, prospective efforts to reduce the model’s structural uncertainty naturally generate hypotheses on the intersectoral relationship between the given geriatric public health intervention and factors in its health ecosystem.

For context, integrated care schemes have brought mixed empirical results to date despite the continued policy interest and funding. One systematic review of 167 integrated care schemes found limited or inconsistent evidence of reductions in primary and secondary care utilisation and cost [118]; another evaluation of Better Care Fund schemes in England found a significant *increase* in hospital admissions for persons with multimorbidity [163]. The worse than anticipated effectiveness prompted a meeting of 50 integrated care experts in 2019 to discuss the possible causes [121]. They identified three key problems: (i) ‘problems with the model’ – i.e., a lack of clear understanding on which components and mechanisms contribute to the desired effect; (ii) ‘problems of implementation’ – due to shortcomings in teamwork, role delineation and identification of patients’ needs and preferences; and (iii) ‘problems of evaluation’ – mainly due to the short evaluation time horizons. Addressing these problems sets further methodological benchmarks. Modelling the multi- and single-need integrations as discussed should address problems (i) and (ii). Long evaluation horizons in models can address problem (iii).

## 7.4 Study strengths and limitations

This study conducted the first comprehensive economic modelling of the major components of the NICE CG161 guideline on community-based falls prevention [13]. The analysis is timely since the guideline is currently in the early stage of update [131]. A key finding was that NICE CG161 recommendations warrant qualifications, particularly regarding the feasibility of environmental interventions and capacity implications. A recent scoping review of 22 existing falls prevention clinical guidelines (all set in developed countries) mentioned no such qualifications, the guidelines’ focus being primarily on the proactive pathway components [438]. The study finding is hence applicable to a wide range of decision-making settings, including less developed health economies where multidisciplinary clinical teams are inaccessible. The commissioning recommendations by the current model also considered further decisional factors including joint efficiency-equity impact and individual-level lifetime outcomes. Moreover, several scenarios placed falls prevention within a wider package of geriatric public health strategies, including earlier-life and contemporaneous frailty preventions and environmental physical activity promotion. See Section 7.2 above for further key contributions.

The study nevertheless has several limitations. First, the model conceptualisation involved a relatively narrow range of commissioning and professional stakeholders. The ‘whole-system’ commissioning of falls prevention recommended by Public Health England would ideally involve not only clinical commissioners and professionals but also housing providers, social workers, community organisations, ambulance crews and fire service (p. 13) [143]. The Covid-19 pandemic severely disrupted the communication with stakeholders, and their inputs were restricted during the model parameterisation phase. Consequently, several model-incorporated evidence sources (e.g., cost-of-illness studies for the acute care cost of hospitalised falls; Section 5.2.5.4) may be considered non-locally generalisable. Obtaining local routine data and running model sensitivity analyses with the locally estimated model parameters would help address this issue. Second, there were methodological issues in using the falls data from ELSA, including substantial recall bias. Prospective, high-frequency falls recording remains the gold standard for falls prevention research [24]. Access to a falls-specific prospective survey which meets this standard *and* includes the wide range of variables in ELSA (e.g., frailty deficit items, productivity) would greatly improve the methodological quality. Third, only preliminary work was conducted on translating the commissioning recommendations to policy implementation; further work is thus warranted on research dissemination.

## 7.5 Further research

Further research suggestions are discussed under the following categories: (1) conceptual modelling (Section 7.5.1); (2) falls epidemiology and intervention modelling (Section 7.5.2); (3) key challenges for public health economic modelling (Section 7.5.3); and (4) evaluation methods (Section 7.5.4).

### 7.5.1 Conceptual modelling

The need to involve a wider set of commissioners and professionals was already noted. Qualitative research and surveys of falls prevention and wider community professionals would provide additional information on the implementation of falls prevention in the local setting [242, 243, 439]. Such information includes whether RCT-based evidence can be translated to routine practice [440], linkages across pathways, and intersectoral integration involving community organisations. Understanding the barriers in the primary care setting is particularly warranted [139, 247]. Qualitative research with older persons can be supplemented by discrete choice experiments that can quantify their strength of preference over key intervention attributes and the likelihood to participate [441, 442]. This would provide quantitative parameters for behavioural factors and the extent of the double jeopardy problem.

A further research item would be to apply the framework analysis in Chapter 2 within secondary syntheses of qualitative data that accompany the development of NICE clinical guidelines, including those for falls and social isolation preventions [13, 443]. Primary qualitative research set in a specific local context may lack generalisability to further contexts; secondary synthesis would hence be more appropriate for a national-level HTA model development [444].

The conceptual model in the current study concentrated primarily on the current and recommended falls prevention practices; yet commissioners perceived falls prevention as a component within a broader geriatric prevention package. A future conceptual model should explore this multi-need integration more deeply, say, between falls prevention and dementia care [445-447], social isolation prevention, physical activity promotion and senior welfare policies. Life-course integration should also be explored given the nontrivial falls risk among middle-aged populations [138].

Finally, a priority for falls prevention is grasping its global dimension. Population ageing is not a developed world problem but a global one: by 2050, those aged 65+ are projected to comprise 21% of the total world population, up from 8% in 2010 [9]. There is an acute scarcity of falls prevention economic evaluations, let alone models, set in the developing country context [332]: only a single model from Chapter 4 was set outside a high-income country [357]. Future research should engage with the unique conceptual issues for falls prevention in developing country contexts. For example, the capacity constraints would be more acute, while non-health outcomes including OOP care expenditure, productivity, and informal caregiver burden would take on greater prominence [2, 72].

### 7.5.2 Falls epidemiology and intervention modelling

This section adds to the suggestions for further research raised in Sections 6.4.4 regarding falls epidemiology and intervention modelling. First, more research on environmental falls risk factors and interventions is a priority, particularly those in external public spaces. Six RCTs of environmental falls prevention interventions identified in a 2008 systematic review were all set in home environments (i.e., HAM) [448]. A systematic review of falls risk factors likewise only identified home-based environmental risk factors [217]. Results of the forthcoming Cochrane systematic review of environmental interventions should be checked to see whether the focus has diversified [449].

A future model could incorporate further falls risk factors and associated intervention types. There is some evidence that vitamin D supplementation of adequate dose reduces falls [450], and it was one of the commissioning recommendations from the systematic review in Chapter 4 [368]. It may also be included in the updated NICE CG161 [130], most likely as a proactive intervention preceded by vitamin D level screening at GP contact. If so, the model for the updated CG161 should evaluate it as a proactive pathway option, whether as a component of multifactorial intervention, its direct substitute, or a complement. One intervention that was part of current practice in Sheffield but not modelled is fall alarm (Table 3.7). A recent Australian study has shown that the alarm is cost-saving by reducing avoidable ambulance callouts by a third [451]. Hence, a future model could incorporate it within the reactive pathway or as a parameter that reduces the proportion of falls requiring medical attention. If capacity constraints are sharply binding, a future model could consider less capacity-dependent interventions such as home-implemented exergames [205].

A future model could also explore how preventions in community and institutionalised settings are integrated. Under the combined populations, institutionalised older persons would constitute a prioritised vulnerable subgroup [452]. The impact of full-scale institutional prevention on the intervention capacity available for the community should be explored. Another key integration is that between falls and fracture preventions. There is a close overlap between them, with many falls prevention RCTs reporting the number of fractures prevented [124]. Yet their clinical protocols often differ, with the fracture prevention emphasising pharmacotherapy for improving bone mineral density [453, 454]. The model could introduce a subgroup of osteoporosis patients that receive pharmacological fracture prevention [344].

### 7.5.3 Key challenges for public health economic modelling

This section discusses further research concerning the four key methodological challenges to public health economic modelling. See also Section 6.4.4 for more research recommendations. Regarding non-health outcomes and societal intervention costs, an important area for improvement is productivity parameterisation. The current model used binary indicators of employment and unpaid volunteering; a categorical variable expressing the variation in the number of hours worked/volunteered would improve the measurement. A further distinction is needed between voluntary paid employment and employment pressured by financial circumstances. The current model measured the productivity *level* rather than *loss* (e.g., absenteeism, presenteeism) as is more commonly used [234]. The former was thought to be more appropriate for older populations for whom productivity (at least in paid employment) is not the default situation. But future models could explore using productivity loss instead. Informal caregiving was highlighted as a risk factor for decline in senior mental wellbeing by NG32 [443], and further research could explore the wellbeing effect of caregiving.

The current model faced difficulties in parameterising intervention process benefits and costs. The implication is that the model did not address a long-running criticism of QALY-based CUA, namely the lack of consideration of patient preferences and process outcomes insufficiently captured by QALY [455]. This is particularly emphasised in the context of geriatric care wherein holistic outcomes are central for assessing person-centred care and concrete health improvements less commonplace than in younger populations [148, 456]. Future models should seek epidemiological and intervention studies that use matching measures of wellbeing and process benefits/costs. An alternative, indirect method would be to quantify the association between process benefits/costs and implementation quality, then capturing the latter’s impact on final outcomes [457].

Regarding heterogeneity and dynamic complexity, further subgroups delineated by specific disease diagnoses could be modelled for the community-based older population. These include Parkinson’s disease, stroke, and other neurological disorder patients for whom specially tailored interventions are trialled and economically evaluated [458-461]. Future models could also improve the intervention tailoring for the cognitively impaired subgroup. There is in fact one New Zealand guideline tailored to this subgroup which recommends exercise, HAM, and nutrition improvement and emphasises close carer involvement and measures to improve adherence [462]. These differ from the multifactorial intervention and Tai Chi incorporated in the current model for this subgroup and warrant further analyses. Multi-need integration strategies should be explored that improve upon the current care structure which manages falls and cognitive impairment separately [463].

The *de novo* frailty index developed using ELSA was a key tool for characterising heterogeneity and dynamic complexity. Further work should psychometrically assess the index in terms of its construct and predictive validities as done for other indices (Table 5.7). Future models should moreover capture the seasonal patterns to falls risk (peaking in the Winter), using monthly cycles or discrete event simulation to capture the within-year variation.

Understanding the demand motives of cognitively impaired older persons is a priority [464]. Parameterising the impacts of social community on behaviour and intervention access is also warranted. One such impact is that of informal caregivers, particularly on cognitively impaired persons’ falls risk and intervention access [465, 466]. Future models should capture the active roles caregivers play in falls prevention, and not just the monetary caregiving burden and time opportunity cost. For example, the ELSA-derived equation in Table E15 showed that informal care receipt *reduced* the likelihood of GP contact, suggesting that caregivers addressed certain care needs of older persons otherwise addressed by GPs. Yet this demonstrates the importance of falls risk awareness among caregivers such that the lower GP contact does not restrict the care recipients’ proactive intervention access. Roles of further professionals and lay personnel should be explored and parameterised: paramedics [75]; allied healthcare professionals [467]; social workers [468]; and members of the rural community [364].

Regarding issues of equity, a key task is to parameterise the dynamic change in older persons’ socioeconomic circumstances. Another is identifying socioeconomic determinants of falls risk which have been underexplored. Moreover, actual commissioning decisions to reduce social inequities of health take place at the geographically defined area level. The Sheffield CCG, for example, targeted city regions with high deprivation and large concentration of older people for its pilot commissioning of Dance to Health (Section 3.7.1.3). Likewise, the main implementation unit for the integrated care scheme in Sheffield is the ‘neighbourhood’ region overseen by a GP practice [212]. Future modelling should incorporate this spatial element, first parameterising the spatial distribution of demographics and frailty across areas of differing social deprivation [469], then associating individuals’ intervention access to their resident area, and evaluating different area-level targeting strategies.

### 7.5.4 Evaluation methods

This section adds to the further research items discussed in Section 6.4.4. First, given the wide range of relevant outcomes used for decision-making, there is scope for exploring the use of multi-criteria decision analysis (MCDA) to weight the different outcomes based on stakeholder preferences; the MCDA could incorporate participant preferences and process benefits not fully captured in EQ-5D [470]. Second, estimation of the value of perfect/improved information is typically conducted alongside VoIM analysis [199], and future models could implement both.

Third, the commissioning recommendations in Section 6.3.3 considered the possibility that some candidate strategies may be ruled out due to excessive public sector budget impacts; but future evaluations could assign lower cost-effectiveness thresholds to strategies with larger budget impacts (to account for the more valuable activities displaced by the larger expenditure) rather than ruling them out in a binary fashion (p. 91) [145]. Another approach is to conduct constrained optimisation given a pre-specified budget constraint [172], although this requires an exhaustive simulation of all intervention permutations under different implementation levels. Incidentally, the discount rates had a large effect on aggregate INMBs (Table F14). Further research is thus warranted on the process of verifying whether the NICE-recommended discount rates are applicable to the decision-making setting.

Finally, future models could explore ways in which measures of community empowerment are incorporated in geriatric public health evaluations and intervention strategy comparisons. This would address the criticism that the aggregation of individuals’ health (and wellbeing) outcomes under CUA does not fully capture the benefits that chiefly accrue to the community in various forms such as stronger community institutions and cohesion [236-238]. The value judgement that *social* welfare can be measured by the aggregation of *individual* welfare is a key principle of Welfarism but not necessarily of Extra-Welfarism where diverse maximands beyond individual utility can be chosen [148]. The current model tracked the number of older persons participating in volunteering work and self-referred interventions as a measure of empowerment. But further research should validate this and other measures, then use them consistently for all intervention strategies for a thorough comparison.

## 7.6 Conclusion

This study met the research aim and objectives initially set out. A credible, validated economic model was developed to assess the performance of UK guideline-recommended community-based falls prevention in the representative local health economy of Sheffield. The recommended strategy was compared to the current practice and found to have high probability of being cost-effective at the commonly accepted cost-effectiveness thresholds (93.4% at £20,000 per QALY gained threshold). It also improved equity in terms of relative and absolute differences in net health benefit gain across SES quartiles. Nevertheless, the recommended strategy is unlikely to be the optimal commissioning option when compared to alternative intervention strategies potentially available to the local decision-maker. It was found that the optimal strategy varied by the chosen decisional criteria including capacity implications, individual-level lifetime outcomes and joint efficiency-equity impact.

The conceptual modelling prospectively reduced the model’s structural uncertainty, while the systematic review (informed by the systematic overview) ensured that best modelling practices and data were incorporated in the final implemented model. The conceptual model also motivated several methodological developments in modelling the key methodological challenges for public health economic modelling such as the dynamic feedback loop between falls and frailty. Evaluation methods were likewise expanded beyond efficiency comparisons to address priority setting challenges. The model outcomes and commissioning recommendations are timely given the pending update to the NICE falls prevention guideline. Yet the key lessons from the model development and analysis should find wider applications in geriatric public health beyond community-based falls prevention.

Overall, the methods and results of this study are of relevance to consumers of economic evidence on community-based falls prevention – i.e., commissioners, falls prevention professionals, advocacy groups for older persons – and producers of the said evidence on falls prevention as well as further geriatric public health interventions.

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1. Despite its label containing CEA, ECEA is perceived here as a CCA because it involves the evaluation and reporting of a wide range of health and non-health outcomes and not just natural health units used for CEA. [↑](#footnote-ref-1)
2. As noted in Table 3.2, a separate meeting with social prescribing organisations took place in June 2018 to discuss the community-based integrated care. However, the organisations clarified that their focus is on working age adults, working with GP practices to address social determinants of health such as long-term unemployment. [↑](#footnote-ref-2)
3. Access to the falls risk assessment and treatment was not restricted to those with MA fall history: 1.58% of those without MA fall history accessed it. However, this access was restricted to those with history of recurrent non-MA falls, with 17.63% of individuals in this group accessing it. [↑](#footnote-ref-3)
4. None of those who had no falls history or history of single non-MA fall received falls risk screening, suggesting that falls history served as a preliminary criterion for screening receipt under UC. [↑](#footnote-ref-4)