Investigating the potential of using mHealth apps to support DASH diet self-management among individuals with high blood pressure in Saudi Arabia

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Declaration

I, Ghadah Alnooh, declare that neither the whole nor any part of the work referenced in this thesis has been previously submitted to any other university or educational institution apart from the University of Sheffield to obtain an academic degree or similar qualification. This thesis is submitted in a publication format, which allows it to be composed of academic publications alongside the traditional thesis sections. These papers may already be published, accepted, or planned for submission. Appendix 1 provides additional information regarding journal copyright statements.

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List of Abbreviations

NCDs: Non-communicable diseases

CVDs: Cardiovascular diseases

MENA: Middle East and North Africa

RCT: Randomised Controlled Trials

BP: Blood Pressure

SBP: Systolic Blood Pressure

DBP: Diastolic Blood Pressure

WHO: World Health Organization

SUS: System Usability Scale

BMI: Body mass index.

eHealth: Electronic health

mHealth: Mobile health

TDF: The theoretical domain framework

BCTs: Behaviour change techniques

BCTTv1: Behaviour change technique taxonomy v1

AQEL: App Quality Evaluation Tool

NHS: National Health Service

Dissemination

PhD Publications

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Alnooh, G., Alessa, T., Noorwali, E., Albar, S., Williams, E., de Witte, L.P. and Hawley, M.S. Identification of the Most Suitable Mobile Apps to Support Dietary Approaches to Stop Hypertension (DASH) Diet Self-management Through a Systematic Search of Two App Stores. *ScHARR PGR annual Conference*, June 2023.

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Other publications

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Abstract

Background: Hypertension is a significant risk factor for cardiovascular disease and stroke, affecting 1.28 billion adults worldwide. Saudi Arabia has a high prevalence of hypertension, with 48.2% of adults aged 40 to 64 living with high blood pressure (BP) in 2018. Lifestyle management is crucial in addressing this issue. Strategies for preventing and controlling hypertension include maintaining a healthy body weight, increasing physical activity levels, and adopting the Dietary Approaches to Stop Hypertension (DASH) diet as the front-line strategy. Effective dietary self-management can enhance adherence to the DASH diet and help control BP. In this context, mobile health (mHealth) apps are increasingly considered valuable resources for managing individuals' diets. Smartphone apps may provide new opportunities to improve nutrition interventions and change behaviour. Nevertheless, despite these advantages, patients and health-care professionals can face difficulties in identifying and selecting the most suitable apps. Further research is needed to determine whether mHealth apps can support DASH diet self-management and improve adherence among individuals with high BP in Saudi Arabia.

Aims: The overall aim of this thesis is to investigate the potential of using mHealth apps to support DASH diet self-management among individuals with high BP in Saudi Arabia.

Methods: Four studies were conducted in two phases. Phase one aimed to identify the most suitable DASH diet self-management apps. An exploratory approach was used to gather information on relevant apps, including their effectiveness, theoretical basis, quality, safety, security, characteristics, and functions. This phase consisted of two studies: 1) a systematic review of existing literature and 2) an app store review. Phase two aimed to select the most suitable DASH diet app for the Saudi Arabian context and to evaluate its feasibility and acceptability within this context. This exploratory phase involved two studies: a qualitative study and a feasibility study. The qualitative study sought to gain insights into the experiences and perspectives of individuals with high BP and healthcare professionals who have used the DASH diet self-management apps identified in phase one as high-quality, secure, and potentially effective (Noom and DASH To Ten). This information was crucial in selecting the most appropriate app for the Saudi context. The feasibility study evaluated the feasibility and acceptability of using the Noom app to support DASH diet self-management among individuals with high BP in Saudi Arabia.

Results: The first phase identified two high-quality, secure, and potentially effective DASH diet apps: DASH To TEN and Noom. In the second phase, the participants in the qualitative study selected the Noom app as the most suitable for the Saudi context. While during the feasibility study, the participants found the Noom app to be feasible and acceptable, they also suggested improvements for greater accessibility to the Saudi population, including translating it into Arabic and simplifying the food logging process.

Conclusion: The contributions of this thesis are significant in addressing a crucial gap in current research: the need for more studies exploring the use of smartphone apps to enhance adherence to the DASH diet to control BP. The research employed a systematic staged approach to identify and select commercial dietary smartphone applications, enabling researchers to make well-informed decisions when selecting dietary apps. This approach provided a solid basis for developing a high-quality RCT of a widely available DASH diet app since this research carefully identified and selected a commercial DASH diet app and evaluated its feasibility, usability, and acceptability among individuals with high BP in Saudi Arabia. However, conducting an RCT in Saudi Arabia may face challenges if the app is not adapted to address participants' recommendations, particularly concerning the need to enhance its educational content to better align with the needs of Saudi users. In addition, dietitians can leverage these findings to recommend two high-quality, potentially effective, and secure apps to their patients, aiding in DASH diet self-management.

This research also offers critical insights into the interactive features of these dietary apps, informed by feedback from both patients and health professionals. These insights are instrumental for researchers and developers aiming to design more effective and user-friendly dietary applications. This research's exploration of the feasibility and acceptability of commercial dietary apps among Saudis can inform further studies in the mHealth field.

Chapter 1 │ Introduction

1.1 An overview of the thesis and its aims and objectives

Non-communicable diseases (NCDs), such as cardiovascular diseases (CVDs), hypertension, and diabetes mellitus, have become a significant challenge for healthcare systems worldwide and account for approximately 74% of all deaths (World Health Organization, 2023a). The mortality rate resulting from NCDs has increased dramatically in Western countries and is also increasing in countries in the Middle East and North Africa (MENA) (Al-Hanawi, 2021; Tyrovolas et al., 2020). In Saudi Arabia, 73.0 % of all deaths have been attributed to NCDs over the past decade (Tyrovolas et al., 2020). Saudi Arabia has seen rapid population growth, reaching 33 million in 2022 (Saudi General Authority for Statistics, 2022). It has also seen significant growth in lifestyle changes, economic development, and technological advancements (Al-Hazzaa & Albawardi, 2021). These developments have led to an increase in lifestyle-related NCDs; CVDs are responsible for 37.0 % of all deaths in Saudi Arabia and are the country's leading cause of death (Alghnam et al., 2021). Major modifiable CVD risk factors include hypertension, smoking, diabetes mellitus, and dyslipidemia (Fuchs & Whelton, 2020; Kannel, 2000). Although Saudi Arabia's government has invested heavily in the healthcare sector and provided accessible healthcare services, hypertension remains widespread (Amir et al., 2023). According to a Saudi Ministry of Health report from 2018, hypertension affects 3.2% of Saudis aged 15 to 24, 48.2% of those aged 55 to 64, and up to 70% of those over 65 (Saudi Ministry of Health, 2018). Additionally, cases of prehypertension have been on the rise, with more than three million cases among males and over two million among females (Saudi General Authority of Statistics, 2018; Saudi Ministry of Health, 2018). A recent systematic review and meta-analysis of 29 studies with 278873 individuals that evaluated the prevalence, awareness, treatment, and control of hypertension in Saudi Arabia found that the condition affected 23 % of Saudi individuals aged 14 years and above (Alshammari et al., 2023). However, the same review revealed that there is still a need to improve awareness among patients, as fewer than half (42.8%) of those with elevated blood pressure (BP) were aware of their condition or receiving treatment (Alshammari et al., 2023).

Lifestyle modification, including optimum diets, physical activity (PA), and alcohol and tobacco control, can control and prevent many NCDs, including hypertension (Campbell et al., 2019). Lifestyle modifications are recommended as the primary treatment for individuals with elevated BP, regardless of whether they are prescribed medication (Whelton, 2017). A Dietary Approaches to Stop Hypertension (DASH) diet is an evidence-based lifestyle intervention that reduces BP (Appel et al., 1997). The DASH diet focuses on consuming nutrient-rich foods, such as fruit and vegetables, whole grains, and low-fat dairy products, while limiting the intake of red meat and processed foods (Sacks et al., 1995). Moreover, it has a specific emphasis on increasing the nutrient consumption of calcium, magnesium, potassium, fibre, and protein, as well as reducing the intake of saturated fat, total fat, and cholesterol (Sacks et al., 1995). A systematic review and meta-analysis of 30 randomised controlled trials (RCTs) with 5545 hypertensive and non-hypertensive participants, comparing the DASH diet to a control diet, found a significant reduction in both systolic BP (SBP) and diastolic BP (DBP) when the DASH diet was combined with other lifestyle interventions (difference in means: −3.2 mm Hg; $P < 0.001$, and −2.5 mm Hg; $P < 0.001$, respectively) (Filippou et al., 2020).

Self-management has emerged as a crucial response to the growing global challenge of managing chronic disease (Shahaj et al., 2019). As defined by the World Health Organisation (WHO), self-management refers to individuals' ability to manage their health conditions either independently or with the assistance of healthcare providers (Organization, 30/06/2022). Self-management practices encompass a range of approaches, including patient education, self-monitoring of BP and behaviour, adherence to prescribed medication regimes, and lifestyle modifications, such as dietary changes and increased PA (Li et al., 2020). A systematic review conducted by Barlow et al. (2002) highlighted that self-management approaches effectively increase participants' knowledge, symptom management, self-efficacy and overall health status, including depression. Dietary self-management has been found to be instrumental in helping hypertension patients adopt and maintain recommended dietary modification (Jones et al., 2022). Thus, it is a crucial strategy to promote the health of patients with high BP.

Communication is vital in healthcare settings as it helps guarantee that patients are receiving the best possible care (Sharma et al., 2022). In the past, patients had to physically visit healthcare facilities to discuss their health concerns and receive treatment (Sharma et al., 2022). With advances in technology, mobile phones have become an essential means of communication for people across the globe (Sharma et al., 2022). What was once a luxury item only accessible to the wealthy is now widely available and affordable (Sharma et al., 2022). The proliferation of mobile phones has been instrumental in the significant increase in Internet accessibility over the past decade. In 2018, approximately 300 million new users embraced the mobile web, and by 2019, the global number of mobile web users had surpassed 3.5 billion, with mobile phones being the primary means of Internet access (Chaqfeh et al., 2023). Notably, 74% of these users are in low- and middle-income countries (Chaqfeh et al., 2023). Globally, there were 6.4 billion smartphone subscriptions in 2022, and this figure is expected to reach 7.7 billion by 2028 (Taylor, Jul 19, 2023). In the context of electronic health (eHealth), mobile and wireless technologies are used to support public health. Information and communication technologies can be used efficiently, cost-effectively, and securely to support health and health-related activities (Organization, 26 March 2018). Using a smartphone makes it easier for patients to connect with healthcare providers and receive timely and effective care, regardless of their location (Sharma et al., 2022). The use of eHealth is becoming increasingly important for individuals in managing their health, especially among those with chronic diseases (Hanlon et al., 2017). A systematic review and meta-analysis assessing risk factors for CVD and potential outcomes by comparing digital and non-digital health interventions found that mobile health (mHealth) interventions have demonstrated promising results in improving weight loss, body mass index (BMI), BP, and (low-density lipoprotein) cholesterol risk factors among patients aiming for the primary prevention of CVD (Widmer et al., 2015). Mobile app-based interventions have been found to effectively improve diet and related health outcomes, with effect sizes similar to those of traditional non-digital interventions (Villinger et al., 2019). For instance, mHealth interventions can aid in improving lifestyle behaviours for individuals with CVD (Chow et al., 2016). Thus, mHealth seems to be able to effectively motivate and persuade users to change their behaviour and achieve their health and wellness goals.

1.1. 2 mHealth for Dietary Self-management in the Context of Saudi Arabia

Saudi Arabia is a developing country but also one of the most powerful economies in the G20 (The International Labour Organization, 2020; The United Nations, 2002). Economic growth has been accompanied by technological advancements and changes in the population's standard of living, resulting in a significant lifestyle change among Saudis (World Bank Group, 2022). The easy availability and affordability of unhealthy foods and sedentary lifestyles have led to high obesity and cardiovascular disease (CVD) rates (Alshammari et al., 2023; Bawazeer et al., 2021). According to a Saudi General Authority of Statistics (2023) report, the prevalence of obesity among Saudi adults with a BMI > 30 was approximately 24%, and 40.5% of Saudi adults were overweight excluding those with obesity (Saudi General Authority for Statistics, 2023).

Several studies conducted in Saudi Arabia have found that self-management practices among patients with high blood pressure (BP) are poor (AlHadlaq et al., 2019; Bakhsh et al., 2017; Innab et al., 2023). These studies have also observed that hypertension self-management behaviour is significantly negatively correlated with increasing age above 50 years, high BMI, and the male gender, while having a positive correlation with high education and motivation. However, Khresheh & Mohammed (2016) reported a positive correlation between older Saudi women with long-duration hypertension and self-management practices. This could be attributed to the fact that older women who have experienced hypertension for extended periods have gained more knowledge and skills in coping with the condition (Hu et al., 2013). A recent narrative review of eight cross-sectional studies involving 14,782 participants examined the prevalence of prehypertension and explored the modifiable risk factors in Saudi Arabia. This study found that obesity and being overweight have been identified as modifiable risk factors in many studies and suggested that weight loss could effectively prevent or delay the progression of hypertension and related cardiovascular events (Al-Kadi, 2022). This conclusion aligns with the WHO recommendations (World Health Organization, 2023a). A recent systematic review of lifestyle factors associated with CVD risk in Saudi Arabia found that over a third of the reviewed population consumed unhealthy diets that were high in fat, low in vegetables and fruit, and poor in fibre, a combination that triples the risk of CVD (Alhejely et al., 2023). Several studies have also demonstrated that Saudis consume more calories from refined and salt-rich fast foods and soft drinks than from fruit and vegetables on a daily basis (Al-Hanawi & Keetile, 2021; Alzahrani et al., 2020; Kazi et al., 2020).

Although Saudis are well aware of the relationships between obesity, high salt intake, and hypertension, which are known risk factors for disease (Alhazmi et al., 2023; Elbashir et al., 2020; Elsheikh et al., 2021), they lack awareness of the importance of staying physically active and eating vegetables and fruit to prevent the development of high BP (Elbashir et al., 2020). It is important to note that these studies were cross-sectional with a small sample size of 2201 participants and may not fully represent the Saudi population.

The Saudi National Heart Center/Saudi Heart Association and Saudi Hypertension Guidelines recommend a DASH diet (Alhabeeb et al., 2023; Society, 2018). However, several cross-sectional studies have found that adherence to following a healthy diet, particularly the DASH diet, is the least practised self-management behaviour among individuals with hypertension (AlHadlaq et al., 2019; Neminqani et al., 2013; Sharaf et al., 2021). It will be informative to investigate the barriers to following the DASH diet among patients with high blood pressure with the ultimate aim of enhancing the overall health of the Saudi population. This research aims to do so by conducting a qualitative study to explore these barriers.

As the prevalence of chronic diseases increases, it is crucial to find ways to improve patient care and empowerment. Mobile health (mHealth) technology is gaining popularity among both healthcare providers and users (Salas-Groves et al., 2023). Saudi Arabia is in the process of rapidly digitalising its healthcare services and linked health economy in order to help realise the Kingdom's Vision 2030 (Al-Anezi, 2020). As part of its 'knowledge society' vision, Saudi Arabia seeks to establish a long-term strategic vision for diversifying and reforming its healthcare systems (Al-Anezi, 2020). Regarding disease prevention and health promotion, the Saudi Vision 2030 aims to build healthier communities, raise awareness of noncommunicable diseases, and develop strategies to prevent chronic diseases from causing severe health problems (Saudi Vision 2030, 2023). In terms of a digital society, Saudi Arabia has one of the highest rates of smartphone, internet and social networking usage in the Gulf and Middle East. The 2019 Saudi General Authority of Statistics report showed that 96.97% of the Saudi population use smartphones (Saudi General Authority for Statistics, 2019).

Despite the general openness of the Saudi population towards using mHealth applications (apps) in the management of chronic disease (Al Ansari et al., 2023; Alessa, Hawley, Alsulamy, et al., 2021; Aljuraiban, 2019), few studies of the use of such apps have been conducted in Saudi Arabia (Alsswey et al., 2021). This lack of studies has been attributed to specific cultural and social factors unique to Saudi citizens, which could impede the adoption and promotion of research on mHealth apps (Alsswey et al., 2021). A survey on implementing mHealth technology in Saudi Arabia has identified significant barriers, including a shortage of mHealth expertise and human resources, insufficient funding, legal and privacy standardisation issues, lack of healthcare professional recommendations, and a lack of awareness of the benefits of mHealth (Alanzi, 2018; Rafiullah & David, 2019). To overcome these challenges and achieve the goals of the Kingdom's Vision 2030, it will be valuable to conduct more studies to shed light on Saudi people's attitudes towards mHealth apps.

Some recent studies have supported the use of smartphone apps to support DASH diet self-management in lowering hypertension in the USA and Iranian populations (Bozorgi et al., 2021; Steinberg et al., 2020; Toro-Ramos et al., 2017). It is worth noting that some of these studies relied on commercially available smartphone apps. This may be because developing a mobile app for public use is a time-consuming and costly process, involving content creation, programming, design, continuous hosting and updating of the app, and provision of customer service and technical support (Jake-Schoffman et al., 2017). On average, it takes about seven to twelve months and costs about US $270,000 to fully develop and launch an app (Jake-Schoffman et al., 2017). This cost does not include the additional expenses of maintaining the app post-development or publishing the app to multiple platforms (Jake-Schoffman et al., 2017). As most researchers are unlikely to have access to such resources, using existing commercial apps for research is more cost-effective and efficient. The commercial availability of DASH diet self-management smartphone apps has increased, but evidence is needed regarding their potential effectiveness, usability, quality, security, and privacy. These information shortcomings might lead to significant concerns about their potential benefits and could even pose a risk to users (König et al., 2021). Therefore, there is a need to investigate these apps' effectiveness, quality, security and privacy levels, usability, and acceptance among users. The current research aims to address this lack of evidence and provide valuable insights for practitioners and policymakers.

Providing successful services to end users requires a deep understanding of cultural norms and preferences (Alsswey et al., 2020). Developing and deploying mHealth technologies in the Arab world requires an understanding of the cultural factors that influence mHealth app acceptance (Aljohani & Chandran, 2021; Alsswey et al., 2020). Additionally, design guidelines for nutrition apps recommend incorporating personalisation features that can cater to individual needs and goals and adapt to personal variables, such as age group and ethnic preferences (König et al., 2021). This guideline emphasises the importance of identifying the most appropriate apps for a particular cultural context and evaluating their potential usability. To date, no studies have explored the potential of DASH diet self-management apps to enhance dietary self-management for controlling hypertension in the context of Saudi Arabia or the other Gulf States. Therefore, to enhance dietary behaviour, it is important to assess the available apps for DASH diet self-management as part of hypertension control, identify and select the most suitable apps for the Saudi context, and assess the feasibility and acceptance of the most suitable apps among patients with high BP in Saudi Arabia. In light of this, the present PhD thesis aims to investigate the potential of using mHealth apps to support Dietary Approaches to Stop Hypertension (DASH) self-management among individuals with high blood pressure (BP) in Saudi Arabia. To accomplish this, the following objectives will be pursued (further details are provided in Section 1.3):

1. To evaluate the evidence in the literature concerning the effectiveness of DASH smartphone apps in improving DASH adherence and reducing BP, as well as assessing their usability and user satisfaction levels.

2. To identify generally available apps suitable for DASH self-management based on their likely effectiveness, quality and security.

3. To explore the experiences, perceptions and acceptance levels of DASH apps among both individuals with high BP and healthcare professionals in Saudi Arabia.

4. To determine which app identified as suitable for DASH self-management is the most appropriate for use in the Saudi context.

5. To assess the feasibility and acceptability of using the selected app to encourage individuals with high BP to improve their dietary habits.

1.2 Background

1.2.1 The transformation of Saudi Arabia's diet and lifestyle: A public health perspective

Nutritional knowledge and eating behaviours differ among countries and, in some cases, even within the same country (Bakhotmah, 2012). Cultural, socio-economic and educational factors all influence these differences (Bihan et al., 2010). Additionally, the local food taxonomy evolves due to changes in income levels and modernisation (Bakhotmah, 2012). In this regard, historically, most Saudis have been Bedouin Arabs, who adapted to a harsh, arid environment with limited resources. They consumed various local foods, such as dates, fresh and dried milk products, livestock products, whole wheat for bread and a modest assortment of vegetables. In fact, these simple yet nutrient-rich ingredients formed the basis of traditional dishes throughout the whole Arab Gulf region (Musaiger, 2006). Moreover, Saudi Arabian lifestyles have traditionally been based on agriculture, whereby many Saudis resided in rural areas and engaged in daily activities that entailed physical activity (DeNicola et al., 2015).

However, the discovery of oil in Saudi Arabia in the 1960s marked the beginning of a period of rapid economic growth (DeNicola et al., 2015). This economic development in both Saudi Arabia and neighbouring countries significantly boosted people's purchasing power and improved the availability of food, leading to profound changes in dietary habits (Zobel et al., 2016). The proliferation of supermarkets and the growth of the fast food industry introduced ultra-processed foods that are high in sugar and saturated fats, which now constitute a major portion of people's daily caloric intake (Zobel et al., 2016). In Saudi Arabia and many other Arab cultures, hospitality, generosity and the tradition of sharing food are prioritised over strict healthy eating guidelines, for example, recommended portion sizes (Bakhotmah, 2012). In a typical household in the Arab Gulf states, formal dinners and celebrations often feature large, shared platters filled with lamb or chicken and rice, which are accompanied by only small portions of salad (Bakhotmah, 2012). In addition, social gatherings are common and it is customary for family members and hosts to encourage guests to eat, even when they are not particularly hungry (DeNicola et al., 2015). This cultural practice, combined with the growing influence of Western food and increased availability of food in general, has contributed to rising rates of obesity and related NCDs in Saudi Arabia (DeNicola et al., 2015). Given these factors, the prevalence of health issues is not surprising.

Both urbanisation and globalisation have also ushered in lifestyle changes across the Arab Gulf states, including Saudi Arabia. Such changes include a heavy reliance on automobiles for transportation, the widespread adoption of labour-saving devices, the growing popularity of satellite television and the increased use of computers and telecommunications, which have all reduced physical activity levels and lowered occupational energy demands, thereby fostering a predominantly sedentary lifestyle among young people and adults (Al-Nuaim et al., 2012). The consequences of these changes are reflected in the rising prevalence of NCDs throughout the Arab Gulf region (Al-Nuaim et al., 2012). Indeed, physical inactivity and unhealthy diets are among the leading contributors to NCDs, including cardiovascular diseases, type 2 diabetes and certain cancers (Abdul Rahim et al., 2014; Al-Nuaim et al., 2012). These health conditions significantly contribute to the global burden of disease, disability and mortality in Arab countries (Abdul Rahim et al., 2014; Hamadeh, 2017). This recognised shift in dietary habits and lifestyle patterns highlights the urgent need for public health strategies to promote healthier eating and increased physical activity to mitigate the escalating prevalence of NCDs in both Saudi Arabia and the wider Gulf region (Al-Nuaim et al., 2012).

Furthermore, the estimated annual direct medical costs associated with ten major NCDs, including diabetes, stroke and coronary heart disease, are estimated to reach US $11.8 billion in Saudi Arabia, equivalent to 13.6% of the country’s total health expenditure in 2019 (World Health Organization, 2022b). The financial repercussions of being overweight and obese are particularly concerning, with the annual direct medical costs of these conditions being estimated at US $3.8 billion, accounting for 4.3% of Saudi Arabia’s health expenditure in 2019 (Aldubikhi, 2023). Yet, alarmingly, projections indicate that these costs may surge by 12.7% from 2020 to 2050, imposing a significant economic burden on the country (Aldubikhi, 2023).

In response to these pressing issues, the Saudi government has embraced a number of innovative initiatives as part of its Vision 2030 (Aldubikhi, 2023). Among these initiatives is a groundbreaking excise tax on sugar-sweetened beverages, which has already shown promising results in terms of improving public health (Alsukait et al., 2020). In addition, the government’s healthy food regulations include mandatory caloric information displays, stringent nutrient composition standards, nutrition labelling, a ban on partially hydrogenated oils and recommended sodium limits (Alsukait et al., 2020; Bin Sunaid et al., 2021). These measures are designed to empower individuals to make informed dietary choices, with the ultimate aim being to reduce the rising incidence of obesity (Bin Sunaid et al., 2021). This is important because the increasing prevalence of obesity poses a significant threat to public health due to being linked to various health complications, including type 2 diabetes, hypertension, cardiovascular diseases and sleep apnea (Althumiri et al., 2021). If left unaddressed, these health issues, such as obesity, diabetes and hypertension, could worsen the economic challenges facing the country. Moreover, without effective interventions, Saudi Arabia could face an overwhelming strain on its healthcare system (Aldubikhi, 2023).

A comprehensive approach is essential for addressing obesity and reducing the associated complications. While various approaches are available, including lifestyle management, medication and surgical interventions, it is essential to emphasise and promote the benefits of lifestyle changes to the Saudi Ministry of Health and other levels of government (Aldubikhi, 2023). Lifestyle interventions exhibit immense promise in relation to preventing obesity and improving community health, although in cases of moderate to severe obesity, pharmacotherapy and surgical options may also prove necessary (Aldubikhi, 2023).

1.2.2 Hypertension

Hypertension (chronic high blood pressure) is a major public health concern because of its high prevalence and its association with cardiovascular disease (CVD). Hypertension is a medical condition characterised by persistent pressure elevations in blood flow through blood vessels (World Health Organization, 2023a). The heart is forced to work harder, and the blood is forced to flow through the blood vessels at a higher pressure (World Health Organization, 2023a). Hypertension is a major risk factor for serious health problems, such as heart disease and stroke (NHS, 2023a; Saudi Ministry of Health, 2023b). It is determined by the amount of blood the heart pumps and the resistance of the arteries to blood flow (Saudi Ministry of Health, 2023b). Hypertension is a disease that develops over time; therefore, it is possible to detect high blood pressure (BP) in its early stages and manage it effectively (NHS, 2023a; Saudi Ministry of Health, 2023b). The measurement of BP involves two numbers. Systolic blood pressure (SBP), which is the higher number, measures the pressure in the arteries when the heart beats. Diastolic blood pressure (DBP), which is the lower number, measures the resistance to the blood flow in the blood vessels between heartbeats. Both are measured in millimetres of mercury (mmHg) (NHS, 2023b).

High BP in adults is classified into six categories based on SBP and DBP levels, as shown in Table 1-1 (Saudi Ministry of Health, 2023b; Williams et al., 2018a).

Table 1-1: Classification of blood pressure for adult

Blood pressure category	Systolic pressure (mm Hg)	Diastolic pressure (mm Hg)
Optimal blood pressure	Less than 120	Less than 80
Normal	120–129	80–84
Prehypertension	130–139	85–89
High blood pressure (Stage 1 hypertension)	140–159	90–99
High blood pressure (Stage 2 hypertension)	160–179	100–109
High blood pressure (Stage 3 hypertension)	Higher than 180	Higher than 110

Hypertension is called the ‘silent killer’ because it often has no warning symptoms and many people are unaware that they have high BP (Bell et al., 2015). Some people may experience dull headaches, vomiting, dizziness, and nosebleeds; however, these symptoms usually occur when the BP levels have become hazardous (NHS, 2023b; Saudi Ministry of Health, 2023b). To diagnose hypertension, BP should be measured by a healthcare professional (Bell et al., 2015; Saudi Ministry of Health, 2023b).

Globally, hypertension affects about 1.28 billion adults aged 30 to 79 years, and only one in five adults (21%) effectively manage their hypertension (World Health Organization, 2023a). The prevalence of hypertension varies from region to region. In low- and middle-income countries, about 31.5% of adults (1.04 billion people) are affected by hypertension, whereas in high-income countries, the prevalence is comparatively lower, affecting only 28.5% of adults (349 million people) (Mills et al., 2020). The high prevalence of hypertension in high-income countries remains a cause for concern. In the United States, for example, there were 78 million adults living with hypertension, based on data from 2007 to 2010 (Bolin et al., 2018; Go et al., 2014). China's situation is even more alarming, as 244.5 million people were living with hypertension in 2015, with 2 million deaths as a result of the disease (Qu et al., 2019). Hypertension is more common among older adults; for example, in the UK, hypertension affects up to 60% of those aged 65 and over, while 9% of adults between 16 and 44 years are affected (NHS, 2023b). Similarly, in Saudi Arabia, hypertension tends to increase with age, affecting 3.2% of people aged 15 to 24 and up to 70% of people aged 65 and over (Saudi Ministry of Health, 2018).

Hypertension can be classified into two categories based on its cause: primary hypertension and secondary hypertension (Saudi Ministry of Health, 2023b). The cause of primary hypertension is still unknown, but it has risk factors, such as obesity, high sodium or low potassium intake, physical inactivity, and alcohol intake (Gupta & Guptha, 2010; Saudi Ministry of Health, 2023b). Non-modifiable factors also play a significant role, including age, family history, genetic influences, and ethnicity (World Health Organization, 2023a). Primary hypertension is more prevalent than secondary hypertension and tends to develop gradually over time (Saudi Ministry of Health, 2023b). Approximately 10% of patients with hypertension are diagnosed with secondary hypertension; this condition is more common among younger people than older people (Alhaddad et al., 2021). Secondary hypertension is caused by other underlying health conditions, such as kidney problems, hormonal issues, thyroid problems, obstructive sleep apnoea, congenital blood vessel abnormalities, and certain medications (Saudi Ministry of Health, 2023b).

Recent guidelines for hypertension management, including risk assessment and treatment strategies, such as lifestyle advice and medication management, need to be successfully implemented to reduce cardiovascular mortality rates (Boateng & Ampofo, 2023). Implementing these strategies can lead to a significant reduction in cardiovascular mortality and is likely to contribute to the global effort to reduce the prevalence of hypertension by 2040 (Boateng & Ampofo, 2023).

1.2.3 Hypertension Management Strategies

Management of hypertension primarily involves pharmacological and non-pharmacological approaches (Seyedmazhari, 2012). Pharmacological strategies include antihypertensive medications (Seyedmazhari, 2012). Non-pharmacological strategies, such as lifestyle modification, play a crucial role; therefore, patients with hypertension should be encouraged to modify their lifestyles (NHS, 2023a; Saudi Ministry of Health, 2023a; World Health Organization, 2023a). Motivating patients to make lifestyle changes can be challenging when managing hypertension (Samadian et al., 2016). Establishing trustworthy relationships between healthcare providers and patients is crucial for success (Samadian et al., 2016). Several well-established lifestyle modifications can effectively lower BP, including losing weight, reducing sodium intake, adopting a healthy diet (such as the Dietary Approaches to Stop Hypertension (DASH) diet), increasing physical activity (PA), and limiting alcohol consumption (Alsinani et al., 2018; Samadian et al., 2016; Saudi Ministry of Health, 2023a). These modifications are recommended for individuals with above-optimal BP, also known as 'pre-hypertensives', and as initial therapy for stage 1 hypertension. For those taking antihypertensive medication, lifestyle modification is recommended as adjunctive therapy (Samadian et al., 2016; Weber et al., 2014). Research has primarily focused on determining the impact on BP of whole-lifestyle modifications or single modifications, such as dietary patterns or individual nutrients (Ndanuko et al., 2016).

1.2.3.1 Lifestyle modifications for hypertension management

1.2.3.1.1 Dietary non-pharmacological interventions

a) The effects of individual nutrients

Sodium intake

High sodium intake is associated with high BP, heart failure, stroke, heart attack, and kidney failure (Dong, 2018). Sodium intake should not exceed 2000 mg/day, equivalent to less than 5 grams of salt per day (World Health Organization, 2023b). The World Health Organization (WHO) has recommended salt reduction as one of the most cost-effective approaches to preventing non-communicable diseases (NCDs), reducing CVD, and reducing medical costs (World Health Organization, 2023b). A meta-analysis of 133 RCTs involving 12,197 participants examined the effect of reduced sodium intake on blood pressure (Huang et al., 2020). The study revealed that individuals with reduced sodium intake experienced significant decreases in 24-hour urinary sodium, SBP, and DBP compared to those with usual sodium intake. Specifically, the mean reductions for 24-hour urinary sodium, SBP, and DBP were 130 mmol (P<0.001), 4.26 mm Hg (P<0.001), and 2.07 mm Hg (P<0.001), respectively. Moreover, for every 50 mmol reduction in 24-hour sodium excretion, there was a corresponding 1.10 mm Hg reduction in SBP (P<0.001) and a 0.33 mm Hg reduction in DBP (P=0.03) (Huang et al., 2020).

Arab Gulf residents consume more sodium than they require, with an average daily intake of >12 grams per person (Alhamad et al., 2015). Traditional Gulf dishes, canned foods, and fast foods, contain high salt levels (Musaiger et al., 2012). The WHO targets reducing salt intake by 30% by 2025 (World Health Organization, 2023b). To achieve a low salt intake, individuals should consume fresh foods, typically processed without salt, and should avoid salting their food. Salt can be substituted with acidic ingredients, such as vinegar, lemon, spices, and herbs (Musaiger et al., 2012).

Potassium intake

A high intake of potassium may play a role in lowering BP (Samadian et al., 2016). However, some argue that the sodium-to-potassium ratio is more critical than specific intake amounts (Samadian et al., 2016). The WHO suggests a potassium intake of at least 90 mmol/day (3510 mg/day) for adults (World Health Organization, 2012). Increasing potassium in the diet has a protective effect in patients with hypertension, as it reduces the BP and has no adverse impact on blood lipid concentrations or renal function in adults (Samadian et al., 2016). Processed food-based diets are high in sodium and low in potassium compared to natural food-based diets (Samadian et al., 2016). Conversely, fruit- and vegetable-based diets tend to have low sodium and high potassium levels (Samadian et al., 2016). A low-sodium diet, combined with a high potassium intake, can significantly reduce the prevalence of hypertension and CVD (Büssemaker et al., 2010). An analysis of 15 RCTs involving 917 patients who were not taking antihypertensive medications and were given potassium supplementation demonstrated that potassium supplementation decreased SBP by 4.7 mmHg and DBP by 3.5 mmHg for all patients. The effect was more significant in individuals with high blood pressure, with a reduction in SBP of 6.8 mmHg and a reduction in DBP of 4.6 mmHg (Binia et al., 2015). Although investigating the effect of single nutrients on BP may be beneficial, these nutrients are primarily delivered through food, and food is generally consumed as a whole diet (Ndanuko et al., 2016).

b) The effects of individual foods

Many meta-analyses have investigated the effects of individual foods on BP. This includes specific fruits and vegetables, nuts, chocolate, and coffee and tea (Desch et al., 2010; Li et al., 2016; Mahdavi-Roshan et al., 2020; Schwingshackl et al., 2017; Xie et al., 2018). All these studies found a significant inverse association between consumption of these foods and hypertension risk. However, in the past twenty years, there has been a growing focus on the use of complex whole diet approaches to prevent or treat hypertension (Savica et al., 2010). The composition of these diets is generally based on pre-existing evidence that the individual constituents have preventative or therapeutic effects on hypertension (Savica et al., 2010).

c) The effects of dietary patterns on BP

Nutrient and food consumption are not isolated but occur in numerous and complex combinations (Shan et al., 2020). To effectively manage high BP, evaluating the impact of the overall dietary pattern is essential, as different diet components can interact (Hu, 2002; Shan et al., 2020). For instance, Ursin et al. (1993) identified food groups and nutrients associated with a low-fat diet; they found that low dietary fat intake was associated with higher consumption of vegetables, fruit, fibre, folate, and whole grains. Given that these food groups independently correlate with a reduced risk of coronary heart disease (CHD), they can pose a confounding factor in studies examining the relationship between dietary fat and CHD. Due to potential interactions between these nutritional components, adjusting for these variables may not eliminate all confounding effects (Hu, 2002). Several studies have proposed examining overall dietary patterns (Shan et al., 2020). Various dietary patterns have been assessed, such as the Palaeolithic, Nordic, ketogenic, high-protein, vegetarian, Mediterranean, and DASH diets, which can be adopted to manage BP (Ndanuko et al., 2016; Schwingshackl et al., 2019). It is also worth noting that dietary patterns may vary across cultures, mainly due to differences in the types of food consumed (Ndanuko et al., 2016). Recently, several systematic reviews and meta-analyses of RCTs have explored the effectiveness of different dietary approaches in lowering BP (Schwingshackl et al., 2019; Sukhato et al., 2020). The evidence for the efficacy of some of these dietary approaches is moderate due to the low number of primary studies or inconsistent results (Sukhato et al., 2020). Examples are detailed below.

1) Paleo diet

The Paleo diet is a nutritional regimen that revolves around consuming foods likely consumed during the Palaeolithic era, which spanned about 2.5 million to 10,000 years ago (Sukhato et al., 2020). The diet primarily consists of lean meats, fish, fruit, vegetables, nuts, and seeds—all of which could have been obtained through hunting and gathering (Sukhato et al., 2020). Conversely, the diet restricts the consumption of foods, such as dairy products, legumes, and grains, that became prevalent after the advent of farming around 10,000 years ago (Sukhato et al., 2020). A meta-analysis, including four RCTs with 159 participants, assessed whether the Paleo diet enhances risk factors for chronic disease among individuals with one or more components of the metabolic syndrome. It concluded that Paleo diets may have slight BP-lowering effects in comparison to control diets based on national nutritional guidelines (Manheimer et al., 2015). The meta-analysis revealed that the mean differences in SBP and DBP were -3.64 mmHg and -2.48 mmHg, respectively. In addition, an updated meta-analysis that included two additional RCTs found that the Paleo diet significantly reduced SBP and DBP, with mean differences of -4.75 mmHg and -3.23 mmHg, respectively (Ghaedi et al., 2019). It is worth interpreting the results of the meta-analysis with caution. While the analysis suggests that a Paleo diet positively affects CVD risk factors, the evidence is inconclusive. The evidence provided by the studies was evaluated as moderate and insufficient to draw solid conclusions (Ghaedi et al., 2019).

2) Nordic diet

The Nordic diet, primarily consumed in Nordic countries such as Denmark, Sweden and Finland, consists of foods of Nordic origin, including different types of berries, whole-grain products, three meals of fish per week, root vegetables, fruit, and low-fat dairy products (Ndanuko et al., 2016; Schwingshackl et al., 2019). One of its unique features is that the diet is rich in berries, which are excellent sources of polyphenols and flavonoids, which may contribute to a reduction in BP. The effects of the Nordic diet on BP were examined in an umbrella review; the analysis of two meta-analyses consistently showed that adhering to a Nordic diet can significantly reduce SBP and DBP compared to usual or other healthy diets. The average reduction in SBP ranged from -3.97 to -5.20; for DBP, it ranged from -2.08 to -3.85. However, it is important to note that due to the limited number of studies (only seven primary studies with 798 adults, all conducted in Scandinavian countries), Nordic diets have been rated as moderately effective in reducing blood pressure (Sukhato et al., 2020).

3) Ketogenic diet

The ketogenic diet has gained popularity in recent years due to its effectiveness in achieving short-term weight loss (Batch et al., 2020). However, there is limited evidence regarding its efficacy and risks, and caution should be exercised, particularly given its high fat, low carbohydrate, and moderate protein content (Batch et al., 2020). A well-formulated ketogenic diet should prioritise dietary fat quality and balance micronutrients and macronutrients (Hanners et al., 2022). A recent meta-analysis of 23 RCTs with 1664 participants found no significant impact of dietary ketogenic interventions on SBP or DBP (Amini et al., 2023). It is also not recommended for patients with diabetes or chronic kidney disease due to the risk of ketoacidosis (Mehta & Sparks, 2022).

4) High-protein diet

The effectiveness of a high-protein diet on BP is controversial, as different studies have produced conflicting results (Dasinger et al., 2020). A meta-analysis of 14 RCTs, including 3277 participants, assessed the relationship between dietary protein and BP. It found that both vegetable and animal protein were linked to significant reductions in blood pressure (Rebholz et al., 2012). Specifically, vegetable protein was associated with a decrease of -2.27 mmHg for SBP and -1.26 mmHg for DBP. In comparison, animal protein was associated with a reduction of -2.54 mmHg for SBP and -0.95 mmHg for DBP, compared to dietary carbohydrate intake (all P-values < 0.001 for SBP and $P = 0.014$ for DBP). However, another meta-analysis of 29 studies, including 12 observational studies with 60,746 participants and 17 RCTs including 1449 participants, assessed the relation between dietary protein and type of protein and BP reduction; it revealed that protein diet did not significantly affect blood pressure (Tielemans et al., 2013). Additionally, an umbrella review of six meta-analyses that examined the effectiveness of a high-protein diet in reducing blood pressure found uncertainty regarding the effects of such a diet (Sukhato et al., 2020). For people with pre-existing kidney failure, it is essential to consider the amount of protein in their diet. Evidence has suggested that a high-protein diet may be associated with declining kidney function, while a low-protein diet may improve kidney function (Dasinger et al., 2020).

5) Vegetarian diet

A 'vegetarian' diet can be classified into several types depending on the level of animal food consumption (Lee et al., 2020). These include the vegan diet, which is entirely plant-based; the lacto-ovo-vegetarian diet, which excludes meat but may include eggs and dairy; the pesco-vegetarian diet, which may consist of fish but limits other meats to less than once a month; and the semi-vegetarian diet, which includes meats besides fish occasionally but limits them to less than once a week (Lee et al., 2020). Research suggests that vegetarian diets generally have higher quality than non-vegetarian diets due to factors such as higher levels of glutamic acid and plant-based protein, which have a blood-pressure-lowering effect, as well as higher fibre, antioxidant, potassium, and lower saturated fat and sodium content, which contribute to a lower body mass index and blood pressure readings (Dasinger et al., 2020; Soeters, 2020). A meta-analysis with 15 RCTs involving 856 participants evaluated the effect of a vegetarian diet on the reduction of BP (Lee et al., 2020). This study found that vegetarian diet consumption significantly lowered SBP and DBP compared to omnivores (mean difference -2.66 mmHg, $p < 0.001$, and DBP was -1.69 mmHg, $p < 0.001$) (Lee et al., 2020). However, it is essential to note that the sample size gathered from all previous clinical trials (858 participants) is insufficient to draw a conclusive conclusion (Lee et al., 2020).

6) The Mediterranean diet

The Mediterranean diet gained recognition as a healthy diet in the mid-20th century, following a post-World War II epidemiological study of the island of Crete in 1953 (Allbaugh, 2015). Subsequently, Ancel Keys et al. (1986) conducted a study analysing the relationship between the Mediterranean diet and coronary risk factors in seven countries. The findings demonstrated the protective effects of the Mediterranean dietary pattern on CVD and mortality. At the same time, the number of deaths attributable to cardiovascular disease has decreased in most developed countries or has followed a flat trend in some Mediterranean countries over the years. In 2014, the prevalence of CVD increased in the Mediterranean countries, Europe, and globally, with CVD becoming the leading cause of death worldwide (Nissensohn et al., 2016). High blood pressure has been identified as the leading risk factor for developing CVD in Mediterranean countries (Nissensohn et al., 2016).

Maintaining a healthy lifestyle, which includes maintaining an adequate healthy diet and engaging in moderate physical activity, would reduce the prevalence of CVD by lowering its main risk factors, which include hypertension (World Health Organization, 2023a). The European hypertension management guidelines recommend a healthy and balanced diet, particularly the Mediterranean diet, based on cultural practices (Williams et al., 2018b). This diet emphasises the consumption of olive oil, fresh fruit and vegetables, limited red meat, and moderate alcohol intake (Filippou et al., 2021). A randomised multi-centre trial in Spain studied 288 high-risk individuals without cardiovascular disease (Estruch et al., 2018). It was revealed that a Mediterranean diet combined with extra-virgin olive oil or nuts could lower the risk of cardiovascular diseases in high-risk individuals by as much as 30% over five years compared to a low-fat diet.

A Mediterranean diet is correlated with low levels of inflammatory biomarkers, which may reduce the risk of cardiovascular disease (Tuttolomondo et al., 2019). An earlier umbrella review comprising six meta-analyses of RCTs discovered that adherence to a Mediterranean diet may decrease BP (Sukhato et al., 2020). All meta-analyses reported a significant decrease in the DBP of Mediterranean diet adherents compared to control groups, with mean differences ranging from -0.70 mmHg to -1.99 (Sukhato et al., 2020). Nevertheless, the evidence for the effect of a Mediterranean diet on SBP reduction needs to be more consistent in terms of statistical significance. The mean difference in SBP in the three significant studies ranged from -1.45 to -3.02. The conflicting results in the systematic reviews and meta-analyses may be attributable to the different control diets and settings in the original studies (Sukhato et al., 2020). The preliminary studies included in the meta-analyses were conducted in countries with different eating habits, such as Italy, Greece, Spain, and the United States (Sukhato et al., 2020). Although they used the Mediterranean diet as an intervention of interest, there may have been differences in the details of individual diets (Sukhato et al., 2020). A recent umbrella review of 411 RCTs and observational studies examined the relationship between changes in blood pressure and dietary patterns, food groups, single foods, beverages, and macro/micronutrients, demonstrating that the Mediterranean diet reduced blood pressure based on moderately high-quality RCTs (Aljuraiban et al., 2023). However, observational studies found no significant association between the Mediterranean diet and BP (Aljuraiban et al., 2023).

7) DASH diet

The DASH diet is a well-established nutritional treatment for hypertension (Appel et al., 1997; Sacks et al., 2001). The National Heart, Lung, and Blood Institute established the DASH diet in an attempt to study the dietary elements that affect BP (Sacks et al., 1999). It has long been recognised that individuals who consume vegetables have lower BP levels than are commonly seen in Western countries (Sacks et al., 1999). Vegetarians in the US, Australia, and Israel were found to have lower BPs than non-vegetarians living in the same countries (Sacks et al., 1999). However, it was difficult to pinpoint which nutrients or foods were responsible for the lower BP levels linked with a vegetarian diet (Sacks et al., 1999).

Epidemiologic studies have shown that certain dietary factors are associated with hypertension (Sacks et al., 1999). Specifically, higher consumption of minerals like potassium, magnesium, calcium, and fibre is associated with lower blood pressure levels, while increased intake of dietary fats is linked to higher blood pressure and an elevated risk of hypertension (Sacks et al., 1999). However, clinical research has indicated that the BP effects of these and other nutrients, when evaluated individually, were small and inconsistent, confirming that only potassium has a BP-lowering effect (Sacks et al., 1999). As a result, the vegetarian diet's large potential influence could not be broken down into specific components (Sacks et al., 1999). The DASH planning group hypothesised that the influence of diet on BP could be attributable to the entire mixture or interactions of nutrients or to unknown elements (Sacks et al., 1999). Although vegetarian diets inspired researchers to create DASH, the planning committee insisted that the trial's results must be acceptable to the general public in the United States; therefore, they decided against recommending a vegetarian diet (Sacks et al., 1999).

The DASH eating plan can offer basic guidelines for a well-balanced, healthy diet that incorporates a variety of foods from each food group (The National Heart, Lung, and Blood Institute, 2020). The DASH eating plan is based on 2000 calories, but this may vary depending on the needs of the individual (The National Heart, Lung, and Blood Institute, 2019). For high-risk individuals (those with hypertension or type II diabetes), the DASH diet recommends a sodium intake of less than 1,500 mg per day (The National Heart, Lung, and Blood Institute, 2020). Scientists have conducted numerous experiments on the DASH diet since it was introduced more than twenty years ago; they observed that following the DASH diet, which includes fruit, vegetables, whole grains, fish, chicken, beans, nuts, and healthy oils (see Table 1-2), was linked to lower BP (The National Heart, Lung, and Blood Institute, 2019).

Table 1-2 : Serving Size in DASH Diet (Padma, 2014; The National Heart, Lung, and Blood Institute, 2020)

Nutrients	DASH diet	Serving size
Whole grains	6–8 daily	1 slice of whole-wheat bread, 1/2 cup cooked rice or pasta
Vegetables and fruit	4–5 daily	1 medium banana, ½ cup of frozen or canned fruit ½ cup corn, cooked or frozen, ½ cup fresh cucumber
Lean meats, poultry, and fish	6 or less	1 egg, 1 ounce of skinless poultry, 1 ounce of seafood
Fats and oils	2–3 daily	1 tablespoon mayonnaise, 2 tablespoons of salad dressing
Low-fat or fat-free dairy products.	2–3 daily	1 cup yogurt, 1 cup skimmed milk
Sodium	2300 mg daily	1 teaspoon of salt contains 2300 mg of sodium, and ⅔ teaspoon of table salt provides 1500 mg of sodium
Sweets	5 or less weekly	1 tablespoon of sugar, 1 tablespoon of jelly or jam
Nuts, seeds, dry beans	4–5, weekly	2 tablespoon seeds, ½ cup cooked beans and peas, ⅓ cup nuts

DASH diet and BP-lowering mechanisms of action

Consumption of the DASH diet has been found to interact with the renin-angiotensin-aldosterone system, improving the physiological effects of angiotensin-converting enzyme (ACE) inhibition

(Maris et al., 2019). This interaction results in a natriuretic and diuretic effect. The natriuretic action of the DASH diet is attributed to its high potassium and calcium content, stemming from fruit, vegetables, and low-fat dairy products (Filippou et al., 2022). Potassium and calcium play a vital role in blood pressure regulation (Staruschenko, 2018; Villa-Etchegoyen et al., 2019).

The DASH diet is a rich source of vitamins, phytochemicals, and antioxidants, including polyphenols and flavonoids (Filippou et al., 2022). These components play a crucial role in reducing oxidative stress. Consuming fruit and vegetables containing inorganic nitrate has been linked to improved endothelial function, a promising avenue for improving cardiovascular health (Jackson et al., 2018). This improvement in endothelial function is associated with reduced arterial stiffness and decreased platelet aggregation due to nitric oxide-related mechanisms (Jackson et al., 2018). These findings collectively suggest that the DASH diet triggers hormonal and vascular responses associated with its hypotensive effect (Nguyen et al., 2012).

DASH diet effectiveness

Several meta-analyses of RCTs have been conducted to assess the impact of the DASH diet on blood pressure reduction compared to a control diet. All these analyses found that the DASH diet significantly reduces BP. The findings from these analyses are detailed in Table 1-3. An umbrella review of five meta-analyses of RCTs on various food patterns that lowered BP confirmed the findings (Sukhato et al., 2020). This review found that BP reduction correlated with the DASH diet, ranging from -3.20 mmHg to - 7.62 mmHg for SBP and from - 2.50 mmHg to - 4.22 mmHg for DBP (Sukhato et al., 2020). Another umbrella review analysed 411 RCTs and observational studies to investigate the connection between blood pressure and various dietary factors, including dietary patterns, food groups, single foods, beverages, macronutrients, and micronutrients. This umbrella review supports the DASH diet recommended by public health guidelines for preventing and controlling hypertension (Aljuraiban et al., 2023).

Table 1-3: A summary of meta-analysis studies that have reported on the effect of the DASH diet on BP

Study	No. of RCTs study	No. of participants	Study duration	BP difference (mmHg)	
				SBP mean (95% CI[a])	DBP mean (95% CI)
Saneei et al. (Saneei et al., 2014)	17	2561	2–26 weeks	-6.7 (-8.3; -5.3)	-3.5 (-4.3; -2.8)
Siervo et al. (Siervo et al., 2015)	20	1917	2–24 weeks	-5.2 (-7.0; -3.4)	-2.6 (-3.5; -1.7)
Gay et al. (Gay et al., 2016)	4	668	6–12 months	-7.6 (-9.9; -5.3)	-4.2 (-5.9; -2.6)
Ndanuko et al. (Ndanuko et al., 2016)	10	2798	8 weeks–12 months	-4.9 (-6.2; -3.6)	-2.6 (-3.3; -1.9)
Filippou et al. (Filippou et al., 2020)	30	5545	2–52 weeks	-3.2 (-5.5; -2.4)	-2.5 (-3.5; -1.5)
Lari et al. (Lari et al., 2021)	52	9491	2–52 weeks	-3.9 (-5.2; -2.6)	-2.4 (-3.4; -1.5)

[a] CI, confidence interval

The 2017 guidelines from the American College of Cardiology (ACC) and the American Heart Association (AHA) suggest a DASH diet for adults with high blood pressure or hypertension (Whelton et al., 2018). Similarly, the 2020 International Society of Hypertension (ISH) guidelines advise preventing or delaying high blood pressure by following a DASH diet (Unger et al., 2020). The Saudi Hypertension Guidelines also recommend the DASH diet for people with high blood pressure (Saudi Hypertension Management Society, 2018).

1.2.3.1.2 Weight reduction

It is important to note that high BP is not solely the result of a high-salt diet. Excessive consumption of calories and unhealthy fats, particularly saturated fats, and inadequate consumption of fruit and vegetables can increase the risk of obesity and hypertension (Public Health England, 2017). In the United Kingdom, the likelihood of developing high BP is more than twice as high in overweight or obese men and three times higher in overweight or obese women (Public Health England, 2017). Similarly, in Saudi Arabia, a recent systematic review of the prevalence and risk factors for hypertension found that obesity is strongly associated with hypertension (Alanazi et al., 2023). A meta-analysis of 25 RCTs that assessed the effect of weight reduction on BP in 4874 individuals found that after losing 5 kg of weight, SBP and DBP decreased by -4.44 mmHg and -3.57 mmHg, respectively (Neter et al., 2003). In individuals who lost more than 5 kg, the SBP and DBP reductions were -6.63 mmHg and -5.12 mmHg, respectively (Neter et al., 2003). Another meta-analysis of 13 RCTs involving individuals with hypertension and prehypertension, and overweight and obese individuals with hypertension, found that adherence to the DASH diet significantly decreased body weight and waist circumference in 8 to 24 weeks and BMI in 8 to 52 weeks (Soltani et al., 2016). Therefore, hypertension can be effectively treated by losing weight. Preventing weight gain will likely reduce hypertension and CVD in the general population (Soltani et al., 2016).

1.2.4 Hypertension self-management

The success of hypertension treatment is highly dependent on the adoption of a healthy lifestyle and adherence to medication. In the presence of chronic illness, effective self-management is necessary to maximise health outcomes. Self-management improves self-reported health status and health-related quality of life while decreasing healthcare utilisation and costs (Gebrezgi et al., 2017; Ko et al., 2018). As described by Richard and Shea (2011), self-management is a person’s ability to effectively manage symptoms, treatments, lifestyle adjustments, and health issues' psychosocial, cultural, and spiritual consequences of health conditions in collaboration with family, community, and healthcare professionals. For individuals with hypertension, self-management involves activities such as regular blood pressure monitoring, adhering to prescribed medication regimens, and following a healthy diet such as the DASH diet to ensure optimal blood pressure levels (Hwang & Chang, 2023). A meta-analysis of 12 RCTs involving 2714 older adults with hypertension assessed the impact of self-management interventions on BP, self-efficacy, medication adherence, and BMI (Van Truong et al., 2021). The results showed a significant decrease in SBP and DBP, as well as increased self-efficacy and medication adherence due to self-management interventions (Van Truong et al., 2021). However, studies have identified challenges for those who self-manage hypertension, including a lack of community resources, lack of motivation, inadequate knowledge, competing health concerns, and non-adherence to medication (Flynn et al., 2013; Khezri et al., 2017).

In Saudi Arabia, several studies have confirmed that although patients demonstrated excellent attitudes and knowledge regarding hypertension, their actual practice of managing the condition was poor (Bahari et al., 2019; Sharaf et al., 2021). Understanding the determinants of adherence is crucial to improving adherence to self-management practice. Some studies have observed that a significant number of patients do not adhere to their prescribed antihypertensive medication regimen (Innab et al., 2023; Sharaf et al., 2021). In addition, they tend to skip or irregularly follow their medication schedule, fail to monitor their BP on a regular basis, and do not maintain a suitable diet or exercise programme (Innab et al., 2023; Sharaf et al., 2021). A qualitative study focusing on low-income women explored the barriers to and facilitators of engaging in healthy lifestyles and found that factors such as the high cost of healthy food, limited availability of healthy options, and time constraints to cook healthy food and engage in PA were major challenges in maintaining a healthy lifestyle (Alageel et al., 2023). Similarly, in the US, adherence to the DASH diet is low among people with high blood pressure (Steinberg et al., 2017). Low adherence to DASH may be attributed to the food environment in the US (Steinberg et al., 2017). Foods that are dense in energy and deficient in nutrients are accessible and inexpensive. Fruit and vegetables are costlier in fast-food restaurants than other foods (Steinberg et al., 2017). This greatly affects people with low incomes, who may live in places where it is difficult to find DASH foods (Steinberg et al., 2017). Despite these challenges, research has shown that DASH can be introduced at low cost to people with low incomes (Young et al., 2008). Foods such as dried beans or frozen vegetables are cheap and compatible with the DASH diet (Steinberg et al., 2017).

1.2.4.1 Motivators of self-management practices

Motivation is a significant factor affecting health behaviour (Hamzah et al., 2019). Health motivation has been applied in various health behaviour theories, including protection motivation theory and the theory of planned behaviour (Bianchi et al., 2023). In psychotherapy, clinicians consider motivation to be one of the primary factors impacting the process. Motivation is a state of activation that arises from a need for fulfilment, such as improving one's quality of life or acquiring a benefit (Golay et al., 2007).

There are two main types of motivation for treatment: intrinsic and extrinsic (Millere et al., 2014). People who are internally motivated understand causality and act according to their own beliefs and values (Millere et al., 2014). In contrast, individuals with external motivation perceive themselves as under pressure from external factors, such as interpersonal, occupational, academic, medical, and legal factors (Millere et al., 2014). Behavioural motivation is a critical component of chronic disease self-management, which influences patients to change their behaviour and adhere to treatment regimens (Jowsey et al., 2014). Rajpura and Nayak (2014) reported that patients motivated to practise self-management strategies continuously tend to make rational decisions in favour of their health and well-being.

One intrinsic motivation reported in patients with hypertension is the desire to live a long, healthy life (Eslavath et al., 2020). A patient's internal feelings and emotions, including feelings of inevitable death, sadness, depression, and stigma, can demotivate them and lead to poor self-management practices (Jowsey et al., 2014). Stress, fear, anxiety, and depression are commonly known to be significant barriers to effective self-management (Golay et al., 2007). However, a study conducted by Alessa et al. (2021) found that Saudi patients with high blood pressure did not identify these factors as barriers to effective self-management. This could be attributed to the prevailing approach to self-management, which primarily focuses on medical and behavioural management, often overlooking the emotional impact of chronic disease on patients (Elissen et al., 2013).

External sources of motivation, such as support from healthcare providers, family members, friends/peers, and social norms, can play a significant role in driving patients with hypertension to practise self-management (Houston et al., 2012; Siddiqui et al., 2024; Steinman et al., 2020). Robust evidence supports the crucial role of the family in helping patients manage hypertension. This includes providing support with food choices and preparation (Flynn et al., 2013), aiding patients in adhering to medication and medical appointments, and facilitating discussions between patients and healthcare providers about hypertension care (Woods et al., 2023). Family members can have a significant impact on helping patients achieve better health outcomes (Whitehead et al., 2018; Woods et al., 2023). There is no doubt that family ties are strong in Saudi Arabia. Bahari et al. (2019) demonstrated the importance of family support in helping Saudi patients perform certain behaviours, such as medication adherence. A qualitative study investigating women's adoption of a healthier lifestyle in Saudi Arabia found that the family played a crucial role in enabling them to follow a healthy lifestyle (Alageel et al., 2023). The study's participants shared that family members could motivate them to exercise more and make positive changes to their diet. However, some women also pointed out that a lack of family support could hamper their health improvement efforts (Alageel et al., 2023). It is necessary to note that the study sample consisted of 29 participants, thus may not fully represent the Saudi population.

Education plays an essential role in motivating patients to self-manage their hypertension (Diana Sherifali & Robyn, 2018). Education empowers patients to participate actively in their disease management, instilling a desire for a positive outcome (Diana Sherifali & Robyn, 2018; Jowsey et al., 2014). Self-management education refers to a structured intervention involving individuals actively monitoring their health parameters and making informed decisions using their knowledge and skills (Diana Sherifali & Robyn, 2018). It also emphasises the importance of collaboration between patients and healthcare providers and the development of effective problem-solving skills to ensure long-term self-care (Diana Sherifali & Robyn, 2018).

Physicians, nurses, and dietitians are critical in motivating hypertensive patients to practise self-management (Jowsey et al., 2014; Wilkinson et al., 2016). Al-Gelban et al. (2011) reported that primary care physicians in Saudi Arabia encourage lifestyle modifications using various measures, such as weight reduction, sodium restriction, physical exercise, and behavioural improvement to prevent and manage hypertension. This is crucial because primary care providers significantly promote dietary behavioural change, and not all patients can access dietitians (Dash et al., 2020). Physician-led discussions can motivate patients to take action (Dash et al., 2020); however, studies show that patients often do not receive adequate information, counselling, or autonomy support from their healthcare providers because of the providers' lack of knowledge of nutrition and Saudi hypertension management guidelines or time constraints (Al-Gassimi et al., 2020; Al-Gelban et al., 2011; Murphy et al., 2015; Shnaimer & Gosadi, 2020). Therefore, it is essential to recognise the significance of intrinsic and extrinsic motivation in promoting self-management among patients with hypertension, especially concerning the DASH diet. Chapter 4 explores more barriers to and facilitators of DASH diet self-management for patients with high BP and healthcare professionals in Saudi Arabia.

Effective interventions should be developed to improve these motivational factors. Using digital health resources is an evolving technique to enhance patient self-management (Steinberg et al., 2017). MHealth approaches, such as apps, are proposed to be more effective than traditional physician-centred methods for delivering advice, such as face-to-face consultations (Dash et al., 2020).

1.2.5 Mobile Health (mHealth)

Two factors contributed to the creation of mHealth, which is a subtype of electronic health (eHealth): (1) the rapid rise of mobile technologies and (2) improvements in mobile programs (‘apps’) aimed at solving medical problems (World Health Organization, 2016). MHealth refers to the use of mobile devices, such as cell phones, patient monitoring devices, and wearable technology, for medical support and health management (World Health Organization, 2011).

The WHO coined the term ‘mHealth’ in 2010. Since then, mHealth technology has grown in popularity and sophistication (World Health Organization, 2011, 2016). Short message service text messages, emails, phone conversations, and mobile phone apps are only some of the features used in mHealth (Zapata et al., 2015). There are several advantages to mHealth, including eliminating geographical hurdles, expanding access, and providing healthcare to isolated people and underprivileged places, potentially aiding in the attainment of universal health coverage (Chen et al., 2017; Wheeler et al., 2018). Using mHealth does not require additional resources, therefore medical information, monitoring, and communications between patients and physicians are less expensive than in-person services (Chen et al., 2017; Wheeler et al., 2018).

The popularity of mHealth has grown because it is a useful tool for enhancing an individual’s health outcomes (Buhi et al., 2013). Systematic reviews assessing the effectiveness of short message service (SMS) systems in managing chronic diseases have found that patients’ medication adherence and their understanding of and attitudes towards their diseases improved as a result of SMS-based interventions (Ebuenyi et al., 2021; Vargas et al., 2017). In Pakistan, an RCT examined the use of SMS intervention in supporting hypertension self-management and found improved adherence to lifestyle modifications, such as changes in dietary habits (DASH diet), in the intervention group (Rehman et al., 2019). However, Parati et al. (2017) found that mobile phone use in self-management is mainly limited to communication between healthcare professionals and patients via SMS or phone calls and that mobile phones offer limited information regarding patient participation in health management. Smartphones provide more opportunities for patient involvement in health management compared to traditional mobile phones. The availability of affordable smartphones has led to increased patient engagement in managing their health (Parati et al., 2017).

In recent years, smartphones and their associated apps have become increasingly accessible and ubiquitous (Chen et al., 2017). This has opened new possibilities for expanding dietetic service delivery to those who may find it difficult to access traditional, clinic-based treatments (Martin et al., 2016). The effectiveness of mobile health in improving self-management of hypertension was examined through a meta-analysis involving 24 RCTs with 8933 adults with hypertension. This study found that mHealth interventions significantly reduced SBP by -3.78 mmHg and DBP by -1.57 mmHg compared to control groups (Li et al., 2020). Another recent meta-analysis comprising 74 studies and 92,686 participants revealed that digital health interventions, including mHealth, telehealth, and combined mHealth and telehealth, effectively reduced SBP and DBP (Yap et al., 2024). However, only the mHealth group improved medication adherence, while the mHealth and combined mHealth and telehealth groups demonstrated enhanced blood pressure control. Additionally, improvements in BMI were explicitly observed in the mHealth group (Yap et al., 2024). This result could be explained by the fact that health apps can empower patients to control their health by enabling them to track their behaviours and receive real-time feedback (Pellegrini et al., 2015; Xu & Long, 2020).

Several systematic reviews have confirmed that using apps can help users make positive dietary and health behaviour changes via short-term nutrition education, health coaching, reminders, and/or diet tracking tools (Paramastri et al., 2020; Villinger et al., 2019). In another systematic review, mHealth interventions were found to be effective in reducing salt intake (Ali et al., 2019). Although there have been RCTs that have used smartphone apps to enhance adherence to the DASH diet (Bozorgi et al., 2021; Darabi et al., 2024; Steinberg et al., 2020), a systematic review of their effectiveness has not been conducted. This research, therefore, fills a crucial gap by conducting a comprehensive review to assess the effectiveness of smartphone apps in promoting DASH diet self-management, as elaborated in Chapter 2.

In 2017, over 350,000 mHealth apps were available in major app stores. Many mHealth apps are commonly used for tracking PA, step counts, food intake, and medication compliance (Mustafa et al., 2022). However, industry reports indicate that most mHealth publishers have an information technology background but lack medical competencies or experience in the traditional healthcare industry (Chen et al., 2017; Research2guidance., 2015). Dietitians, trained and skilled experts in diet and nutrition, could offer valuable insights into the best treatment strategies to be incorporated into such apps (Chen et al., 2017). Since dietitians use smartphone health apps and other mHealth technologies in patient care, understanding their experiences could enhance the ongoing development of apps to support dietetic practice (Chen et al., 2017).

However, there is limited research on the design features and characteristics that dietitians seek to include in health apps to support their patients (Chen et al., 2017). A study of Canadian dietitians that examined factors affecting app use and recommendation in practice found that dietitians had difficulty finding appropriate apps and expressed concerns about the quality and privacy of nutrition apps (Lieffers et al., 2014). To identify the suitable app(s) for DASH diet self-management, it is necessary to assess commercially available apps based on their quality, potential effectiveness, and data privacy/security. This evaluation process is detailed in Chapter 3.

1.2.5.1 mHealth in Saudi Arabia

The concepts of mHealth and digital health are still new in Saudi Arabia (Al-Anezi, 2020). This is evident from the limited number of studies and large-scale research activities in the country's healthcare sector and research institutions (Al-Anezi, 2020). However, mHealth has recently attracted considerable attention from healthcare ecosystems and stakeholders in Saudi Arabia (Al-Anezi, 2020). This is due to the increasing recognition of the transformative role that digital health and mHealth can play in improving healthcare delivery services, patient care, and overall well-being (Al-Anezi, 2020).

Several studies have been conducted in Saudi Arabia to explore the feasibility and acceptability of smartphone apps for managing chronic diseases, such as hypertension, diabetes, and obesity (Alnasser et al., 2019; Alotaibi et al., 2014; Alzahrani et al., 2023; Rafiullah & David, 2019). These studies have highlighted the potential of mHealth apps as valuable and accessible tools for combating and preventing health issues. Most of these studies have also developed their own apps to overcome the limitations of commercial Arabic smartphone apps (Alnasser et al., 2019). For instance, while many weight-loss apps are available in Arabic, a review has shown that most do not follow evidence-based weight-loss practices (Alnasser et al., 2016). While they may provide dietary and lifestyle recommendations and meal-planning practices, they often lack tools for self-regulation and tracking to modify dietary behaviours and PA (Alnasser et al., 2016). One of the reasons for this could be the lack of Arabic food databases.

Most researchers in Gulf Cooperation Council countries have used food composition databases from non-representative populations/countries, including the US Department of Agriculture (Bawajeeh et al., 2021). Despite researchers' efforts to overcome the limitations of commercial Arabic smartphone apps by developing their own, their apps were limited to the study population. Researchers did not release their apps commercially, possibly due to the prohibitive resources required to release a commercial app, including programming and design expertise and the requirement to provide ongoing support (Jake-Schoffman et al., 2017; Turner-McGrievy et al., 2017). Therefore, this study evaluates the commercially available DASH diet apps, which are supported in English, explores the perceptions and experiences of Saudi healthcare providers and patients with high BP regarding these apps, and selects the most suitable app for patients with high BP in Saudi Arabia. Chapters 4 and 5 describe the exploration of app features and characteristics that can support dietary self-management for patients with high BP in Saudi Arabia, as well as the feasibility and acceptability of such an app among this population.

1.2.6 Theories and models of health behaviour and Information System

1.2.6.1 Overview of theories commonly applied to develop nutrition smartphone apps

Self-management of chronic conditions requires the patient to be committed and diligent in following treatment plans. Many behaviours are involved in these treatment plans, including dietary intake, PA, and medication compliance (Salas-Groves et al., 2023). Behavioural theories and models play a crucial role in shaping health interventions that promote sustainable changes in health behaviour (Salas-Groves et al., 2023). Understanding how behavioural theories and models can inform digital health interventions is crucial for promoting lasting changes in health behaviour (Salas-Groves et al., 2023). In addition, as technology develops, especially electronic health and its incorporation into people's personal and professional lives, ongoing discussions have been initiated about embracing or rejecting it. Researchers have explored this topic for several decades and have developed various theories and models relating to technology acceptance and efficient utilisation (Marangunić & Granić, 2015). The following subsections discuss the most commonly used theories and models and how they are applied in researching apps that support dietary self-management among patients with high BP.

1.2.6.1.1 The Health Belief Model

The health belief model (HBM) is the most frequently utilised and accepted theory of health behaviour (Butts & Rich, 2021). The concept was created in the 1950s by a group of social psychologists working for the United States Public Health Service, who were seeking to explain why people would not participate in health prevention or promotion initiatives (Butts & Rich, 2021). These social psychologists examined what hindered people from participating in preventive programmes (Butts & Rich, 2021). As a result, the HBM was established. This theory explores how people's perceptions of their susceptibility to disease influence their perceptions of the benefits of attempting to prevent disease and their willingness to act (Butts & Rich, 2021).

The HBM was developed to investigate the impact of a variety of health belief patterns on a person's behaviour, and it can be used to assist in disease prevention programmes and health promotion. It is used to forecast and explain how people's health behaviours evolve over time. The model examines individual perceptions and belief patterns, which include 1) perceived susceptibility; 2) perceived severity, that is, beliefs about the severity of the condition and the repercussions that come with it; 3) cues to action and individual perceptions of the threats and the subjective advantages of taking a recommended action; 4) perceived benefit, that is, the efficacy and validity of pursuing a specific path of action; 5) perceived barriers, that is, the consequences or disadvantages of performing the advised action; and 6) self-efficacy, meaning how confident patients are in their abilities to alter their behaviours (Butts & Rich, 2021). According to the model, patients' attitudes towards their illnesses and their willingness to make positive disease-management changes have a significant impact on their ability to perform well (Glanz et al., 2008) (as indicated in Figure 1-1). However, it is important to note that a stimulus is also required to initiate self-management behaviours.

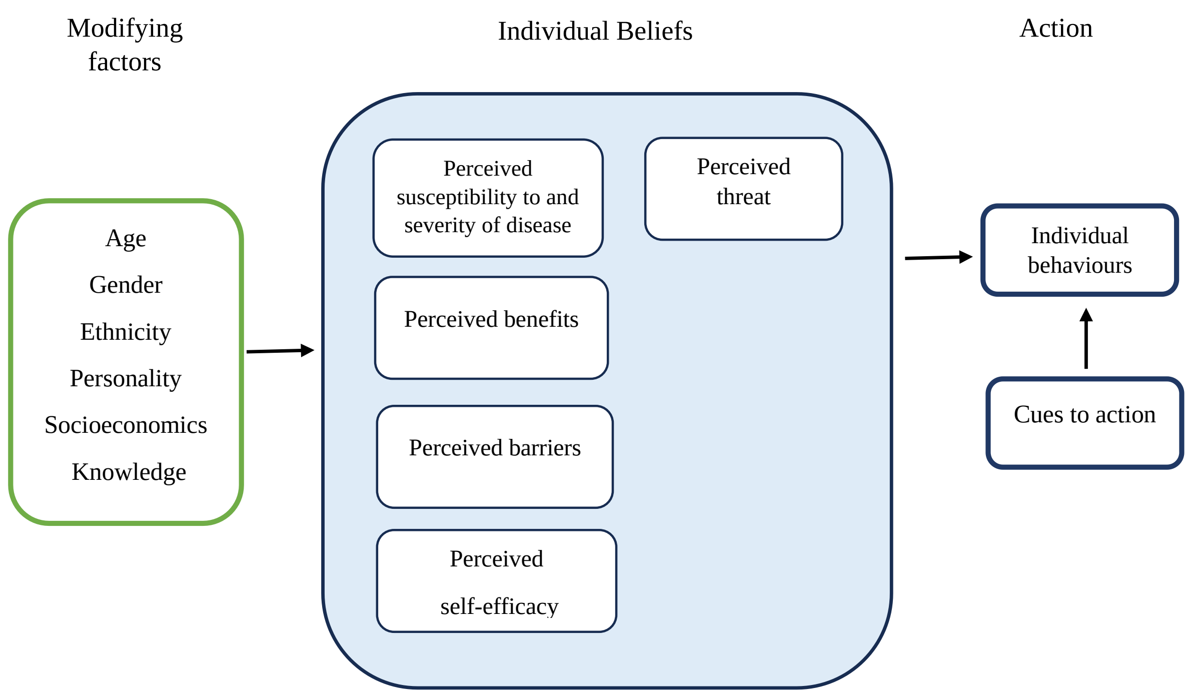

Figure 1-1*:* Health Belief Model (HBM) (Champion & Skinner, 2008)

The HBM is a widely used explanation of self-management behaviour. Over the past twenty years, the HBM has been used to assess patients' attitudes toward chronic conditions (Carpenter, 2010). Additionally, the HBM has been used to inform useful interventions that target different aspects of its main constructs to address health-related behavioural issues (Carpenter, 2010). Several studies have demonstrated the effectiveness of the HBM as a tool for improving self-management of chronic conditions, including hypertension and salt reduction (Carpenter, 2010; Chen et al., 2013; Jalilian et al., 2014). Several advantages are associated with the HBM. It is straightforward to put into practice and allows for research into new healthcare prevention approaches (Glanz et al., 2008). It can also forecast various health-related behaviours (Glanz et al., 2008).

The HBM has gained popularity as a tool for the self-management of chronic disease and has shown promising results. However, it primarily focuses on psychological factors and tends to overlook the impact of economic and environmental factors on health and self-management behaviour. Additionally, it does not consider the effects of social norms or peer influence, which could significantly affect an individual's health behaviour (Sheeran & Abraham, 1996).

1.2.6.1.2 Theory of Reasoned Action/Theory of Planned Behaviour

One of the most common models for explaining health behaviour is the theory of planned behaviour (TPB) (Ajzen, 1991), which is an extension of the earlier theory of reasoned action (Fishbein & Ajzen, 1977). TPB argues that intention is the most important determinant of behaviour. A person's intentions, which indicate how much effort they intend to devote to a particular behaviour, are determined by their attitudes, which represent their assessment of that behaviour (McDermott et al., 2015). Behavioural intentions are influenced by attitude, subjective norms, and personal behaviour control (PBC). An individual's attitude towards a particular behaviour results from their beliefs and how they evaluate those beliefs (Ajzen, 1991). Subjective norms refer to a person's beliefs about whether they should or should not follow a particular behaviour as a normative belief, as well as to their inspiration to comply with that behaviour (Ajzen, 1991). PBC has two underlying components: the ability to control belief perceptions of barriers and resources that influence behaviour and the perceived significance of the power of these obstacles or resources (Fishbein & Ajzen, 1977). Consequently, based on the theory, individuals will be more inclined to consume the recommended number of vegetables daily when they maintain a positive attitude towards that behaviour, perceive social pressure from those whose opinions they value, and feel confident that they can eat the recommended amount (McDermott et al., 2015). A person's intention and perception of capability determine the likelihood of engaging in this behaviour. The TPB is hypothesised to mediate the effects of all other influences, including biological, environmental, and cultural influences (McDermott et al., 2015).

Besides considering environmental and structural factors, the TPB can also determine why individuals engage in certain behaviours (Glanz et al., 2008). The main difference between TPB and HBM is that TPB emphasises social norms as an essential variable in analysing and understanding behaviour (Glanz et al., 2008). Nevertheless, the theory has some drawbacks and limitations. For instance, it does not consider the variables of fear or mood. It may be reasonable to assume that a theory of behaviour that does not consider these variables will be limited (Glanz et al., 2008). Furthermore, it is essential to note that behavioural intentions do not always result in self-management activities and behaviours, since economic and environmental factors may also influence these activities (Glanz et al., 2008).

TPB's predictive abilities have been criticised. A meta-analysis of 42 studies evaluated the association between TPB variables and specific food choice behaviours (McDermott et al., 2015). McDermott et al. (2015) argues that TPB may have limitations in fully understanding and influencing these behaviours. The evidence suggests that while TPB variables are moderately to strongly associated with both intention and behaviour, these associations are weaker when making healthy choices and avoiding unhealthy ones, especially among younger people (McDermott et al., 2015). The meta-analysis emphasises the complexity of dietary behaviour and the need to explore alternative models and factors that drive individual food choices.

1.2.6.1.3 Trans Theoretical Model

Prochaska and Di Clemente created the transtheoretical model (TTM). Using this framework, different theories of self-management and behavioural change, such as TPB and self-efficacy, can be integrated into a relatively straightforward framework (Glanz et al., 2008). The TTM consists of four dimensions: stages of change (SOC), processes of change (POC), decisional balance, and self-efficacy. SOC evaluates a person's readiness to adopt a healthy diet. POC evaluates behavioural and cognitive techniques to encourage the adoption or maintenance of behaviour that can affect stage progress. Self-efficacy evaluates the individual's confidence in making behavioural changes in different situations. Decisional balance involves the capability to weigh the pros and cons of eating healthily (Ren et al., 2021; Rodriguez et al., 2019). SOC is the core construct of these four dimensions, while the other three facilitate stage transitions (Horiuchi et al., 2012). The TTM differs from other health behavioural theories by dividing a person's behavioural change into five sequential, progressive stages as follows: pre-contemplation (in which individuals have no intention to change their dietary behaviour), contemplation (in which individuals have the intention to change their dietary behaviour within the next six months), preparation (in which individuals have intention to change their dietary behaviour within the next 30 days), action (in which individuals have recently started eating a healthy diet for < 6 months), and maintenance (in which individuals have adopted a healthy diet for > 6 months) (Ren et al., 2021; Rodriguez et al., 2019).

This model aims to promote positive changes in patients' self-management practices. This is accomplished by tailoring the intervention to the individual's readiness and motivation to adopt new behaviours (Glanz et al., 2008). As patients go through self-management and behaviour modifications, it is common for them to move between different stages associated with specific activities (Glanz et al., 2008). During this process, patients may encounter changes in their environment and experiences, which may modify their behaviours, beliefs, cognitions, feelings, and relationships (Glanz et al., 2008). Therefore, assessing each patient's readiness to progress from one stage to the next is essential to providing adequate support for behaviour change (Glanz et al., 2008).

TTM-based health education has been found to effectively change self-care behaviours in patients with hypertension (Sjattar & Arafat, 2021). Different types of TTM-based educational interventions are available, but the most suitable is tailored behaviour intervention, implemented for at least six months (Sjattar & Arafat, 2021). This intervention involves a combination of counselling and education, which is delivered through electronic media (Sjattar & Arafat, 2021). Rodriguez et al. (2019) assessed the impact of TTM-based tailored telephone counselling interventions on enhancing DASH diet adherence among a cohort of 533 individuals with diabetes or chronic kidney disease with high BP over six months. The results indicated a statistically significant improvement in DASH diet scores. However, it is important to note that the study's duration was relatively short, six months, and the sample size was comparatively small.

The TTM is widely used in self-management and behaviour change research. However, it has received criticism for its limited predictive value and partial utilisation of its own dimensions. The TTM lacks activity change determinants and validated staging algorithms, making it less effective in predicting behavioural change outcomes (Adams & White, 2005; Spencer et al., 2007). Furthermore, a systematic review of TTM-based PA interventions found that only a few studies have used all four dimensions, i.e. self-efficacy, SOC, POC, and decisional balance (Hutchison et al., 2009). To overcome these limitations, experts suggest a more comprehensive approach that fully integrates the TTM elements.

Progress has been made in research on applying TTM to dietary behaviour (Spencer et al., 2007). However, additional experimental studies are required to establish the superiority of TTM-based dietary interventions over other interventions (Spencer et al., 2007).

1.2.6.2 Information System Theories

1.2.6.2.1 Technology Acceptance Model

Various theories aim to explain why individuals accept or reject new technologies. One of the most widely recognised models is the technology acceptance model (TAM), developed by Davis in 1989 (Davis et al., 1989). The model describes the factors influencing people's willingness to use and accept a new technology. It builds upon and adapts the theory of reasoned action to specifically address technology use, proposing that an individual's attitudes towards technology are shaped by their perceptions of its ease of use and usefulness, impacting their intention to use it. The TAM has been extensively used and is a robust and valid model, particularly within office technology uptake (King & He, 2006). There is evidence to support the model's effectiveness within healthcare technology (Holden & Karsh, 2010). The TAM provides a valuable framework for understanding why individuals may or may not adopt new technologies.

Although the TAM is extensively used in various contexts, it has several limitations (Taherdoost, 2018). One of the main criticisms of the TAM is that it is not suitable for investigating technology adoption in the healthcare context due to its oversimplification of complex social situations, in which factors such as privacy become important (Holden & Karsh, 2010). Another criticism of the TAM is its low predictive power in accounting for behavioural intention and actual behaviour (Lu et al., 2009). Furthermore, the TAM's focus on technological factors overlooks the impact of organisational, social, and personal factors on technology acceptance (Ward, 2013).

Venkatesh and Davis (2000) expanded the TAM to include subjective norms, images, result demonstrability, output quality, and job relevance as factors that directly affect perceived usefulness (as indicated in Figure 1-2). They also introduced voluntariness and experience as moderators of paths from subjective norms to perceived usefulness and intention to use (Venkatesh & Davis, 2000). This updated model, known as TAM 2, was validated through a longitudinal study conducted in four different organisations. However, TAM 2 is less suitable for the consumer context, as it introduces constructs that are only applicable to the employee context (e.g. job pertinence and quality of output).

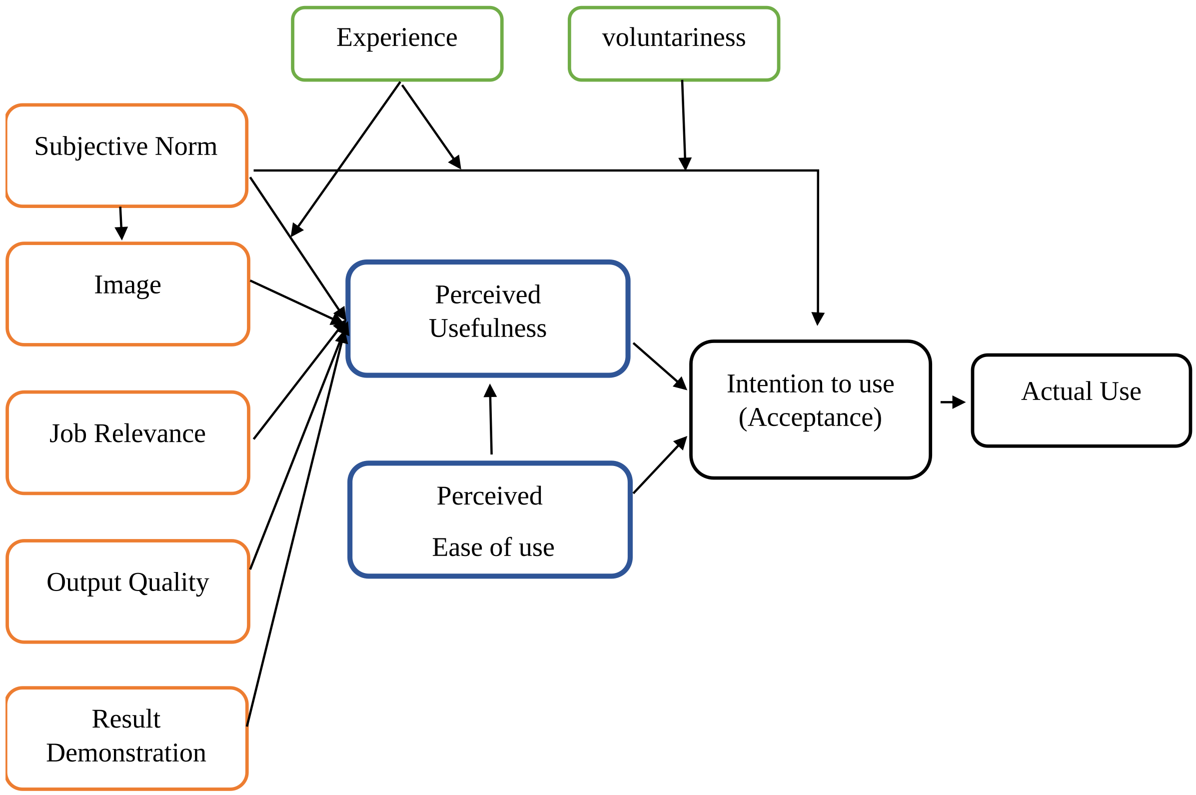

Figure 1-2 : Technology Acceptance Model (Venkatesh & Davis, 2000)

TAM 2, a model that explains the factors affecting users' acceptance of technology, was expanded by Venkatesh and Bala in 2008 to include six different constructs that influence perceived ease of use (Venkatesh & Bala, 2008). These constructs are computer self-efficacy, computer anxiety, computer playfulness, perceived external control, perceived enjoyment, and objective usability. The resulting model, known as TAM 3, suggests that all of these constructs directly impact perceived ease of use. Furthermore, Venkatesh and Bala (2008) hypothesised that experience moderates all of the new paths, except those from computer self-efficacy and perceived external control to perceived ease of use. Perceived ease of use is also mediated by perceived usefulness and behavioural intention. The researchers tested TAM 3 in the same way as TAM 2 and found that it accounted for 53% and 35% of the variance in behavioural intention and use behaviour, respectively (Venkatesh & Bala, 2008). However, TAM 3 shares the same limitations as TAM 2. Despite this, the model provides a comprehensive understanding of the factors influencing users' acceptance of technology, which can be useful for designers and developers in creating more user-friendly products and services (Venkatesh & Bala, 2008).

Each theory discussed above has strong and weak points. While they may share specific attributes, they also possess unique elements that set them apart.

1.2.7 Theories Applied for Identification and Evaluation of DASH Diet Smartphone Apps

1.2.7.1 The Behaviour Change Wheel

Several frameworks are available for developing effective interventions. However, a systematic review of nineteen behaviour change frameworks found that none was comprehensive, and few were conceptually coherent or linked to a model of behaviour change (Michie et al., 2014). Some frameworks focused on beliefs and perceptions, while others emphasised unconscious biases or the social environment (Michie et al., 2014). To address these limitations, the behaviour change wheel (BCW) was developed by synthesising the standard features of the frameworks and linking them to a broad model of behaviour change (Michie et al., 2011). This approach allows the BCW to be applied across different behaviours and settings.

The BCW comprises three essential layers for supporting behaviour change. These include: 1) the COM-B model that focuses on the determinants of behaviour (capability, opportunity, and motivation for behaviour); 2) intervention functions that can be utilised to address these determinants; 3) policy categories that can facilitate change on a more structural level (Michie et al., 2011). The COM-B model serves as the core of the BCW model and aims to facilitate behavioural diagnosis by identifying the determinants of behaviour. This includes an individual's physical and psychological capabilities (such as skills and knowledge), social and physical opportunities (such as norms of practice and time/space), as well as reflective and automatic motivations (influenced by beliefs, emotions, or habits) (Michie et al., 2011). This model can aid in developing interventions by easily mapping the determinants of behaviour to specific intervention functions, such as education, training, or enablement (Courtenay et al., 2019).

The theoretical domains framework (TDF) further unpacks the COM-B by segmenting psychosocial drivers of behaviour into fourteen domains (such as knowledge, memory, skills, and identity) (Cane et al., 2012). Doing so avoids any potential ambiguity when trying to understand the determinants of COM-B (see Table 1-4). For example, a psychological capability barrier may result from a lack of knowledge or poor memory, which may require different intervention functions, such as education or enablement (Courtenay et al., 2019). Consequently, other behaviour change techniques (BCTs) would be required for each intervention, such as providing information to increase knowledge or using prompts and cues to enhance memory (Courtenay et al., 2019).

As this field evolved, the TDF was incorporated as an additional layer of the BCW, and the COM-B was mapped to the TDF, as shown in yellow in Figure 1-3 (Michie et al., 2011). This allows for selection of specific BCTs from the BCT taxonomy version 1 (Michie et al., 2013) to be used as intervention components to facilitate behaviour change (Courtenay et al., 2019).

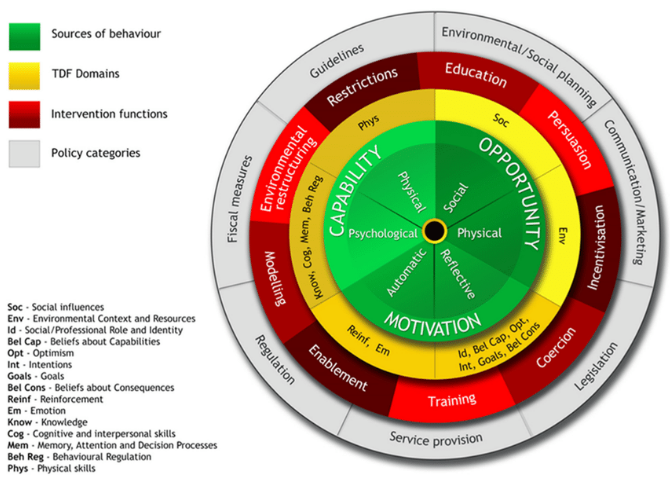

Figure 1-3: Behaviour Change Wheel (BCW) and TDF domains (Michie, et al, 2014)

BCTs are an active ingredient in interventions that aim to alter a person's behaviour. Several taxonomies of BCTs related to specific behavioural domains have been developed. A hierarchically structured taxonomy consisting of 93 distinct non-overlapping BCTs grouped into 16 categories was published in 2013, known as the behaviour change techniques taxonomy (BCTT) v1 (Michie et al., 2013). These BCTs are considered the crucial elements of an intervention that will bring about the desired change in behaviour.

Table 1-4: Links between the COM-B system and the TDF (Alexander et al., 2014)

Component	Sub-component	Theoretical domains
Capability	Psychological capability	Knowledge Skills (cognitive and interpersonal) Memory attention and decision process Behavioural regulation
	Physical capability	Skills (physical)
Motivation	Reflective motivation	Social/professional role and identity Beliefs about capabilities Optimism Beliefs about consequences Goals Intentions
	Automatic motivation	Reinforcement Emotion
Opportunity	Physical environment	Environmental context and resources
	Social environment	Social influences

Abraham and Michie (2008) sought to provide a thorough understanding of the design and implementation of interventions. They attempted to identify the effective elements of an intervention—a challenging task due to the complexity of the interventions. They found that self-monitoring, promoting goal setting, and reviewing and providing feedback are among the most effective elements. However, it is important to determine whether a single BCT has an effect or whether a combination of BCTs is needed to achieve the desired outcome. Despite this uncertainty, knowledge of how useful certain elements are for some individuals in specific situations can be utilised to develop new interventions (Michie et al., 2008).

Linking BCTs to theories will increase our understanding of their functional associations and how their outcomes (effects) indicate their underlying mechanisms. This approach will enable researchers to better grasp how to use BCTs in the most effective way possible. However, Cane et al. (2012) have argued that categorising BCTs with theories is impractical, given the substantial number of BCTs in this taxonomy and the theories that need to be analysed. Cane et al. (2015) propose a different approach. The theoretical constructs, such as TDF can be grouped and linked to BCTs. Michie et al. (2015) confirm that the TDF can be consistently grouped with BCTs.

Research has shown that many health apps lack a theoretical foundation and consistently use BCTs (Alessa et al., 2019; Bondaronek et al., 2018; Salas-Groves et al., 2023). This raises concerns about their potential effectiveness and emphasises the need to better understand their impact. These findings underscore the importance of investigating the theoretical mechanisms behind commercial DASH diet apps. In this study, the BCTs of the DASH diet self-management apps were first determined and then linked to TDFs in order to explore the mechanisms of action that underpin the apps. Chapter 3 explains the process of linking BCTs to TDFs.

1.2.7.2 Social Cognitive Theory

Social cognitive theory (SCT) has become increasingly common in chronic illness self-management (Salas-Groves et al., 2023). Developed by Bandura in 1977, this theory emphasises the crucial role of social context in shaping individual behaviour. It explains how behaviour is influenced by observing caregivers and peers and by reinforcement, such as rewards or punishments (Bandura, 1986). In 1986, Bandura refined SCT by highlighting the importance of personal factors in an individual's environment for understanding and predicting self-management behaviour (Bandura, 1986). SCT highlights the essential role of the interplay between individuals, their actions, cognition, and environment. For example, SCT suggests that adopting positive self-management behaviours is more likely to succeed when there is a continuous interaction between an individual's thoughts, actions, and environment within a social context (Bandura, 2004).

To promote self-management through intervention, SCT employs the concepts of self-efficacy, outcome expectation, environmental determinants of behaviour, observational learning, self-regulation, and reinforcement (Bandura, 1986; Glanz et al., 2008). Outcome expectation is the term used to describe an individual's belief regarding the likelihood of a specific outcome resulting from the performance of a particular behaviour (Bandura, 2004). For example, a person with high blood pressure may believe they can effectively manage their blood pressure by controlling their diet. However, outcome expectations alone are not enough to change self-management behaviour (Bandura, 2004). According to Bandura (1986), some patients lack efficacy expectancy, which is an individual's own estimation and judgement of their ability to perform a particular self-management behaviour. In other words, self-efficacy is a person's confidence level in their ability to complete a given task or action. Developing new self-management practices requires cultivating efficacy expectations. The concept of self-efficacy explains why some people with high blood pressure may struggle to adopt self-management behaviours, such as eating healthily, despite being aware of their benefits (Bandura, 1986).

Bandura (2004) proposed that an individual's ability to learn from their experiences and modify their behaviour depends heavily on their self-efficacy. However, self-efficacy can vary from person to person, and several factors can influence a patient's ability to self-manage their chronic disease and change their behaviour (Bandura, 2004). The difficulty of the new behaviour, the lessons learned from past experiences, and the patient's level of expectation are some of the factors that determine the success of self-management and behavioural change. Research suggests that patients with high self-efficacies are more likely to succeed in self-managing their medical conditions (Qin et al., 2020; Simpson & Jones, 2013). On the contrary, those with low self-efficacies may face challenges in managing their health (Qin et al., 2020; Simpson & Jones, 2013). To support patients in effectively managing their condition, healthcare providers should focus on fostering their sense of self-efficacy.

A meta-analysis of 54 RCTs revealed that interventions aimed at promoting dietary self-efficacy are more effective when they comprise various specific features (Prestwich et al., 2014). These features include self-monitoring, which involves keeping track of one's food-related behaviour, receiving feedback on performance, reviewing behavioural goals, offering contingent rewards for diet success, and planning for social support/social change (Prestwich et al., 2014). Interventions incorporating these elements are more successful in increasing dietary self-efficacy than those that do not (Prestwich et al., 2014). Based on the meta-analysis findings, developing more effective theory- and evidence-based behavioural interventions may be possible. This research assessed the self-efficacy of people with high blood pressure by adopting Zhao's six-item diet self-efficacy scale (Zhao et al., 2021). Additionally, SCT informed the interview guide used in the feasibility study (For further details, see Chapter 5).

1.3 Research Questions

This chapter has presented an overview of the prevalence of chronic disease, particularly hypertension, in Saudi Arabia. It highlights common risk factors such as obesity and dietary habits, with a specific focus on the impact of high salt, low consumption of fruit and vegetables, and high consumption of fast food among the Saudi population.

The importance of dietary self-management in promoting healthy nutritional behaviours is underscored here. A smartphone app is presented as a promising tool for improving dietary self-management. Although DASH self-management apps are increasingly available commercially, more research is crucial to evaluate their potential effectiveness, as well as their usability, security, and privacy. When evaluating dietary self-management apps, it is important to consider the diverse needs and expectations of different cultures. Research needs to identify and select the most appropriate apps for specific cultural settings and assess their feasibility. There is a lack of prior research on the feasibility and acceptability of commercial dietary self-management apps for individuals with high blood pressure in Saudi Arabia.

Given these knowledge gaps, this project aims to investigate the potential of using mHealth apps to support DASH diet self-management among individuals with high blood pressure in Saudi Arabia. The focus is to identify and select the most suitable commercial DASH diet app for the Saudi Arabian context and assess its feasibility and acceptability among Saudi Arabians with high blood pressure. Five primary research questions guide this research.

1) What is the evidence in the literature for the effectiveness of DASH diet smartphone apps in improving DASH diet adherence and, accordingly, reducing BP, as well as their usability and user satisfaction? (**Chapter 2**)

2) Which generally available apps are suitable for use in DASH diet self-management on the basis of their likely effectiveness, quality, and security? (**Chapter 3**)

3) What are the experiences, perceptions, and acceptance levels of these apps among people with high blood pressure and healthcare professionals in Saudi Arabia? (**Chapter 4**)
4) Which of those apps identified as suitable for DASH diet self-management is the most suitable for use within the Saudi context? (**Chapter 4**)
5) Is it feasible and acceptable to use the selected app to encourage people with high blood pressure to improve their dietary habits? (**Chapter 5**)

1.4 An Overview of Research Programme and Methods

This research used a multi-stage mixed-methods framework. Owing to its multi-stage design, the research was divided into two phases, each including two studies. The four studies were integrated at the methods level through a building approach, where the results of one study inform the succeeding study (Figure 1-4). The study implemented integration at all levels, from the development of the design and methodology to the data interpretation (Figure 1-4). Researchers can rely on one of three approaches to data interpretation: integration through narrative, transformation, and joint displays (Fetters et al., 2013). In this research, data from the four studies at the interpretation and reporting stages were integrated through narratives. Three approaches can be used for narrative integration in research reports: weaving, contiguous, and staged approaches. This study employed a staged integration approach, which is a typical practice in multi-stage MMR (Fetters et al., 2013). In this approach, the findings of each stage are reported and published separately as the data are analysed. Each paper briefly acknowledges previous work (Fetters et al., 2013). Chapter 6 provides a comprehensive summary and reflection on the critical findings from Chapters 2 to 5. This approach reinforced the conclusions presented in those chapters and offered a more nuanced understanding of the utility of dietary smartphone apps in general, particularly the selected app in Saudi Arabia.

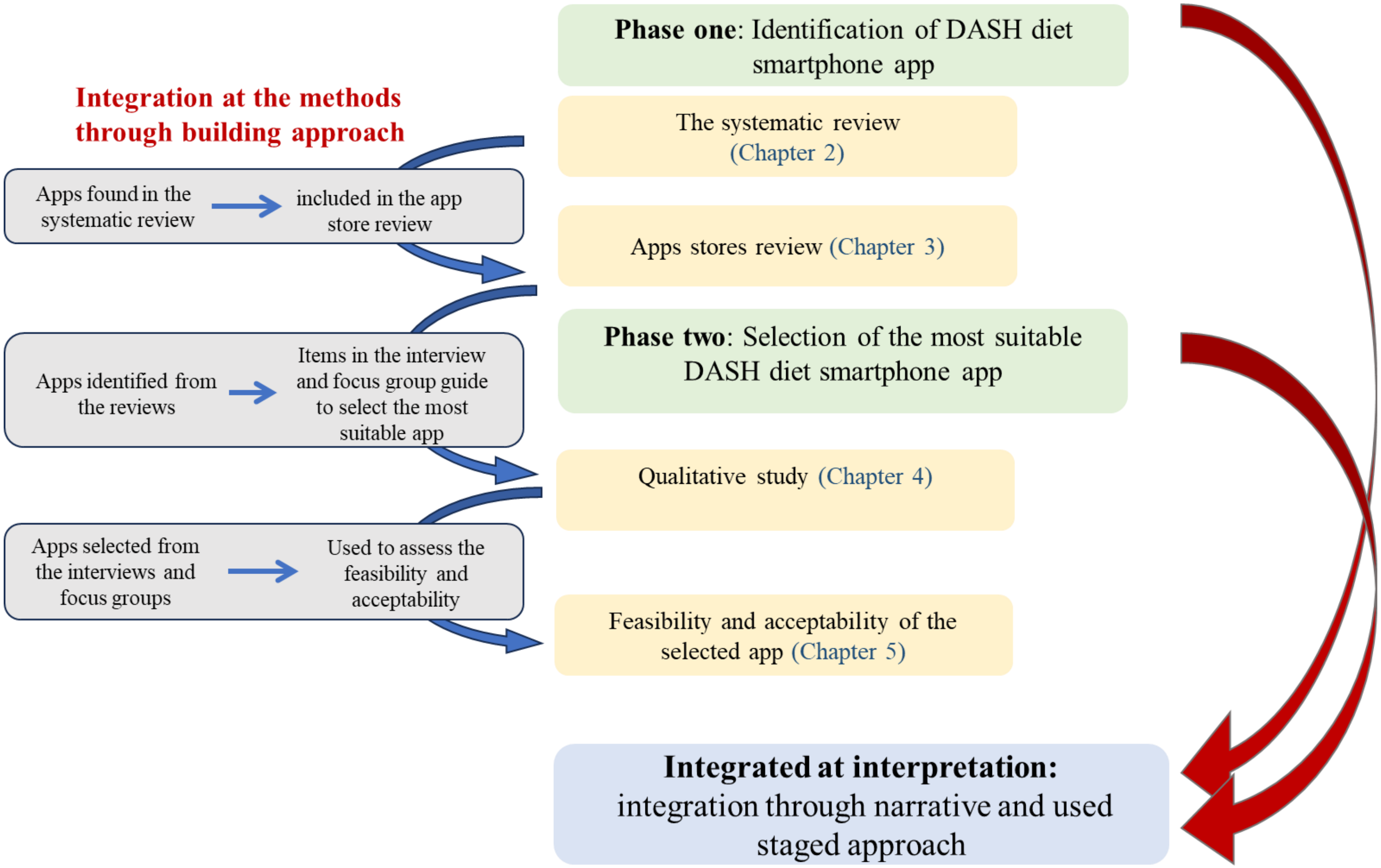

Figure 1-4: Multistage mixed method framework

Table 1-5 Summary of the studies

Research question	Design	Sample	Data sources	Analysis	Outcome
Phase One					
Study 1 (Chapter 2)					
1. What is the evidence in the literature for the effectiveness of DASH diet smartphone apps in improving DASH diet adherence and, accordingly, reducing BP, as well as their usability and user satisfaction?	Systematic review of the existing literature	NA[a]	Systematic searches of electronic databases such as Embase, Scopus and CINAHL were conducted to identify studies conducted between 2008 and 2021 on using DASH smartphone apps to support self-management.	A narrative summary of the studies was conducted.	The primary outcome measures included blood pressure and DASH diet adherence. This study also assessed the apps' usability and acceptability, as well as user engagement and satisfaction.
Study 2 (Chapter 3)					
1. Which generally available apps are suitable for use in DASH diet self-management on the basis of their likely effectiveness, quality, and security?	Review of app stores and content analysis.	NA[a]	The iPhone (Apple App Store) and Android app stores (Google Play).	Descriptive analysis was used.	Assessment of the likelihood of effectiveness, general quality, privacy, and security of apps to determine their suitability for use in DASH diet self-management.

Phase Two					
Study 3 (Chapter 4)					
Research question	**Design**	**Sample**	**Data sources**	**Analysis**	**Outcome**
1. What are the experiences, perceptions, and acceptance levels of these apps among people with high blood pressure and healthcare professionals in Saudi Arabia? 2. Which of those apps identified as suitable for DASH diet self-management is the most suitable for use within the Saudi context?	Qualitative study.	People with high blood pressure and healthcare professionals (family physicians and dietitians) recruited from King Abdullah bin Abdulaziz University Hospital, Riyadh, Saudi Arabia.	Semi-structured interviews, focus groups, and observation.	The qualitative data were analysed using a thematic framework analysis.	Identification of the most suitable app for the Saudi Arabian context by understanding the experiences and perceptions of people with high blood pressures and healthcare professionals who were using the identified apps.
Study 4 (Chapter 5)					
1. Is it feasible and acceptable to use the selected app to encourage people with high blood pressure to improve their dietary habits?	convergent parallel mixed-method	All people with high blood pressure who participated in study 3.	Engagement with app diet tracking, self-efficacy evaluation, 3-day food intake recording, system usability questionnaire survey, and online semi-structured interviews with the participants who completed the study.	The quantitative data were analysed using a quantitative descriptive analysis, and the qualitative data were analysed using a thematic framework analysis.	Evaluation of the participants' adherence to the DASH diet and self-efficacy and engagement with diet tracking. The participants were asked to rate their satisfaction with the perception of the app's usability using the system usability scale. Semi-structured online interviews assessed the app's feasibility and acceptability.

[a] Not applicable

1.5 Conclusion

This chapter provides an overview of the research and explains its rationale. In addition, it has offered a comprehensive overview of hypertension prevalence, risk factors, and practical strategies for managing high BP among patients around the globe and in Saudi Arabia specifically. It has explored non-pharmacological dietary interventions along with the most suitable diet for the Saudi population of patients with hypertension. Despite the numerous benefits of adopting a healthy lifestyle, various barriers hinder adherence, such as the high cost of nutritious food, busy lifestyles, and a lack of awareness. Using dietary smartphone apps has increased participants' awareness and improved their dietary behaviour and is a way to overcome these obstacles and promote self-management. Previous research has shown that theoretically based interventions are more effective in improving dietary behaviour. Therefore, this chapter has offered a comprehensive outline of commonly used behaviour change theories for developing dietary apps and the prevalent theories used to evaluate acceptance of these apps.

This chapter has identified several areas in the existing literature that require further investigation. This research was structured into two phases. Phase one sought to assess the evidence supporting the effectiveness of DASH diet apps and to identify the most appropriate DASH diet self-management apps to support DASH diet adherence. This phase encompassed a systematic review and an app store review. Phase Two aimed to select and test the most suitable app for the Saudi context from the app list identified in Phase one. To achieve this, a qualitative study was conducted involving individuals with high blood pressure and healthcare professionals (family physicians and dietitians), and a feasibility study was conducted with individuals with high blood pressure. The four studies were then described, including their objectives, data collection methods, and data analyses. The chapter has also explained how the four studies and research findings (Chapters 2-5) are integrated. The upcoming chapter will present the systematic review, marking the initial phase of this research.

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Phase one: Identification of DASH diet smartphone apps

- ***Systematic review***
- ***Apps stores review***

Chapter 2 | The use of dietary approaches to stop hypertension (DASH) mobile apps for supporting a healthy diet and controlling hypertension in adults: systematic review

In this chapter, the first study of this thesis is described. The chapter provides a comprehensive systematic review that consolidates the existing scientific evidence on the effectiveness of smartphone apps in supporting dietary self-management to enhance DASH diet adherence and subsequently reduce blood pressure. Moreover, the review evaluates user engagement, satisfaction, acceptance, and the usability of DASH mobile apps. This chapter is presented in a published format with permission from the publishers. It has been published in JMIR Cardio as "The use of dietary approaches to stop hypertension (DASH) mobile apps for supporting a healthy diet and controlling hypertension in adults: systematic review", authored by Alnooh, G., Alessa, T., Hawley, M. and de Witte, L. in 2022, Volume 6, Issue 2, with page number e35876 and DOI https: //doi.org/10.2196/35876.

Abstract

Background: Uncontrolled hypertension is a public health issue, with increasing prevalence worldwide. The Dietary Approach to Stop Hypertension (DASH) diet is one of the most effective dietary approaches for lowering blood pressure (BP). Dietary mobile apps have gained popularity and are being used to support DASH diet self-management, aiming to improve DASH diet adherence and thus lower BP.

Objective: This systematic review aimed to assess the effectiveness of smartphone apps that support self-management to improve DASH diet adherence and consequently reduce BP. A secondary aim was to assess engagement, satisfaction, acceptance, and usability related to DASH mobile app use.

Methods: The Embase (OVID), Cochrane Library, CINAHL, Web of Science, Scopus, and Google Scholar electronic databases were used to conduct systematic searches for studies conducted between 2008 and 2021 that used DASH smartphone apps to support self-management. The reference lists of the included articles were also checked. Studies were eligible if they (1) were randomised controlled trials (RCTs) or pre-post studies of app-based interventions for adults (aged 18 years or above) with prehypertension or hypertension, without consideration of gender or sociodemographic characteristics; (2) used mobile phone apps alone or combined with another component, such as communication with others; (3) used or did not use any comparator; and (4) had the primary outcome measures of BP level and adherence to the DASH diet. For eligible studies, data were extracted, and outcomes were organised into logical categories, including clinical outcomes (e.g., systolic BP, diastolic BP, and weight loss), DASH diet adherence, app usability and acceptability, and user engagement and satisfaction. The quality of the studies was evaluated using the Cochrane Collaboration's Risk of Bias tool for RCTs, and nonrandomised quantitative studies were evaluated using a tool provided by the US National Institutes of Health.

Results: A total of 5 studies (3 RCTs and 2 pre-post studies), including 334 participants, examined DASH mobile apps. All studies found a positive trend related to the use of DASH smartphone apps, but the 3 RCTs had a high risk of bias. One pre-post study had a high risk of bias, while the other had a low risk. As a consequence, no firm conclusions could be drawn regarding the effectiveness of DASH smartphone apps for increasing DASH diet adherence and lowering BP. All the apps appeared to be acceptable and easy to use.

Conclusion: There is weak emerging evidence of a positive effect of using DASH smartphone apps for supporting self-management to improve DASH diet adherence and consequently lower BP. Further research is needed to provide high-quality evidence that can determine the effectiveness of DASH smartphone apps.

Keywords: DASH diet; Dietary Approach to Stop Hypertension; smartphone app; mobile app; blood pressure

2.1 Introduction

Hypertension is a serious medical condition that has become a public health problem. Globally, in 2015, 1.13 billion people (1 out of 4 men and 1 out of 5 women) had hypertension, and most of them were living in low- and middle-income countries (World Health Organisation, 2022). Hypertension is attributed to the following 2 kinds of risk factors: (1) modifiable risk factors, which include unhealthy diet, physical inactivity, obesity, and consumption of tobacco and alcohol; and (2) nonmodifiable risk factors, which include family history of hypertension, age over 65 years, and chronic diseases, such as diabetes and kidney disease (World Health Organisation, 2022). Uncontrolled hypertension might lead to significant complications, such as heart failure, stroke, kidney failure, and economic difficulties stemming from both treatment costs and human capital loss (Aldiab et al., 2018; AlHadlaq et al., 2019; Motlagh et al., 2016; World Health Organisation, 2013; Saudi Ministry of Health, 2022). Several studies have shown that hypertension is often poorly controlled and that treatment measures include preventive behaviours and risk factor management (AlHadlaq et al., 2019; Hallberg et al., 2016; Motlagh et al., 2016). The World Health Organisation recommends the participation of patients through self-monitoring of weight, consumption of diets that are low in sodium and fat, physical activity, smoking cessation, stress reduction, and regular hospital visits to better control hypertension (World Health Organization, 2013).

Self-management is one of the most effective approaches for dealing with hypertension, allowing people with hypertension to feel more responsible for their own health (Shahaj et al., 2019). The Joint National Committee on the Prevention, Detection, Evaluation, and Treatment of High Blood Pressure has given 6 self-management recommendations that are considered essential for high blood pressure (BP) control: (1) adhering to medication protocols, (2) following the Dietary Approaches to Stop Hypertension (DASH) diet, (3) engaging in physical activities, (4) limiting alcohol consumption, (5) avoiding tobacco, and (6) maintaining a healthy weight (Chobanian et al., 2003).

The DASH diet was established by the National Heart, Lung, and Blood Institute (NHLBI) (Sacks et al., 1999). It provides basic recommendations for a balanced healthy diet that includes various foods (The National Heart, Lung, and Blood Institute, 2020). Specifically, the DASH diet comprises vegetables, fruits, whole grains, fish, poultry, beans, nuts, and healthy oils (The National Heart, Lung, and Blood Institute, 2019). The DASH diet also recommends a sodium intake of 2300 mg/day or 1500 mg/day for high-risk individuals (e.g., those with hypertension or type 2 diabetes) (The National Heart, Lung, and Blood Institute, 2019). The diet is also focused on consuming foods that are rich in potassium, calcium, magnesium, protein, and fiber (The National Heart, Lung, and Blood Institute, 2019).

Consumption of the DASH diet is correlated with a reduction in BP (The National Heart, Lung, and Blood Institute, 2019). Recently, an umbrella review was conducted to summarise the available systematic reviews and meta-analyses of randomised controlled trials (RCTs) on different dietary patterns that reduce BP (Sukhato et al., 2020). The review found that a decline in BP correlated with the DASH diet, with the mean differences ranging from −3.20 mmHg to −7.62 mmHg for systolic blood pressure (SBP) and from −2.50 mmHg to −4.22 mmHg for diastolic blood pressure (DBP) (Sukhato et al, 2020). In addition, for 8 years in a row, *US News and World Report* ranked the DASH diet developed by the National Institutes of Health as the "best overall" diet among almost 40 diets that were reviewed (The National Heart Lung, and Blood Institute, 2020).

Additionally, systematic reviews have concluded that the DASH diet is beneficial for not only reducing BP, which was its original intended purpose, but also decreasing the risk of cardiovascular diseases, including that of the main subclasses "coronary heart disease," "heart failure," and "stroke" (Salehi-Abargouei et al., 2013; Siervo et al., 2015). Furthermore, several systematic reviews investigating the DASH diet's effects on insulin resistance and obesity have found that it may play an important role in controlling hyperglycaemia and reducing weight (Shirani et al., 2013; Soltani et al., 2016). Based on these results, the DASH diet has been promoted as a first-line nonpharmacological therapy along with lifestyle modifications for the treatment of many chronic diseases (Salehi-Abargouei et al., 2013; Shirani et al., 2013; Siervo et al., 2015; Soltani et al., 2016).

According to the NHLBI, adherence to the DASH diet in the United Sates is low (Steinberg et al., 2017). Understanding the determinants of adherence is crucial for improving adherence (Steinberg et al., 2017). At the clinical level, primary care physicians can offer guidance on proper nutritional habits for the treatment of hypertension (Steinberg et al., 2017); however, physicians often state that they have insufficient time, resources, and knowledge for dietary counselling (Steinberg et al., 2017). Additionally, commitment to several consulting sessions is challenging for patients (Zou et al., 2020).

Over the past decades, there has been a rapid increase in the use of smartphones, and by 2022, it is projected that there will be 6.8 billion smartphone users (Alessa et al., 2019). In parallel, there has been a rapid increase in mobile apps providing information and health services (Alessa et al., 2019). Smartphones running health apps are of particular interest because they can promote patient engagement and self-management, and allow for remote follow-up without the need for in-person physician visits (Li et al., 2020; Lunde et al., 2018; Zou et al., 2020).

Research Aim

This review aimed at synthesising existing evidence on the effectiveness of smartphone apps that support self-management to improve DASH diet adherence and accordingly reduce BP, as well as assessing app usability and acceptability, and user engagement and satisfaction. To the best of our knowledge, no studies have summarised the effects of DASH smartphone apps on DASH diet adherence.

2.2 Methods

2.2.1 Guideline

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline for systematic reviews was used to conduct and report this systematic review (Liberati et al., 2009).

2.2.2 Data Sources and Search Methods

The following electronic databases were searched: Embase (OVID), Cochrane Library, CINAHL, Web of Science, Scopus, and Google Scholar. The databases were searched using keywords related to dietary approaches to stop hypertension, the DASH diet, and smartphone apps and using MeSH terms, as well as appropriate synonyms (see Appendix 4 for the search strategy). The terms were combined using Boolean operators OR and AND. The search was restricted to English language research published from 2008, when the first app store was introduced (Eren & Webster, 2015), to February 22, 2021. Google Scholar was used to search for any additional grey literature using a collection of text words chosen from the papers found in the electronic databases, such as "DASH diet mobile phone apps" and "DASH diet smartphone apps." Reference lists of the included studies were checked by hand searching to find additional potentially relevant research.

2.2.3 Inclusion Criteria

The population, intervention, comparison, outcome, and study design (PICOS) framework was used to create the inclusion criteria (Liberati et al., 2009).

Population

The review included studies that involved people with prehypertension and hypertension who were aged 18 years or over, without consideration of gender or sociodemographic characteristics. Overweight and obese people, including those with hypertension, were included because a higher BMI is associated with a higher risk of eventually developing hypertension (Leggio et al., 2017).

Intervention

The intervention target was mobile phone apps for dietary behavioural change. To be included, a study had to focus mainly on evaluating a mobile app that assists users in adopting, improving or maintaining the DASH diet to reduce BP. Studies that combined the mobile phone app with another component, such as communication with others (such as a coach or research team) by phone, text message, or email, were also included.

Comparator

The review included studies that used any comparator, for example, studies comparing usual care with the DASH mobile phone app or any other control intervention. Studies without a comparator, such as pre-post pilot studies, were also included.

Outcome

The primary outcome measures of the included studies were BP level and adherence to the DASH diet.

Study Design

This review included RCTs and pre-post studies. To minimise the probability of missing important articles, both peer-reviewed articles and under-review articles were included.

2.2.4 Exclusion Criteria

The following criteria were used to exclude studies: (1) Studies that focused on a healthy population, adolescents and children, or pregnant women; (2) Studies that only used messaging, which included SMS text messaging and emails, or only used websites; (3) Studies solely describing the development of a mobile system’s technology; (4) Studies that did not focus on the DASH diet; and (5) Conference abstracts, conference papers, protocols, and studies not published in English.

2.2.5 Selection of Studies

Reference management software (Endnote X9.0, Clarivate Analytics) was used to import and collect study citations for selection and to deduplicate articles. The screening and selection of titles of studies were conducted by 2 researchers (GA and TA) independently based on eligible criteria. In the second phase, GA and TA checked the abstracts of selected titles. Titles and abstracts received 2 points if they matched the criteria, 0 points if they did not, and 1 point if there was doubt. A study was included in the next phase if the sum of reviewer scores for the title was 2 or more. Studies that received less than 2 points were excluded. Cohen's kappa was used to evaluate the agreement of reviewers on each phase of the title and abstract selection process. Controversial studies and disagreements between reviewers were discussed with other researchers (LdW and MH).

2.2.6 Data Extraction

Two reviewers (GA and TA) independently extracted data and cross-checked the data. The reviewers piloted a standardised form that was used to extract data. Any disagreements were resolved through discussion with the other researchers (LdW and MH) until consensus was obtained. The data included study characteristics (authors, year of publication, follow-up duration, and country); information on participants (sample size, age, gender, and diseases they had); information on apps (name, type, and functionalities); app input (the information obtained from users and the mode of entering user data); intervention characteristics; mode of intervention delivery (e.g., stand-alone app or combined with another component such as phone or text message); and intervention content (information that the intervention gives to users). In addition, the theoretical framework used to develop or guide the intervention was extracted. For health outcomes, the primary and secondary health outcomes were extracted. We extracted the outcome data from the last follow-up and from both control and intervention groups.

2.2.7 Data Analysis and Synthesis

A narrative summary of the studies was conducted. The data from each study were extracted, and the outcomes were organised into logical categories, including clinical outcomes (e.g., SBP, DBP, and weight loss), DASH diet adherence, app usability, acceptability, and user engagement and satisfaction. The variety of study methods and reported outcomes meant that a meta-analysis was not possible. This review followed the PRISMA 2020 statement (Page et al, 2021) (Appendix 5).

2.2.8 Assessment of the Risk of Bias

Two reviewers (GA and TA) independently assessed the risk of bias of the included studies. Any disagreements were addressed through discussion with the other researchers (LdW and MH). The risk of bias was assessed using the Cochrane Collaboration's Risk of Bias Tool for RCTs, 2018 (Higgins et al., 2019). Risk ratings of "low," "high," and "some concerns" were assigned to each RCT study based on the presence of the following items: performance bias, selection bias, detection bias, attrition bias, reporting bias, and other bias. The overall risk of bias was high if any element was classified as high risk (Higgins et al., 2019). Robvis software, a visualisation tool for risk of bias assessments in systematic reviews, was used (McGuinness & Higgins, 2021).

Nonrandomised quantitative studies were evaluated using a tool for pre-post studies without a control group, which was provided by the US National Institute of Health (NIH) (The National Heart, Lung, and Blood Institute, 2021). The quality ratings were "good," "fair," or "poor." If the rating was poor, reasons were noted.

2.3 Results

2.3.1 Summary of the Search Results

A total of 185 publications were identified from the searches, all of which came from electronic databases, as follows: 30 publications from Embase, 84 from Cochrane Library, 15 from CINAHL, 19 from Web of Science, 35 from Scopus, and 2 from Google Scholar. After duplicates were removed, 137 publications were screened for eligibility. From these, 122 were excluded after screening the titles and abstracts, and 15 full texts were retrieved. Examining the latter led to the exclusion of 10 publications that did not meet the inclusion criteria. In total, 5 publications were included in the analysis (Figure 2-1).

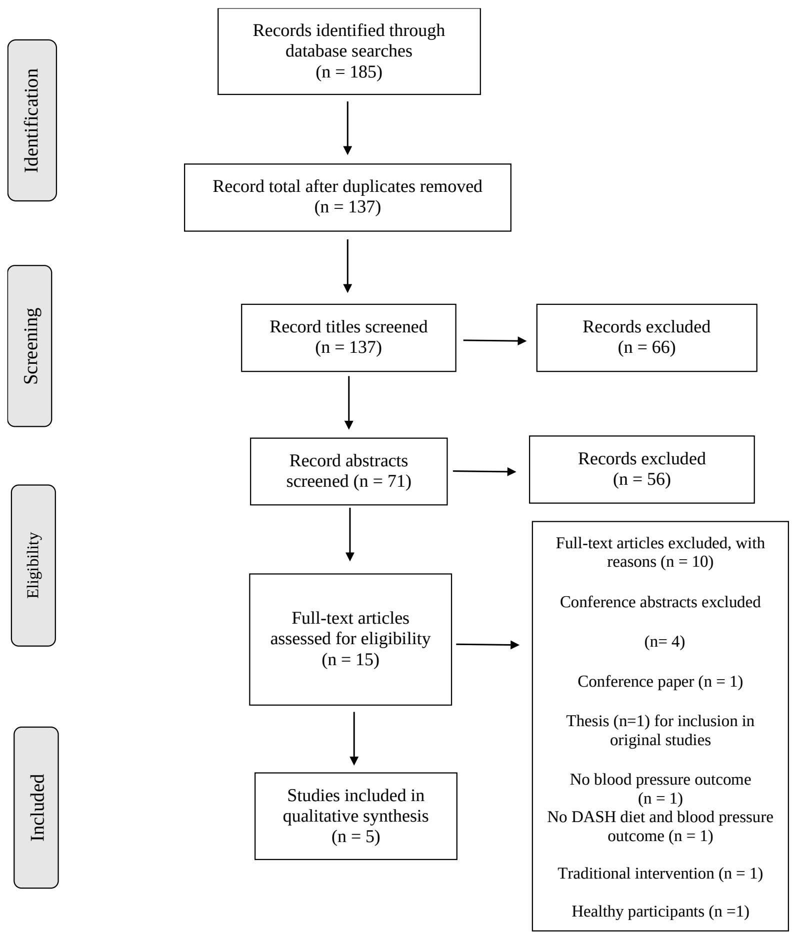

Figure 2-1 PRISMA flow diagram

2.3.2 Characteristics of the Studies

Of the 5 included studies, 3 were conducted in the United States (Steinberg et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020) and 2 in Iran (Bozorgi et al., 2021; Darabi et al., 2020). All were published between 2017 and 2021 (Appendix 6). The included studies had sample sizes ranging from 17 to 120 participants, with a total of 334 participants. Four studies included both males and females (Bozorgi et al., 2021; Darabi et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020), whereas 1 study included only females (Steinberg et al., 2020). Participants from all the studies ranged in age from 18 to 75 years. Three studies (Bozorgi et al., 2021; Steinberg et al., 2020; Weerahandi et al., 2020) included participants with either hypertension or prehypertension alone, or participants with hypertension who were overweight or obese (Darabi et al., 2020; Toro-Ramos et al., 2017).

Of the 5 studies, 3 were RCTs (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020) and 2 were pre-post pilot studies (Toro-Ramos et al., 2017; Weerahandi et al., 2020). In terms of duration, the interventions were commonly conducted for 3 to 6 months (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020).

All studies supported self-management of the DASH diet and hypertension. They all aimed to enhance self-management with increased patient awareness through educational information (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020). One study enhanced self-management without involving a human coach to monitor patients remotely (Bozorgi et al., 2021), whereas the remaining 4 studies aimed to enhance self-management by involving a human coach (Toro-Ramos et al., 2017; Weerahandi et al., 2020) or research teams to monitor patient data and health status remotely (Darabi et al., 2020; Steinberg et al., 2020). All studies reported the effectiveness of the apps in terms of dietary behavioural changes and controlling BP (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020). Four studies evaluated user engagement (Bozorgi et al., 2021; Steinberg et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020); 2 assessed user satisfaction (Bozorgi et al., 2021; Steinberg et al., 2020); 1 evaluated user acceptance (Weerahandi et al., 2020); 1 assessed usability, user knowledge, and user attitudes (Bozorgi et al., 2021); and 1 evaluated user self-efficacy (Darabi et al., 2020).

One study reported having applied behavioural theories (self-efficacy theory was applied) (Darabi et al., 2020). The 4 remaining studies did not report using behavioural theories.

However, the functionalities of the apps were investigated, and identifiable components of behavioural change strategies were discovered in every study, for example, self-monitoring, feedback, setting goals, and messages.

2.3.3 Intervention Characteristics

The app characteristics are shown in Table 2-1. Each of the reviewed studies used a different app (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020), with 2 apps commercially available (apps available to the public on an app store) (Steinberg et al., 2020; Toro-Ramos et al., 2017) and 3 developed specifically for the study (Bozorgi et al., 2021; Darabi et al., 2020; Weerahandi et al., 2020). Among the 3 reviewed RCTs, the control groups in 2 RCTs received usual care (Bozorgi et al., 2021; Darabi et al., 2020), while the other control group received a mobile phone app to track food, without receiving feedback and motivational messages (Steinberg et al., 2020).

Table 2-1 App intervention characteristics

App intervention type	Name of app Purpose	App type	App functionalities
APP + 1 other approch (Communication with a coach by phone call to establish personalised DASH[a] diet plans and feedback)	Noom Healthy weight loss and more	Commercial [b]	Self-monitoring (BP [c], weight, and PA [d]) Diet self-monitoring with a comprehensive and easily accessible nutrient database Educational information - Goal setting Feedback – Motivation message- Reminder
App + 2 other approaches (motivation and feedback text message + DASH video and booklet)	Nutritionix diet tracking	Commercial	Diet self-monitoring with a comprehensive and easily accessible nutrient database
APP + 1 other approach (Communication with coach by text message or email)	DASH mobile	Non-commercial [e]	Self-monitoring (BP, weight, daily diet and PA). Educational information- Feedback motivation message- Goal setting Communication with a coach by chat
App + 2 other approaches (phone call + text message)	DASH-related recommendations	Non-commercial	Educational information
App stand-alone	Blood Pressure Management Application (BPMAP)	Non-commercial	Self-monitoring (BP) Educational information Feedback – Motivation message Reminder- DASH diet plan

[a] **DASH:** Dietary Approach to Stop Hypertension. [c] **BP:** blood pressure. [d] **PA:** physical activity. [b] Smartphone app that is available on app stores. [e] Smartphone app that is not available on app stores.

2.3.4 Outcomes

2.3.4.1 Effect on BP and Weight

All studies (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020) examined the direct impact of DASH mobile app interventions on health outcomes in terms of BP, and 4 studies assessed weight loss (Bozorgi et al., 2021; Darabi et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020). Four studies reported a positive effect of the DASH diet app on both SBP and DBP (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020; Toro-Ramos et al, 2017), and 3 studies reported significant results (Bozorgi et al., 2021; Darabi et al., 2020; Toro-Ramos et al., 2017). In total, 3 studies reported significantly reduced weight loss (Bozorgi et al., 2021; Darabi et al., 2020; Toro-Ramos et al., 2017) (Tables 2-2 and 2-3).

Table 2-2: Blood pressure and weight loss effects in randomised controlled trials.

Study	Total length of intervention	N	Blood Pressure			Effect	BMI (kg/m2)	Effect
			SBP [a] (mmHg)	DBP[b] (mmHg)	The mean changes arterial pressure (MAP) (mmHg)			
Darabi et al. (2020) mean (SD)								
Intervention	12 Weeks	44			NR [c]	Positive		Positive [d]
Baseline			150.43 (10.19)	94.15 (7.69)			29.51 (2.89)	
12 weeks			144.65 (10.36)	88.59 (8.34)			29.40 (2.91)	
Control		44						
Baseline			155.88 (16.81)	96.13 (8.41)			28.53 (2.57)	
12 weeks			161.09 (17.46)	97.61 (7.27)			28.64 (2.62)	
Bozorgi et al. (2021) mean (SD)								
Intervention	24weeks	60	NR	NR		Positive		Positive
Baseline					108.9 (13.5)		29.7 (3.4)	
24 weeks					94.8 (3.42)		28.6 (3.2)	
Control		60						
Baseline					114.9 (14.30)		28.5 (3.6)	
24 weeks					100.1 (7.20)		28.4 (3.7)	
Steinberg et al. (2020) mean (SD)								
Baseline for both groups mean (SD)	3 Months	59	122.9 (14.2)	80.2(8.8)	NR	Neutral[e]	NR	NR
Between group difference mean (95% CI)			-2.8 (95% CI -1.8 to 7.4)	-3.6 (95% CI -0.2 to 7.3)				

[a] **SBP:** systolic blood pressure. [b] **DBP**: diastolic blood pressure. [c] **NR:** not reported. [d] Blood pressure was significantly reduced by the app. [e] Blood pressure was neutrally affected by the app.

Table 2-3: Blood pressure and weight loss effects in pre-post studies

Study	Total length of intervention	N	Blood Pressure		Effect	BMI (kg/m2)	Effect
			SBP [a]	DBP [b]			
Weerahandi et al.(2020) Mean (SD)							
Baseline	120 days	17	138.6 (21.47)	86.9 (16.10)	Neutral [c]	33.6 (7.46)	Neutral
120 days			139.75(15.85)	89.50(13.85)		33.83 (7.64)	
Toro-Ramos et al. (2017) Mean (SD)							
Baseline	24 weeks	50	130.93(12.81)	83.03(11.32)	Positive [d]	33.60 (8.29)	Positive
Change from baseline to 24 weeks			−5.98 (17.60)	−5.06 (11.89)		−1.21 (1.38)	

[a]**SBP:** systolic blood pressure. [b]**DBP:** diastolic blood pressure. [c]Blood pressure was neutrally affected by the app.[d] Blood pressure was significantly reduced by the app.

2.3.4.2 DASH Diet Adherence

The 3 randomised studies (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020) evaluated the effects of apps on dietary behavioural changes. The DASH score was used to evaluate adherence to the DASH diet and was calculated using 9 target nutrients, including total fats, saturated fats, protein, cholesterol, calcium, magnesium, sodium, and potassium (Darabi et al., 2020; Steinberg et al., 2020). The sum of all nutrient goal values, with a maximum of 9, was used to calculate the DASH score. A value of 1 was assigned if the DASH target for a nutrient was met, 0.5 if the intermediate target was met, and 0 if no target was met (Mellen et al., 2008). Bozorgi et al, (2021) used a food frequency questionnaire to assess dietary change.

Three studies demonstrated that using a DASH app resulted in better adherence to the DASH diet and consequently lower BP (Table 2-4). Darabi et al. (2020) demonstrated that using a smartphone app to educate patients about the DASH diet and improve self-efficacy resulted in better adherence to the DASH diet, with significant differences between each group at the end of the trial. Bozorgi et al. (2021) evaluated the app's impact on patient adherence to the DASH diet. They observed increased consumption of fruits, vegetables, and dairy in the intervention group compared with the control group.

Moreover, the consumption of low-fat and low-salt diet plans increased by 1.7 and 1.5 points, respectively. Steinberg et al. (2020) compared dietary changes between women who used app-based diet tracking (control group) and those who used app-based diet tracking with feedback on DASH adherence through text messages (intervention group) over 3 months. They found that both groups' DASH scores improved significantly after 3 months. A single-unit increase in the DASH score in the intervention group was linked to a 2.7 (95% CI 0.4-5) mmHg drop in SBP (*P*=.03) and a 1.3 (95% CI 1.0-3.6) mmHg drop in DBP (*P*=.26). In the control group, the association was a little weaker, with a single-unit increase in the DASH score linked to a 1.7 (95% CI 2.1-5.4) mmHg drop in SBP (*P*=.37) and a 1.8 (95% CI 0.8-4.4) mmHg drop in DBP (*P*=.16).

Table 2-4: Change in the Dietary Approach to Stop Hypertension (DASH) adherence score.

Study (follow-up) and DASH[a] score	**Change in the DASH adherence score**		
	Intervention group, mean (SD)	**Control group, mean (SD)**	**Effect**
Darabi et al. (2020) (12 weeks)			
Baseline score	2.895 (0.457)	2.931 (0.534)	Positive [b]
End of trial score	3.837 (0.761)	3.875 (0.699)	
Bozorgi et al .(2021) (24 weeks)			
No assessment reported	NR [c]	NR	NR
Steinberg et al. (2020) (12 weeks)			
Baseline score	2.2 (1.3)	2.3 (1.3)	Positive [b]
End of trial score	3.1 (1.4)	3.1 (1.3)	

[a] **DASH:** Dietary Approach to Stop Hypertension. [b] DASH adherence was significantly increased by the app.

[c] **NR:** not reported.

2.3.4.3 App Usability and Acceptability, and User Engagement and Satisfaction

Four studies assessed user engagement (Bozorgi et al., 2021; Steinberg et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020), 2 evaluated user satisfaction (Bozorgi et al, 2021; Steinberg et al, 2020), and 1 evaluated user acceptance (Weerahandi et al., 2020). All focused on the patients' perspectives, and 1 study also assessed patients' knowledge and app usability (Bozorgi et al., 2021).

User engagement was assessed by logging food intake, BP, weight, and step count. Chats, phone calls, and text messages were also incorporated (Bozorgi et al., 2021; Steinberg et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020). Generally, participants' use of the apps to record food, BP, and weight was high.

In the 2 studies that evaluated user satisfaction, participants were very accepting of the use of apps (Bozorgi et al., 2021; Steinberg et al., 2020). In the study by Steinberg et al. (2020), participants reported that the app was easy to use, and that they used it frequently and would recommend it to friends. They also reported that the DASH score was helpful and motivational, and that the timing of the text messages was convenient and helped them achieve their goals (Steinberg et al., 2020). In the study conducted by Bozorgi et al. (2021), the results suggested that usability was good.

2.3.5 Quality Appraisal of Studies

All RCTs included used an appropriate random allocation sequence for randomisation. The allocation sequences were concealed by all studies until the participants were enrolled. Therefore, all studies had low bias risk due to randomisation (Figure 2.2).

The staff in studies testing the DASH diet smartphone app and the participants during the experiment were aware of the assigned interventions in 3 and 2 studies, respectively. In all studies, a suitable analysis was used to estimate the effect of the assigned intervention (intention-to-treat or modified intention-to-treat analysis). Accordingly, the risk of bias due to deviations from intended interventions had "some concerns" in all studies.

In all studies, outcome data were available for most or all participants. The "missing outcome data" domain was deemed to have low risk of bias in all studies (Figure 2.2).

All included studies evaluated the outcome of interest (ie, BP level and DASH diet adherence) using appropriate measures and used methods that were comparable between intervention groups. However, in all studies, the assessor of the outcome was not blinded. For this reason, all studies were rated as having high risk of bias in the "measuring the outcome" domain (Figure 2.2).

The prespecified analysis plan (eg, protocol) was published in 2 studies. Therefore, 2 studies were considered to have low risk of bias due to selection of reported results (Figure 2-2). All studies were judged to have high risk of bias in the last domain, "overall bias," because they had a high risk in at least one domain.

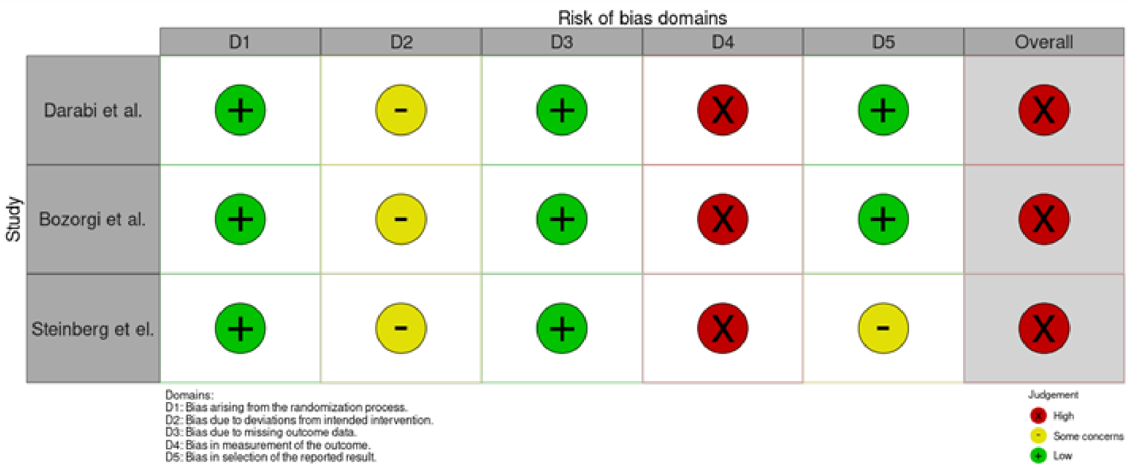

Figure 2-2 Summary of the risk of bias assessment using the Cochrane Collaboration's Risk of Bias tool.

Of the 2 pre-post studies, 1 was of poor quality due to the study's design (pilot study, small sample size, and lack of power analysis) (Weerahandi et al., 2020). Moreover, there was some missing information that affected study validity. The other study was deemed to be of fair quality because it had a good sample size, and a clear method was used (Toro-Ramos et al., 2017). Quality assessment results are reported in Appendix 7.

2.4 Discussion

2.4.1 Principal Findings

This systematic review aimed to synthesise evidence on the effectiveness of DASH smartphone apps that support self-management in order to improve DASH diet adherence and consequently reduce BP. It also aimed to examine satisfaction, acceptability, engagement, and usability of DASH smartphone apps. Our review highlighted weak emerging evidence of a positive effect of using DASH smartphone apps. However, the evidence is inconclusive because some studies on the topic are of low quality due to the fact that blinding of participants and the assessor was not implemented, and the study protocol was not published. Furthermore, 1 of the 3 studied RCTs was unpublished, that is, the manuscript is under review. Therefore, the data do not allow firm conclusions about the effectiveness of DASH smartphone apps to increase DASH diet adherence and lower BP.

This review indicates that a DASH mobile app that engages patients and encourages self-management of the DASH diet may be helpful in improving adherence to the DASH diet. The findings are in line with the findings of other systematic reviews that involved chronic kidney disease dietary mobile app interventions for changing user dietary behaviour, which illustrated that the use of nutritional apps enhanced adherence to sodium reduction, protein intake, caloric intake, and fluid dietary limitations (Campbell & Porter, 2015; Kosa et al., 2019). Our results show that using a DASH smartphone app may improve DASH diet adherence and consequently reduce BP and body weight (Bozorgi et al., 2021; Darabi et al., 2020; Toro-Ramos et al., 2017). This is consistent with systematic reviews that have focused on traditional interventions, which showed that adherence to the DASH diet significantly reduces SBP, DBP, and body weight (Filippou et al., 2020; Soltani et al., 2016).

In this review, all apps had some similar functionalities; 3 out of the 5 apps combined 3 functionalities, including educational information, feedback, and messages (reminder or motivation), with other functions. We could not determine the most effective functionalities because there was no clear difference in the results between apps with different functionalities (Alessa et al., 2018; Li et al., 2020). In this review, we found no difference between commercial and non-commercial apps in terms of their characteristics.

Interventions involved the mobile app alone or in combination with other communication tools, such as phone calls, chats through the app itself, or text messaging. It was not possible to determine from the results whether combining the app with other modalities increased effectiveness. However, Schoeppe et al. (2016) found that apps were most successful when combined with other tools rather than used as a stand-alone intervention.

The findings with regard to usability and feasibility are in line with studies assessing dietary smartphone apps for changing the behaviour of chronic kidney disease patients (Kosa et al., 2019),which also found that the apps were useable and feasible. Studies assessing the acceptance and usability of mobile apps for chronic disease management support our results regarding acceptance (Alessa et al., 2018; Fu et al., 2017).

After examining the risk of bias of the included studies, the findings of this review should be treated with caution because several studies had a high risk of bias. Three RCTs and 2 pre-post pilot study were included. Four out of the 5 studies had methodological issues. These difficulties arose from potential biases in all RCTs because blinding of participants and assessors was not implemented, the study protocol was not published (Steinberg et al., 2020), or the study duration was short (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020; Toro-Ramos et al., 2017; Weerahandi et al., 2020). Due to the nature of using apps, blinding of subjects was not possible across interventions. One of the 3 RCTs is still under review (Darabi et al., 2020). All RCTs used an appropriate random allocation sequence for randomisation and concealed the allocation sequence (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020). The outcome data were available for most or all participants (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020). One pre-post pilot study had limitations that included small sample size, short duration, and missing information (Weerahandi et al., 2020).

2.4.2 Strengths and Limitations of This Review

The studies included in this review have some limitations. First, 4 included studies were evaluated as “low quality,” implying that unreliable outcomes were possible. These factors, together with heterogeneous outcomes and the methods used to quantify them, make drawing generalisable conclusions difficult. Owing to the variability in study designs, a meta-analysis was not possible. Second, 1 study was under review, and low-quality studies were considered because more recent findings are often helpful. Finally, in the included studies, the socioeconomic characteristics of participants were rarely reported; nevertheless, when they were reported, they revealed a high educational level, thus further limiting the generalisability of the results.

Additionally, this review has certain limitations. First, few studies exploring the use of smartphone apps to enhance DASH diet adherence could be found, even though the authors established a comprehensive search strategy for the 5 main databases and manually reviewed the reference lists of each full-text article to identify potentially relevant research for inclusion in this systematic review. Second, due to the low number of RCTs, we were unable to evaluate the effectiveness of DASH smartphone apps. Third, studies written in languages other than English were excluded, increasing the chance of relevant research being missed.

Despite these limitations, to our knowledge, this is the first systematic review investigating the effectiveness of using smartphone apps for patient adherence to the DASH diet, which is known to lower BP, and assessing user satisfaction and app acceptance. This review also highlights the crucial issue of the lack of high-quality research in this field, and thus, this review could help improve future research on the use of DASH smartphone apps by people with hypertension.

2.4.3 Future Directions

In general, the methodological quality of the research included in this study was poor. This suggests that future studies should include a sufficient number of participants and a sufficiently long duration, and should ensure blinding of assessors and low attrition rates. It would also be beneficial to conduct a well-designed RCT with multiple arms using apps with different combinations of functionalities to identify the most effective combinations. The results of this review are applicable to short-term app use because most interventions lasted between 3 and 6 months. Longer-term studies are needed to integrate smartphone apps into people's daily routines and assess their usefulness for long-term DASH diet adherence. It is also essential to evaluate and understand users' acceptance of and satisfaction with these apps. Most studies included in this review evaluated DASH diet adherence by calculating the DASH score based on a food recall questionnaire that may be impacted by inaccurate reporting by participants (Bozorgi et al., 2021; Darabi et al., 2020; Steinberg et al., 2020). Future studies should incorporate objective measures, such as urinary excretion, to measure dietary adherence to DASH (Kwan et al., 2013).

2.5 Conclusion

This review identified 5 studies including a total of 334 participants. Use of smartphone apps to increase DASH diet adherence and reduce BP in hypertensive patients is clearly in the early stages of development. However, the fact that studies were found in 2 different countries (using 5 smartphone apps with similar functionalities) and that all of them were published in the last 4 years indicates that the research community is now taking interest in the DASH diet. All the apps seemed to be accepted and easy to use. Although it is impossible to draw firm conclusions from the current evidence, the studies indicated positive trends, suggesting that DASH smartphone apps could be useful tools to increase DASH diet adherence and reduce BP. Further research is needed that can provide higher-quality evidence to determine the effectiveness of DASH smartphone apps to improve adherence to the DASH diet and correspondingly lower BP.

2.6 References

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Chapter 3 | Identification of the Most Suitable Mobile Apps to Support Dietary Approaches to Stop Hypertension (DASH) Diet Self-Management: Systematic Search of App Stores and Content Analysis

The previous chapter presented a systematic review of the existing literature on the effectiveness of smartphone apps in supporting dietary self-management to enhance DASH diet adherence and subsequently reduce blood pressure. This study finds weak emerging evidence of a positive effect of using DASH smartphone apps for supporting self-management to improve DASH diet adherence and consequently lower BP. However, most of the studies examined in the previous chapter developed their own smartphone apps, which are not generally available to the public. Therefore, examining the likely effectiveness, quality and privacy/security of commercially offered DASH diet smartphone apps in the marketplace is informative.

This chapter aims to assess DASH diet self-management apps, which are generally available through app stores, based on their quality, likely effectiveness, and data privacy/security to identify the most suitable app(s). This chapter is presented in a published format with permission from the publishers. It has been published in Nutrients as “Identification of the Most Suitable Mobile Apps to Support Dietary Approaches to Stop Hypertension (DASH) Diet Self-Management: Systematic Search of App Stores and Content Analysis” authored by Alnooh, G., Alessa, T., Noorwali, E., Albar, S., Williams, E., de Witte, L.P. and Hawley, M.S., in 2023. Volume 15, Issue 15, with page number 3476 and DOI: org/10.3390/nu15153476.

Abstract

Smartphone apps might provide an opportunity to support the Dietary Approaches to Stop Hypertension (DASH) diet, a healthy diet designed to help lower blood pressure. This study evaluated DASH diet self-management apps based on their quality, likely effectiveness, and data privacy/security to identify the most suitable app(s). A systematic search and content analysis were conducted of all DASH diet apps available in Google Play and the Apple App Store in the UK in November 2022. Apps were included if they provided DASH diet tracking. A previous systematic literature review found some commercial apps not found in the app store search, and these were also included in this review. Three reviewers used the App Quality Evaluation Tool (AQEL) to assess each app's quality across seven domains: knowledge acquisition, skill development, behaviour change, purpose, functionality, and appropriateness for adults with hypertension. Domains with a score of 8 or higher were considered high-quality. Two reviewers assessed the apps' data privacy and security and then coded Behaviour change techniques (BCTs) linked to the Theoretical Domain Framework (TDF) underpinning the likely effectiveness of the apps. Seven DASH diet apps were assessed, showing the limited availability of apps supporting DASH diet self-management. The AQEL assessment showed that three apps scored higher than eight in most of the AQEL domains. Nineteen BCTs were used across the apps, linked to nine TDF action mechanisms that may support DASH diet self-management behaviours. Four apps met standards for privacy and security. All seven apps with self-monitoring functionality had sufficient theoretical basis to demonstrate likely effectiveness. However, most had significant quality and data security shortcomings. Only two apps, Noom and DASH To Ten, were found to have both adequate quality and security and were thus deemed suitable to support DASH diet self-management.

Keywords: DASH diet; hypertension; self-management; smartphone app; mHealth; behaviour change techniques; quality.

3.1 Introduction

Hypertension is one of the leading causes of increased morbidity and mortality worldwide (World Health Organization, 2023) due to the negative impact of high blood pressure (BP) on cardiovascular and renal functions (Alessa et al., 2018; Mule et al., 2016). Elevated BP levels are caused by a complex combination of genetic and environmental factors (World Health Organization, 2023). Thus, it is critical to focus on modifiable risk factors for controlling hypertension. The evidence suggests that blood pressure can be lowered by adopting a dietary pattern such as the DASH diet, eating less saturated fat and total fat, obtaining enough potassium, limiting salt intake, and limiting alcohol consumption (Bazzano et al., 2013; Savica et al., 2010).

The DASH eating plans offer dietary recommendations based on calorie requirements, with a focus on the consumption of grains, fruit, vegetables, lean meat, fish, dairy, and nuts and a limited consumption of sweets, sugar-sweetened beverages, and saturated fats (Appel et al., 1997; Bazzano et al., 2013; Karanja et al., 1999). The eating plan was created to increase fibre, calcium, magnesium, and potassium intake while lowering cholesterol (Karanja et al., 1999). An umbrella review of systematic reviews and meta-analyses has demonstrated that the DASH diet, either alone or in combination with other lifestyle changes—including sodium restriction, weight loss, or physical activity—is effective for lowering BP levels (Chiavaroli et al., 2019). Even though reducing BP lowers the risk of kidney and heart disease, most people struggle to control their BP with medication or lifestyle changes (Chow et al., 2013; Epstein et al., 2012). Self-management is one of the most effective strategies for dealing with hypertension, as it allows people with hypertension to take more responsibility for their own health (Shahaj et al., 2019). Dietary self-management often requires users to record their meals in order to help control the consumption of calories and specific nutrients, i.e., carbohydrates or cholesterol (Rusin et al., 2013). Healthcare professionals will often advise patients to keep a diet diary, the key argument for this being that it assists patients in changing their behaviour by encouraging them to take more responsibility for their health and to reflect on their eating habits (Rusin et al., 2013).

The current increase in information and communication technology, such as mobile health, has aided chronic condition self-management (Logan, 2013; Marcolino et al., 2018). Smartphone sales worldwide exceed 2 billion per year, and there are more than three billion smartphone users today (Mitrea & Borda, 2020). Mobile apps support clinical intervention strategies by leveraging the multifunctional capabilities of mobile devices (Rivera et al., 2016). Mobile health interventions are promising in low- and middle-income countries regarding promoting physical activity and healthy diets (McCool et al., 2022). Several systematic reviews and meta-analyses have assessed the role of dietary monitoring for chronic disease management (El Khoury et al., 2019) and changing dietary behaviour using mobile phone applications (Teasdale et al., 2018). They found that dietary monitoring has positive effects on managing chronic diseases, particularly weight loss and changes in dietary behaviour. Also, adherence to dietary self-monitoring via apps may help registered dietitians determine patients' dietary patterns and recognise factors supporting or impeding goal attainment (Chen et al., 2018).

Many smartphone apps are already readily available to hypertensive patients, and the number is rapidly growing (Goldberg & Levy, 2016; Kumar et al., 2015). While most of these apps are designed to assist people with hypertension with management and control (Goldberg & Levy, 2016; Kumar et al., 2015), a systematic review by Alessa et al. (2019) found that few studies report the effectiveness of apps in supporting the self-management of hypertension. Similarly, there are only a few studies on the effectiveness of apps to help patients adhere to the DASH diet. For example, a recent systematic review found only five studies that met the inclusion criteria and evaluated DASH diet app interventions to improve DASH diet self-management (Alnooh et al., 2022)

Self-management programmes that are accompanied by theory-based interventions have been demonstrated to be more effective (Al-Washali et al., 2018; Lepard et al., 2015). Behaviour change techniques (BCTs) are an important feature of nutrition apps since such techniques involve observable and reproducible components that can be used to alter behaviour (Chen et al., 2018). The theoretical frameworks provided by such programmes enable the identification of target behaviours and behavioural modification strategies required to attain desirable health outcomes. However, according to studies, many commercial health apps lack the theoretical underpinning and consistent use of BCTs (Alessa et al., 2019; Bondaronek et al., 2018).

The shortcomings raise serious concerns about health apps, which may provide little or no benefit and may even pose a risk to users (Edwards et al., 2016), thus underscoring the importance of providing adequate information to patients and healthcare professionals about the effectiveness and quality of these apps, as well as the strength of their privacy and security measures. In addition, the findings of Alessa et al. (2019) highlight the value of describing and exploring the probable theoretical mechanisms of action in commercially available apps. The Theoretical Domain Framework (TDF) and BCT Taxonomy v1 (BCTTv1) have been widely used to define BCTs in health interventions and to study the probable theoretical mechanisms of action by grouping BCTs with TDF mechanisms of action, particularly those BCTs related to chronic diseases (Alessa et al., 2019; Steinmo et al., 2015).

However, app quality involves more than effectiveness, and there has been considerable debate about how to define it, with many frameworks available. In 2016, a review and content analysis by DiFilippo et al. (2018) assessed the availability and quality of DASH diet applications in Apple's app store in the US using the App Quality Evaluation (AQEL). They found a lack of free apps supporting DASH education, and the free apps that were available needed improvement, while paid apps could be beneficial in supporting DASH education. Furthermore, most health applications were found to lack suitable privacy and security safeguards to protect users' data, thereby posing a threat to user confidentiality (Alessa et al., 2018; Alessa et al., 2019; Huckvale et al., 2015), thus jeopardising both users' personal information and their trust in the app.

We carried out a systematic review to evaluate the effectiveness of smartphone apps that support dietary self-management to improve adherence to DASH diets and, consequently, lower blood pressure (Alnooh et al., 2022). Five studies met the inclusion criteria and were included (three RCTs and two pre-post studies), two of which were conducted on apps that are available on app stores (Noom and Nutritionix Track). This study found that there is weak emerging evidence that DASH smartphone apps improve adherence to the DASH diet and consequently lower blood pressure.

To date, only one study has examined the quality of DASH diet apps in the US Apple App Store (DiFilippo et al., 2018). No previous review has provided a comprehensive analysis of DASH diet self-management apps that are available on the most popular platforms: iPhone (Apple App Store) and Android (Google Play) stores, including the quality of apps, their privacy and security, and their behavioural change mechanisms, giving an indication of their potential effectiveness. As such, there is a lack of evidence available to guide the choice of which apps are suitable to support self-management of the DASH diet. Therefore, our research question in this study was: Which generally available apps are suitable for use in DASH diet self-management, based on their likely effectiveness, quality, and security?

3. 2 Materials and Methods

3.2.1 App Identification and Selection

In November 2022, systematic searches were conducted in the UK, specifically in the iPhone (Apple App Store) and Android (Google Play) stores. These two platforms were chosen because they are the most widely used operating systems worldwide (Karthick & Binu, 2017). Apps were identified using the following keywords: ‘DASH diet’, ‘high blood pressure diet’, and ‘hypertension diet’. These search keywords were entered individually, with no specific search categories such as health and fitness, into the Apple App Store and Google Play database search bars.

For screening, each app’s title, description, and screenshots were considered by the primary researcher (GA) using an iPhone 7 (version iOS 14.4, Apple Inc., Cupertino, CA, USA) to identify apps in the Apple App Store and an Android Samsung Galaxy S20 5G (version Android 12, Samsung Electronics, Suwon, South Korea) to identify apps in the Google Play Store. The app inclusion criteria were as follows: (1) the app allows the user to track their diet intake; (2) the app and the description of the app were written in English; and (3) the DASH diet was included in the app description. The app exclusion criteria were as follows: (1) apps not related to the DASH diet; (2) apps not meant for self-management (i.e., offering only information to promote the DASH diet, DASH diet recipes and plans, etc.); (3) apps offering a variety of diets (i.e., DASH is not the primary focus); (4) apps designed for doctors and dietitians to use in their professional work; and (5) apps for food sales or takeaway orders. Average user ratings were not employed as a selection criterion in the current study, in contrast to earlier studies that assessed the content of health apps by selecting apps based on user reviews (Choi et al., 2021; Zečević et al., 2021), as their subjectivity may not always provide relevant information on app quality (Stoyanov et al., 2015).

If an app appeared on both platforms, either version could be used for testing. Apps that appeared many times during the search process were only listed once. All relevant apps were downloaded, including free and paid apps. The researcher selected the paid version of an app if the paid version included increased functionality. The apps were then checked to see whether or not they met the inclusion criteria. Finally, the apps were run for three days if they fulfilled the criteria, so that the researcher could investigate whether the app provided any reminders or notifications.

In addition, commercially available apps found in the previous (updated) systematic literature review were included if they were not found in the app store searches (Alnooh et al., 2022).

3.2.2 Data Extraction

The data extraction process involved using a Microsoft Excel spreadsheet to compile information from the apps. Each of the apps' name, developer, price, functionality, and recent updates and versions were all noted on the spreadsheet.

3.2.3 In-Depth Analysis

All the apps were downloaded and evaluated by four reviewers—one registered dietitian (EN), one nutrition epidemiologist (specialising in online dietary assessment tools, SA), one nutritionist (GA), and one mHealth specialist (TA). The app's quality was assessed by three reviewers (EN, SA, and GA), while privacy, security, and likelihood of effectiveness were evaluated by two reviewers (TA and GA).

3.2.3.1 Likelihood of Effectiveness of the DASH Diet App and Theoretical Underpinnings

As few DASH diet apps have been evaluated for effectiveness (Alnooh et al., 2022), the presence of BCTs was quantified to indicate the likelihood of effectiveness. The apps were examined to determine whether they were supported by theoretical frameworks, referred to as TDF mechanisms of action. To determine the mechanisms of action that underpin existing apps, the BCT Taxonomy v1 was used to code each app's content and extract the number of BCTs in each app, as well as their frequency of use (Michie et al., 2013). Each BCT was coded as (0) if it was absent and (1) if it was present (Alessa et al., 2019). The two reviewers (GA and TA) conducted the analyses independently. The Cohen's kappa for each item was calculated and used to determine the interrater reliability for the presence or absence of BCTs.

The BCTs were then mapped onto the TDF mechanisms of action based on expert consensus that has been reported in previous studies relating BCTs to TDF domains for health interventions, and all researchers in this study agreed with this mapped judgement (Cane et al., 2015; Steinmo et al., 2015). The two reviewers (GA and TA) worked independently to link the BCTs to the TDF in order to explore the domains underpinning the app. Disagreements were resolved by discussion with other researchers (LdW, EW, MSH).

3.2.3.2 General App Quality

The quality of each app was evaluated using the AQEL tool. This assessment tool is used to measure the quality of apps that aid in the development and selection of nutrition interventions (DiFilippo et al., 2017). AQEL has five domains: Educational domains (behaviour change potential, knowledge acquisition support, and skill development) address how the app will increase knowledge, improve skills, and change behaviour. Meanwhile, the other two domains deal with the app's functionality, including its speed, colours, icons, and overall purpose, which should have a clear name and description (DiFilippo et al., 2017). There are also two modifiable domains: the app's suitability for the target age group (adults) in terms of nutrition needs and cognitive ability and its relevance to the target audience (in this case, those seeking help with DASH diet self-management to control hypertension). Notably, this tool has been used to evaluate the quality of existing nutrition apps (Ahmed et al., 2021; DiFilippo et al., 2018; Lee et al., 2021).

The reviewers (SA, EN, and GA) downloaded the selected DASH apps and familiarised themselves with each app and its features before beginning the evaluation. Then, they completed the AQEL survey in Qualtrics (version 2016–2017, Provo, UT, USA) individually. As each domain contained a different number of questions, all sum scores were translated to a 10-point scale for comparison. For each app, the average score for each domain evaluation was calculated. Apps receiving a score of eight or more in most domains were considered high-quality (DiFilippo et al., 2018).

3.2.3.3 Privacy and Security

Privacy and security were assessed in accordance with the guidelines set by the Information Commissioner's Office in the UK and the Online Trust Alliance (Online Trust Alliance, 2013; Information Commissioner's Office, 2103). These guidelines are composed of eight questions that can be answered with yes, no, or not specified/not applicable to evaluate the accessibility and availability of privacy policies, data sharing, collection methods, and data security, as defined by the privacy and security statement. The apps were assessed independently by two researchers (GA and TA), and disagreements were addressed through discussions with other researchers (LdW, EW, MSH).

3.2.4 Statistical Analysis

SPSS software (IBM SPSS Statistics for Windows, Version 26.0. IBM Corp., Armonk, NY, USA) was used for all of the analyses. The frequencies of BCTs and TDFs were generated as mean and standard deviation (SD). To examine interrater reliability, two-way random absolute intraclass correlation coefficients (ICCs) utilising average measures were used to assess the continuous data. Good and excellent agreement were defined as an ICC between 0.75 and 0.90 and greater than 0.90, respectively, while moderate agreement was defined as between 0.50 and 0.75 (Koo & Li, 2016). Also, Cohen's kappa was used to assess the interrater reliability of the ordinal data. Perfect agreement was defined as 0.81–1.00, and moderate agreement was defined as 0.61–0.80 (McHugh, 2012). The mean scores with SD were calculated for each domain of app quality evaluation for the reviewed apps.

3.3. Results

3.3.1 Identification of DASH Diet Self-Management Apps in the Published Literature and App Store

A total of 659 apps were found after searching the two app platforms (419 in the Android Google Play Store and 238 in the iPhone Apple App Store). A previous systematic review identified two apps—Noom and Nutritionix Track (Alnooh et al., 2022), that the app store searches did not capture, as neither of the apps' titles nor descriptions mentioned the DASH die. However, both of these apps have been used in interventional studies targeting DASH diet self-management (Alnooh et al., 2022). Therefore, both applications were included. The apps' titles and descriptions were reviewed for eligibility. A total of 647 apps were excluded because they did not meet the criteria for inclusion. The remaining 12 apps were then analysed further. A further five apps were excluded because their basic functions did not work (n = 1), the information was related to other diets (n = 1), they offered a variety of diets (i.e., DASH was not the primary focus; n = 1), or they were linked to research projects requiring an access code (n = 2). Finally, this review included seven apps: six free (in-app purchases) and one paid. Figure 3-1 illustrates a summary of the selection of apps using the PRISMA flow diagram.

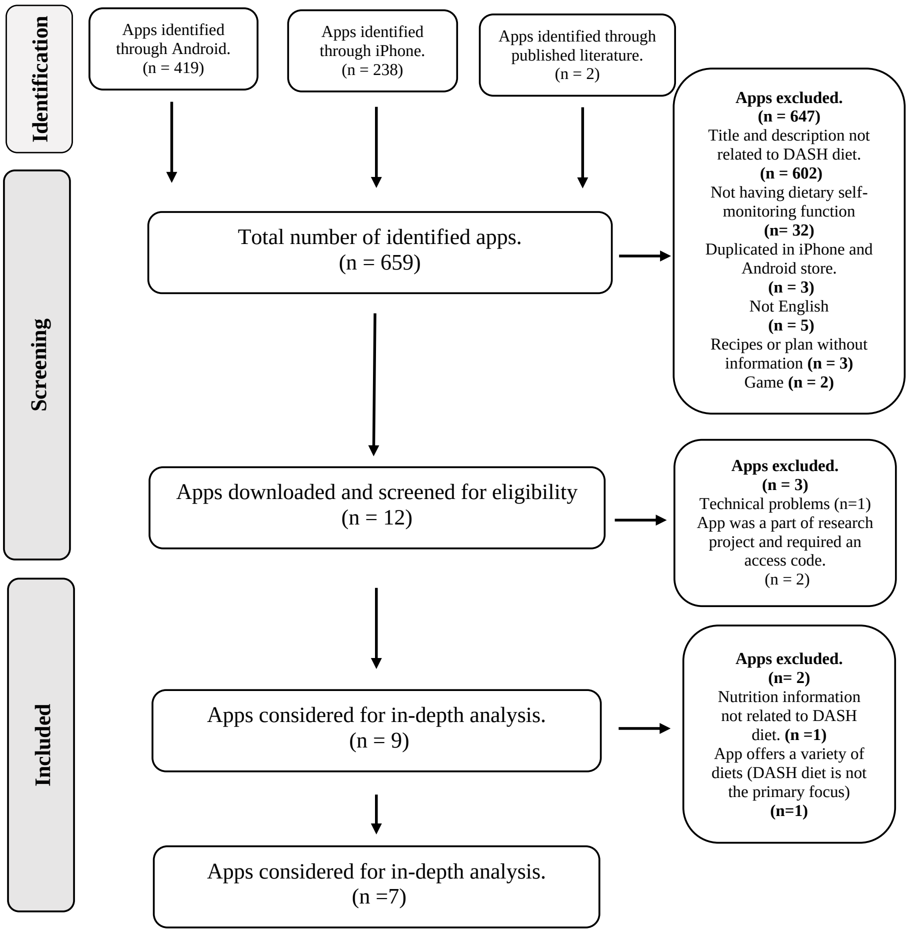


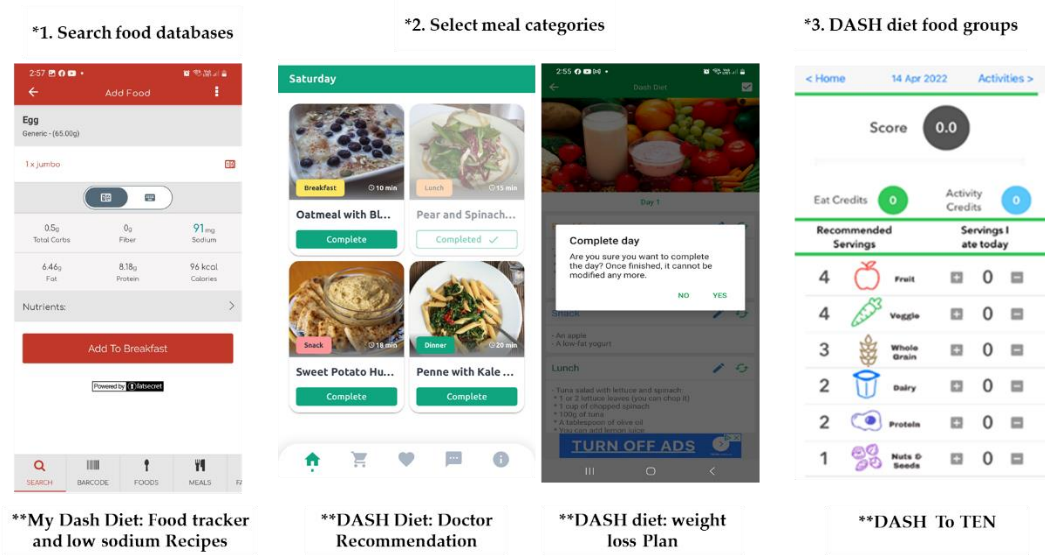
Figure 3-1: Flow diagram of app search and selection.

3.3.2 Characteristics of the Selected Apps

Three out of the seven apps that fulfilled the selection criteria were accessible on both platforms. There were three apps available on iPhone only and one app available on Android only. The data for each app are presented separately and can be found in Appendix 8.

One of the seven apps was a fee-based download, at a cost of £0.81. The remainder of the apps were available for free download, although they required a monthly subscription to access all the features, new meal updates, personal plans, or extra measurements, including BMI, waist measurements, and heart rate. The costs ranged between £1.90 and £121.82 per item or for the programme. One app also required a one-time purchase of a premium tracking service that estimates vitamins and minerals in food. All the apps were in English, while some of them were also available in Spanish, German, and Korean. The apps examined were released between 2011 and 2020.

Furthermore, all the apps allowed for the quantity of food consumed to be recorded and provided feedback on progress. These apps allow users to enter their food intake data using a variety of methods. Three apps provide a comprehensive database with information from the USDA Food Composition Database, chain restaurant statistics, and other sources (Figure3-2). Users can add restaurant meals not already included in this database as well as create custom meals or recipes to simplify the entry of home-cooked meals that they consume regularly. Two apps allow users to select meal categories (breakfast, lunch, etc.) without specifying the quantity or DASH diet food groups, e.g., vegetables or fruit. The remaining two apps include tools to track the intake of DASH diet food groups (Figure 3-2). Some include images to illustrate nutritional information, such as graphs to describe the food's nutritional value. Some apps also include credits (points) or a facial expression symbol (an emoji) to illustrate when users meet a DASH diet serving recommendation.



***The food tracker methods; ** the app's name**

Figure 3-2: The food tracker Methods

3.3.3 The Nutritional and General App Functionalities

Table 3-1 illustrates the nutritional and general app functionalities.

Table 3-1: The nutritional and general app functionalities.

Name of app	App Functions
My DASH Diet: Food Tracker and low sodium Recipes	• Self -monitoring (food, water, BP, physical activity, and weight). • Communication with friends by email. • Feedback (macronutrients, micronutrients such as sodium intake, weight, BP, and water). • Educational information used credible sources. • Goal setting (sodium intake and weight) • Recipes and shopping list. • Intelligent recognition system to identify food barcodes and search functionality.
Noom	• Self-monitoring (food, water, BP, blood glucose, physical activity, weight). • Communication with the coach through the in-app chat. • Feedback (food groups, weight and BP). • Educational information used credible sources. • Goal setting (weight). • Notification to log food, read the articles and push notifications to indicate the user has high blood pressure and needs to see a doctor. • Quiz to assess users' information. • Intelligent recognition system to identify food barcodes and search functionality.
Nutritionix Track	• Self-monitoring (food, water, physical activity and weight) • Communication with coach through the in-app chat. • Feedback (macronutrients, micronutrients such as sodium intake, weight, and water) • Goal setting (weight). • Notification to log food. • Intelligent recognition system to identify food barcodes and search functionality. • Used food picture

Name of app	App Functions
DASH Diet Tracker	• Self -monitoring (food and weight) • Feedback (food groups intake) • Goal setting (weight)
DASH diet: Plan personalized: weight loss	• Self-monitoring (to follow DASH diet plan and weight) • Educational information none provided the sources. • Feedback (follow DASH plan and weight) • Dash Diet Plan • Shopping list • Notification (to track DASH plan and weight).
DASH Diet: Doctor Recommendation	• Self -monitoring (to follow DASH diet plan and weight) • Communication with app team through the in-app chat. • Feedback (follow DASH plan and weight) • Educational information uses credible sources. • Goal setting (weight) • Recipes and shopping list. • Notification of dietary plan.
DASH To Ten	• Self-monitoring (food, water, sleep, medication, meditation). • Feedback (food groups intake, and wight). • Goal (weight) • Educational information uses credible sources. • DASH diet Plan. • Notification to log food and push notifications to indicate the user had exceeded the DASH diet recommendations).

3.3.4 Behaviour Change Techniques and Theoretical Domain Framework

3.3.4.1 The Presence of Behaviour Change Techniques

This study identified 19 BCTs in the seven reviewed apps. The coding of BCT presence or absence achieved an ‘almost perfect’ agreement between the reviewers (Cohen’s kappa 0.84).

The maximum number of BCTs in one app was 19, and each app contained at least eight BCTs. The mean number of BCTs was 12.7 (SD 3.6). Eight BCTs were present in all seven apps reviewed: “self-monitoring of behaviour”, “self-monitoring of outcome of behaviour”, “problem solving”, “action planning”, “feedback on outcomes of behaviour”, “review behaviour goal”, “goal setting (behaviour), and “review outcome goal”. One of the nineteen BCTs, categorised as “social incentive”, was only present once. The Appendix 9 provides an overview of the frequency of common BCTs.

3.3.4.2 Mechanisms of Action of the Theoretical Domain Framework

The BCTs found in the seven apps reviewed could be mapped onto nine different TDF mechanisms of action. Each app had a different number of TDF mechanisms of action, ranging from six to nine, with a mean of 7.7 (SD 1.1). Table 3-2 presents the frequency of TDF mechanisms of action used in the seven apps. Further information can be found in Appendix 10.

Table 3-2: The Theoretical Domain Framework mechanisms of action mapped Behaviour change techniques.

The theoretical domain framework	Behavioural change techniques	Frequency of TDF domain in apps (N)
Beliefs about capabilities	Social support Problem solving Action planning	7
Goals	Goal setting (outcome) Goal setting (behaviour) Review outcome goal(s) Review behaviour goal(s) Action planning	7
Knowledge	Information about health consequences Instruction on how to perform a behaviour Credible source Feedback on behaviour Feedback on outcomes of behaviour Biofeedback	7
Skills	Problem solving Biofeedback	7
Beliefs about consequences	Feedback on behaviour Feedback on outcomes of behaviour	7
Behaviour regulation	Self-monitoring of behaviour Self-monitoring of outcome(s) of behaviour Problem solving	7
Memory attention and decision process	Prompts / cues Habit formation	5
Reinforcement	Credible source	4
Emotion	Reduce negative emotion.	1

3.3.5 General App Quality

Three reviewers (SA, EN, and GA) used the apps before evaluating them. Interrater reliability (n = 3) was deemed to be good (ICC > 0.75) for six apps and excellent for one app (ICC = 0.92). Only three apps (DASH To Ten, Noom, and My Dash Diet: Food Tracker and low sodium Recipes) received high scores (>8 of 10) across four out of seven AQEL quality domains, while the remaining apps received low scores (<8 of 10) across most of the AQEL quality domains (Table 3-3). Each of the three high-scoring apps received high scores in the AQEL domains of 'knowledge building' and 'appropriateness for adults'. Regarding app appropriateness for high blood pressure patients, only the My Dash Diet: Food Tracker and low sodium Recipes app received a high score because it was found to track food intake and sodium consumption, blood pressure, body measurements, macro- and micro-nutrients, water intake, weight, and physical activity. Although the other two apps received a lower score on their appropriateness for supporting DASH diet self-management for hypertensive patients, with scores of 7.5 and 7.1, their scores were still higher than those of the other apps. This was because both apps, DASH To Ten and Noom, tracked food intake, but they did not automatically calculate sodium consumption and instead only provided information about the amount of sodium consumed. However, both tracked physical activity and water intake. Noom also reported BP readings but provided no specific information regarding the DASH diet, although it adopted a similar method to the DASH diet and its lessons and strategies were well suited to the DASH diet recommendation (Frinzi, 2020).

Table 3-3: Mean App Quality Evaluation to support DASH diet self-management out of 10 (n= 3 Raters).

App Name	App Quality Evaluation Domain						
	Behaviour Change Potential	Knowledge Building	Skill Building	Function	App Purpose	Appropriate for Adults	Appropriate for Hypertension
My Dash Diet: Food tracker and low sodium Recipes	7 (0.2)	8.2 (0)	7.4 (0.6)	7.2 (0.4)	10 (0)	9.3 (0.5)	8.5 (0.4)
DASH Diet: Doctor Recommendation	6.5 (0.9)	4.4 (1.0)	6.7 (0)	7.6 (0.2)	6.1 (0.9)	8.6 (0.5)	3.8 (0)
DASH To Ten	7 (0.2)	8 (0.2)	7 (0.6)	8 (0.6)	8.3 (0.1)	8.6 (0.5)	7.5 (0)
DASH Diet Tracker	2.8 (0.6)	2.5 (0.2)	4.4 (1.9)	4.8 (0.2)	4.4 (0.9)	4.3 (0.5)	0 (0)
DASH diet: weight loss Plan	0.6 (0.2)	0.9 (0)	2.9 (2.5)	4.7 (0.9)	2.7 (0.9)	3.6 (0.5)	0 (0)
Noom	8.4 (1.2)	9.2 (0.5)	7.8 (0)	9.1 (1.1)	3.4 (0.2)	9.6 (0.5)	7.1 (1.4)
Nutritionix track	5.03 (1.02)	3.2 (0.42)	5.5 (1.5)	7.1 (0.24)	8.3 (0)	8 (0.47)	3.8 (0.24)

Note: Data are presented as the mean (SD).

3.3.6 Data Privacy and Security

3.3.6.1 Availability and Accessibility of Privacy Policy

Of the seven apps in this study, six had a privacy policy, and one (DASH Diet Tracker) did not. None of these six had applied a short-form privacy and security notice describing the key data practices detailed in the entire privacy policy, and this may be because the policies had already been written concisely. Multilingual policy was uncommon; only the Noom app provided the policy in three other languages (Korean, Spanish, and German).

3.3.6.2 Data Gathering and Sharing

All the apps disclosed the fact that they collected personally identifiable information, such as email or age. For five apps, the developer reported that they share the data they collect with third parties and explained the data-sharing practice. Only one app (My Dash Diet: Food Tracker and low sodium Recipes) disclosed that it does not share user information with anyone.

3.3.6.3 Data Security

Four apps described how the user's data were kept secure: Noom, DASH To Ten, Nutritionix track, and DASH Diet: Doctor Recommendation. The privacy policy stated that data security and privacy were critical to their operations and that user data were encrypted, anonymised, or only viewed by authorised individuals. Only one app (My Dash Diet: Food Tracker and low sodium Recipes) did not discuss user data security. Overall, four apps met data privacy and security standards. Data gathering, sharing, and security, as detailed in the privacy policies, can be found in Appendix 11.

3.3.7 Selection Process

All seven apps identified as potentially supporting DASH diet self-management are shown in Table 3-4. The most suitable apps were selected based on their likely effectiveness, adequate privacy and security, and high quality.

All apps have a theoretical basis, and of the nine TDF mechanisms of action that underlie these apps, between six and nine are involved in each app. Thus, all seven apps were deemed likely to be effective. Regarding app quality, four apps were excluded because they scored low (App Quality Evaluation (AQEL) < 8) in most domains. Three apps were excluded because one had no privacy policy and two did not adequately protect user data. Therefore, Noom and DASH To Ten were the only apps that met the selection criteria.

Table 3-4: The Apps' quality, privacy and security, and theoretical underpinning (n = 7).

App Name	Version Type	No of BCTs	TDF Mechanisms of Actions, n	Quality of App, n	Privacy and Security
My Dash Diet: Food tracker and low sodium Recipes	iPhone and Android	14	7	4 domains > 8	X
DASH diet: weight loss Plan	Android	8	8	0 domains > 8	X
DASH To Ten	iPhone	13	9	4 domains > 8	✓
DASH Diet Tracker	iPhone	9	6	0 domains > 8	X
DASH Diet: Doctor Recommendation	iPhone	14	8	1 domain > 8	✓
Noom	iPhone and Android	19	9	4 domains > 8	✓
Nutritionix track	iPhone and Android	12	7	2 domains > 8	✓

3.4 Discussion

3.4.1 Principal Findings

Dietary apps have the potential to improve dietary behaviour. However, these apps must be effective, secure, and high-quality to achieve their potential. The number of DASH diet apps that provide dietary self-management is limited. Only seven apps were found that met the inclusion criteria, including supplying dietary self-monitoring and feedback that contributes to enhancing diet outcomes (Teasdale et al., 2018). The results of this study demonstrate the risks of commercial app availability. Although all seven apps are built using established theory, only two apps (Noom and DASH To Ten) were deemed high-quality and demonstrate sufficient privacy and security measures. Only one of these apps (Noom) has been assessed for efficacy in a trial (Toro-Ramos et al., 2017). Addressing gaps in app development (such as safety concerns and a lack of quality) is essential for improving app quality, privacy, security, and effectiveness. One way of achieving this is by increasing engagement with researchers and experts (Akbar et al., 2020; Alessa et al., 2021a). These improvements would increase both consumer trust and provider confidence (Akbar et al., 2020; Alessa et al., 2021a).

3.4.2 App Functionalities

All apps in this review provided interactive features, including dietary self-monitoring and feedback, and some offered educational information about the DASH diet and goal setting. These findings agree with another study that reported that self-monitoring, goal setting, and providing feedback were the most frequently identified types of BCTs on weight management apps (Bardus et al., 2016) because these functions are essential components of behaviour change (DiFilippo et al., 2015). According to a previous content analysis of weight management apps with interactive features, apps that provide features such as tracking behaviours were associated with higher engagement scores across the Mobile App Rating Scale domain (Bardus et al., 2016). In addition, some of the apps also sent notifications to remind users to log their food intake to increase engagement with the behaviour change app (Bell et al., 2023). Interactive functions in dietary apps may improve engagement and effectiveness (Bardus et al., 2016; DiFilippo et al., 2015). Therefore, interactive functionality should be included in the development of future apps to promote DASH diet self-management.

The apps included various approaches that users could take to log their food intake. For example, in some apps, users could calculate their food servings based on DASH recommendations; however, the portion sizes were described textually without images or icons that could help the user determine the correct serving size, as was also found by a previous study that assessed popular nutrition apps (Franco et al., 2016). Qualitative research exploring the barriers to following the DASH diet among Black Americans has shown that most patients faced difficulty calculating their food servings because it was unfamiliar (Tyson et al., 2023). Therefore, dietary apps should provide a serving size guide to assist users in calculating their food serving size.

In other apps, users could select meal categories (breakfast, lunch, etc.) without specifying the quantity they consumed or the DASH diet food groups (vegetables, fruit, etc.) to which the foods belonged. Although being able to choose the meal category simplified the selection process, this approach is imprecise since some users prefer a more detailed approach (Rusin et al., 2013).

Alternatively, users could select food via text search from large food databases or barcode scanner technologies, which is the most common method of recording food intake among nutrition apps (Rusin et al., 2013). König et al. (2021) reported that participants expressed satisfaction with using a comprehensive food database to self-monitor their food intake. Further qualitative research is needed to explore the best approaches to food logging.

3.4.3 Likelihood of Effectiveness and Theoretical Underpinnings of the DASH Diet Apps

The effectiveness of only two of the reviewed apps was supported by published studies (Alnooh et al., 2022), and only one of these apps provided evidence about its effectiveness and discussed and demonstrated the necessity of such evidence in its app store description. In the absence of direct evidence of effectiveness for most apps, we used the presence of BCTs to indicate the likelihood of effectiveness. All apps utilised BCTs, which mapped onto TDF mechanisms. Nineteen BCTs overall, ranging from eight to nineteen per app, were identified. The current study's finding in this regard is higher than the average number of BCTs found in prior app reviews, which ranged from two to eight in apps aimed at changing adults' physical activity and dietary behaviours (Direito et al., 2014; Middelweerd et al., 2014). Moreover, a systematic review of studies investigating the effect of apps on nutrition behaviours and nutrition-related health outcomes found that apps included a range of 2–11 BCTs (Villinger et al., 2019).

In the current review, the most common BCTs were feedback, monitoring, goals, and building knowledge. These self-regulation strategies have been demonstrated to be effective in enhancing dietary behaviour (El Khoury et al., 2019; Pearson, 2012; Teasdale et al., 2018). This study's finding agrees with the findings of a systematic review and meta-analysis that evaluated the effectiveness of nutrition-related app-based mobile interventions, highlighting that the majority of interventions involved four clusters of behaviour change techniques (BCTs), namely “goals/planning”, “feedback/monitoring”, “shaping knowledge”, and “social support” (Villinger et al., 2019). Furthermore, previous work suggests that dietary behaviour change apps targeting weight management need to include goal setting, monitoring behaviour, and providing feedback on that behaviour since these BCTs encourage app users to improve their dietary behaviour (Lieffers et al., 2018).

The impact of the number of BCTs on intervention efficacy is still inconclusive; some studies indicated that interventions that include more BCTs seem to have a greater impact than interventions with fewer techniques (Webb et al., 2010), while others observed no effect (Michie et al., 2009). Moreover, certain BCTs may be more effective when used in combination with others (Van Genugten et al., 2016). The employment of a variety of BCT groups, as well as the techniques used within each BCT group, could theoretically improve effectiveness by tackling dietary self-management barriers.

The use of a theoretical framework is critical to developing behaviour change interventions (Glanz & Bishop, 2010). The assessment of the theoretical underpinning of the apps revealed that the 19 BCTs identified in the seven reviewed apps linked to nine TDF mechanisms of action that may support DASH diet self-management. Our results, supported by previous research, identified the main TDF domains that could support chronic disease self-management and influence patients’ behaviours (Alessa et al., 2019; Ferrara et al., 2019; Thomas & Mackintosh, 2014). Which combinations of BCTs or TDF mechanisms improve chronic disease self-management, however, is unknown (Michie et al., 2018b; Morrissey et al., 2016). There have been limited investigations into how existing apps map BCTs to TDF domains. The current study’s linking of BCTs to TDF mechanisms of action may therefore assist developers and researchers in identifying suitable BCTs when developing apps and determining which BCTs are most effective and why (Atkins et al., 2017; Michie et al., 2018a).

3.4.4 General App Quality

The quality assessment of the apps that supported DASH diet self-management indicated the need to improve their quality. Only three apps scored well in the majority of the AQEL domains. However, none of the included apps scored well (AQEL > 8) in all educational domains (behaviour change potential, knowledge building, and skill building). This finding is consistent with a previous study that evaluated apps that supported DASH diet education and found that few apps were of sufficient quality in this area (DiFilippo et al., 2018). It is essential to educate patients about self-management to support chronic disease management, and they need ongoing help to improve their self-management skills and achieve the desired behavioural change (Novak et al., 2013). Therefore, it is imperative to improve the educational domains of commercial applications of the DASH diet.

Regarding appropriateness for hypertensive patients, the current study found that most DASH diet apps scored low and that only My DASH Diet scored well (AQEL > 8); this is because it tracks sodium intake, a critical factor in reducing blood pressure (National Heart, Lung, and Blood Institute, 2003).

3.4.5 Data Privacy and Security

Due to the large size of the app market, regulatory control of data protection is difficult (Alessa et al., 2019; Bondaronek et al., 2018). As a result, app developers are responsible for guaranteeing data privacy and security (Wicks & Chiauzzi, 2015). The examination of the apps' privacy policies revealed that the privacy and security of users' data could be significantly improved, which is consistent with the results of a previous study that assessed apps supporting the self-management of hypertension and found that many lacked privacy policies, most of which violated users' privacy and data security (Alessa et al., 2019). The key advantage of collecting and analysing users' data via app is that developers may be able to improve their products using the data (NICE, 2014). However, information regarding these practices should be accessible and easy to understand so that potential users can decide whether to download and install the app (Singh et al., 2016).

3.4.6 Strengths and Limitations

The systematic approach used for app identification and assessment is one of this study's strengths. Six hundred and fifty-nine apps, both free and fee-based, were screened across the two most common mobile phone platforms to identify a sample. The sample was assessed by four independent reviewers with diet, nutrition, and mHealth expertise. The evaluation also covered various aspects, including quality by using validated AQEL, privacy and security, and likely effectiveness. Additionally, this is the first systematic review to investigate the apps' theoretical underpinnings by mapping BCTs to TDF mechanisms. For transparency purposes, a list of the apps analysed has been provided. Providing an app list has been recommended as a good method to conduct quality health-related app reviews, as it might assist users and healthcare providers in making informed choices as well as inspire app developers to improve their app's content (BinDhim et al., 2015).

This study has several limitations. Firstly, app stores are not designed to conduct robust, rigorous searches in the same manner as electronic journals. Furthermore, due to the nature of search algorithms and personalised app content in commercial app stores, it may be difficult to remove duplicates directly from app store searches (Grainger et al., 2020). Therefore, it can be challenging to repeat the search strategy (Grainger et al., 2020). Currently, there are no established guidelines for conducting and reporting systematic searches of app stores. However, efforts are being made to reach an agreement on such guidelines (Grainger et al., 2020). Secondly, our search was limited to publicly accessible apps, and we did not contact any developers whose apps required a code to access. Thirdly, this review only focuses on the two most common platforms in the UK marketplace. Other countries could offer DASH diet apps with different features, qualities, and BCTs. Fourthly, this review did not consider apps available in languages other than English. Therefore, it is necessary to conduct further research on other marketplaces and languages. Fifthly, we evaluated apps for eligibility by checking their titles and descriptions against the inclusion and exclusion criteria. As a result, we may have missed apps that did not include our search terms in their titles and descriptions. To some extent, these issues were overcome by including commercial apps found in a recent systematic review that assessed the effectiveness of DASH diet apps that support dietary self-management. We also updated the search to ensure no recently published studies were missed. Sixthly, if the quality and security assessment had been conducted by app users instead of researchers or by individuals with characteristics different from the assessors who conducted the current evaluation, the results might have been different. To overcome these issues, four researchers independently evaluated the apps, resulting in high interrater reliability and thereby limiting bias. Moreover, apps were assessed within three days, and some app features and BCTs might have been overlooked, such as follow-up prompts, which can require prolonged usage. Therefore, future studies should examine the optimal time frame for assessing an app's quality and whether BCTs are present. Finally, the evaluation of data privacy and security was limited to the analysis of the apps' policy statements, despite the fact that there is evidence of a misalignment between policy statements and app developers' actual practices (Huckvale et al., 2015).

3.4.7 Implications

More studies are needed to evaluate DASH diet apps. It is currently unclear which app features or characteristics effectively increase users' diet adherence. Therefore, RCTs are needed to determine the effectiveness of theory-based apps. Additionally, qualitative research is necessary to examine users' experiences with apps and BCTs. Furthermore, the optimal number of BCTs and TDF mechanisms of action for dietary apps is unknown. Thus, more studies are needed to investigate the effectiveness and suitable number of BCTs and TDF mechanisms of action to increase dietary adherence. Little information is available about how users incorporate these apps into their daily routines or the facilitators and barriers to increasing diet adherence using apps. Future studies are needed to assess the acceptability and usability of the highest-quality apps that support DASH diet self-management.

The findings of our study also have practical implications for multiple stakeholders. First, dietitians, healthcare professionals, and potential users should be aware of the limitations regarding the security of personal data and the quality of DASH diet apps in supporting DASH diet self-management. Second, using our findings, dietitians may have sufficient information to suggest a high-quality app to patients to support DASH diet self-management. Finally, the findings can help smartphone application developers address privacy, security, and app quality to improve the current market.

3.5 Conclusions

Although DASH diet apps are widely available, few apps support the self-management of the DASH diet. All seven apps with self-monitoring functionality had a sufficient theoretical basis to demonstrate their likely effectiveness. However, most had significant shortcomings in their quality and data security. Only Noom and DASH To Ten were distinguished as high-quality because they scored well in most AQEL domains and demonstrated sufficient privacy and security measures. However, none scored well (AQEL > 8) in all the educational domains essential for improving dietary self-management skills. Future research is needed to evaluate the acceptability, usability, and effectiveness of these high-quality apps. Additionally, more efforts are needed to improve the quality of DASH diet apps, especially in the education domain, with data security and interactive functions to help high blood pressure patients manage their diet. The identified DASH diet apps inform the next phase of the PhD.

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Additional information

Three reviewers (SA, EN, and GA) used the apps before evaluating them. Interrater reliability (n = 3) was deemed to be good (ICC > 0.75) for six apps and excellent for one app (ICC = 0.92).

Table 3-5: Interrater Reliability of App Quality Evaluations to support DASH diet self-management

App Name	Statistic		
	Interclass Correlation Coefficient (7,3)	**95% Confidence interval**	**P value**
My Dash Diet: Food tracker and low sodium Recipes	0.92	0.74-0.98	0.0001
DASH Diet : Doctor Recommendation	0.84	0.56-0.96	0.0001
DASH To Ten	0.88	0.63-0.97	0.0001
DASH Diet Tracker	0.77	0.41-0.95	0.0001
DASH diet: weight loss plan	0.80	0.47-0.95	0.0001
Noom	0.89	0.69-0.98	0.0001
Nutritionx track	0.81	0.50-0.96	0.0001

Phase two: identification of DASH diet smartphone apps

- ***Experiences and Perceptions of Healthcare Professionals and Patients with High Blood Pressure Accessing Commercial DASH Diet Apps: A Qualitative Study***

- ***An investigation of the feasibility and acceptability of using a commercial DASH diet app in Saudi Arabia in people with high blood pressure: a mixed methods study***

Chapter 4 | Experiences and Perceptions of Healthcare Professionals and Patients with High Blood Pressure Accessing Commercial DASH Diet Apps for Dietary Self-management in Saudi Arabia: A Qualitative Study

This chapter describes the first study of the second phase of this thesis. The first phase identified two high-quality, secure, and potentially effective apps to support DASH diet self-management. The second phase aimed to select and test the most appropriate DASH diet self-management app for the Saudi Arabian context. This phase consists of two studies: a qualitative study and a feasibility and acceptability study.

This chapter discusses the selection of the most suitable DASH diet self-management app for the Saudi context, which was achieved by gaining insights into the experiences and perspectives of healthcare professionals and individuals with high blood pressure. This study thoroughly explored their usage of two previously identified high-quality, secure, and potentially effective DASH diet self-management apps (Noom and DASH To Ten- see chapter 3). This chapter has been written as a manuscript, which I intend to submit to the *JMIR mHealth uHealth* journal. The title of the manuscript is “Experiences and Perceptions of Healthcare Professionals and Patients with High Blood Pressure Accessing Commercial DASH Diet Apps for Dietary Self-management in Saudi Arabia: A Qualitative Study”.

Abstract

Background: The Dietary Approaches to Stop Hypertension (DASH) diet can help to effectively manage high blood pressure; however, patient adherence to the DASH diet is generally low. Dietary smartphone apps are increasingly being used to address this, and they have provided opportunities to improve DASH diet adherence and control blood pressure.

Objective: This study aimed to select the most suitable DASH diet self-management app for the Saudi Arabian context by understanding the experiences and perceptions of people with high blood pressure and healthcare professionals who used two DASH diet self-management apps determined in a previous study to be high-quality, secure, and potentially effective (Noom and DASH To Ten).

Methods: An exploratory qualitative study was conducted with ten healthcare professionals, including family physicians and dietitians, who were interviewed individually, and fifteen patients, who participated in four focus groups. Participants were given the two apps and asked to try each for one week. Focus groups and individual semi-structured interviews were held at the end of the trial to explore participants' experiences and perceptions of using the two high-quality, secure and potentially effective DASH diet smartphone apps and to select which was more suitable for the Saudi context. The transcripts were analysed using a thematic framework analysis.

Results: This study identified four main themes. 1) Managing hypertension by following the DASH diet is crucial. Most participants reported that adhering to the DASH diet was challenging due to a lack of motivation and willpower, inadequate support from family members, and the fact that healthy food is often expensive. 2) Dietary apps' potential and current reach are significant. Participants expressed an interest in using the apps; however, certain barriers hinder their widespread adoption, including the perceived difficulty of use, concern about apps' content and the failure of apps to support the local language. 3) Comparing apps was important. Participants emphasised that they should have a straightforward sign-up process, a comprehensive food database, and features like feedback, realistic goal setting, and reminders to increase adherence to the DASH diet. 4) The Noom app was deemed the most suitable for high blood pressure patients in Saudi Arabia because it was perceived as highly interactive. It provides users with motivational information, personalised feedback, and an extensive food database. It also places significant emphasis on mindfulness, particularly regarding eating habits. Participants made several recommendations for the apps' improvement; these included Arabic language support, automatic sodium and potassium consumption calculations, and lower cost. Participants also expressed a desire for training in the use of the app.

Conclusions: The study's findings provide new insights into the experience of using two high-quality, secure, and potentially effective apps to support DASH diet self-management. Overall, the Noom app could be suitable for people with high blood pressure in Saudi Arabia, but further research is needed to determine its feasibility and acceptability for long-term use.

Keywords: high blood pressure, hypertension, dietary approaches to stop hypertension, DASH diet, self-management, smartphone apps, Saudi Arabia

4.1 Introduction

Hypertension is a primary cause of cardiovascular disease and the leading cause of premature deaths worldwide. The Middle East region has witnessed a significant rise in noncommunicable diseases, including cardiovascular disease, due to dietary changes leading to obesity, and urbanisation, resulting in decreased physical activity (Okati-Aliabad et al., 2022). The Dietary Approaches to Stop Hypertension (DASH) diet can reduce hypertension and improve cardiovascular disease outcomes (Tyson et al., 2023). The DASH dietary guidelines recommend a diet rich in fruit, vegetables, whole grains, nuts, fish, and low-fat dairy while limiting sweets (Steinberg et al., 2017). There is a paucity of studies examining DASH diet adherence among Saudis. In general, however, Saudis have poor dietary habits, including low consumption of fruit and vegetables and high consumption of fast food, which contains saturated fats, high calories, and sodium, which can result in obesity and high blood pressure (BP) in adults and children (Alshaikh et al., 2018; Amer et al., 2022; Elbashir et al., 2020).

Using nutrition smartphone apps has proven to be an effective and low-cost intervention strategy for improving dietary behaviour (Samoggia & Riedel, 2020). A systematic review was conducted to assess the effectiveness of smartphone apps in promoting self-management to improve adherence to the DASH diet and reduce BP (Alnooh et al., 2022, chapter 2). The review suggested that using DASH smartphone apps may improve dietary self-management, enhance adherence to the DASH diet, and lower BP. However, there is insufficient research evidence supporting the effectiveness and usability of the widely available commercial DASH diet apps. A recent content analysis of DASH diet smartphone apps available in the major app stores identified two high-quality, secure, and potentially effective DASH diet apps: DASH To Ten and Noom (Alnooh et al., 2023, chapter 3).

To successfully integrate technology into medical management, healthcare professionals must be able to use data from health apps to support diagnosis and provide treatment recommendations (Chen et al., 2018; Vasiloglou et al., 2020). Apps are a valuable tool healthcare professionals can use to enhance their routine practices, engage patients, improve care, and possibly reduce costs (Ward et al., 2008). Moreover, patients with diabetes, hypertension, or obesity may use these apps to self-monitor their diets and physical activities (Karduck & Chapman-Novakofski, 2018; Steinberg et al., 2020).

Several studies have been conducted on how healthcare professionals use and view diet apps for dietary assessment and monitoring. According to a survey of sports dietitians, approximately 30% use apps to monitor and assess their patients (Jospe et al., 2015). Another study suggested that nutrition apps may improve patient outcomes compared with traditional methods (Karduck & Chapman-Novakofski, 2018). Chen et al. (2017) found that dietitians in the UK, Australia, and New Zealand prefer apps that are designed for specific patient needs and that can be integrated into their work systems. A previous study, however, found that while Canadian dietitians were enthusiastic about nutrition apps, they expressed concerns about their use in daily practice, including a lack of credibility and accuracy of content (Lieffers et al., 2014).

The acceptability of an app influences its successful use in self-management (van der Weegen et al., 2014; Vo et al., 2019). However, most apps were developed without consulting potential users about their needs (Alessa et al., 2019; Jamaladin et al., 2018). The factors influencing healthcare professionals' and patients' use of health apps must be identified. Assisting and optimising nutrition care and clinical practice processes requires improving the design and implementation of nutrition apps (Vasiloglou et al., 2020). In Saudi Arabia, dietitians play a vital role in monitoring and assessing individuals' dietary needs, while family physicians are responsible for treating patients with hypertension in outpatient settings (Almuqati et al., 2020). In particular, family physicians are responsible for assessing and guiding newly diagnosed patients and those requiring prescription medication and lifestyle changes to manage their chronic conditions (Almuqati et al., 2020). It is essential to determine the expectations of healthcare professionals in order to provide the best possible care for patients with hypertension. This study seeks to determine whether healthcare professionals and patients recommend using two high-quality, secure, and potentially effective DASH diet apps and whether they are useful to them. Further, the study gathers opinions regarding what is missing, what is needed, and what could be improved in these two apps, and selects the most suitable DASH diet app for the Saudi context. To the best of our knowledge, there are no studies on the perspectives, preferences, and recommendations of healthcare professionals and high-blood pressure patients regarding these apps in Saudi Arabia.

Study Aim

This study aimed to select the most suitable app for the Saudi Arabian context by understanding the experiences and perceptions of people with high blood pressure and healthcare professionals (family physicians and dietitians) who have used two DASH diet self-management apps (Noom and DASH To Ten).

4.2 Methodology

4.2.1 Study Design

This study used an exploratory, qualitative approach to explore healthcare professionals' (family physicians and dietitians) and patients' experiences using two high-quality, secure, and potentially effective DASH diet self-management apps to select the most suitable app for the Saudi context.

In the context of this study, it is essential to understand participants' personal experiences with high blood pressure, the meanings they associate with such experiences, and the discourses and practices surrounding these experiences in their particular contexts – to understand, for example, how and why participants living with high blood pressure do or do not engage in healthy lifestyle activities (e.g. following a healthy diet). It will also provide insight into their general attitude toward and acceptance of dietary smartphone apps, including two DASH diet self-management apps. Qualitative methods are ideal for this purpose because they reveal participants' personal perspectives and the context of events, processes, and structures (Miles et al., 2018). This study followed the consolidated criteria for reporting qualitative research (COREQ) checklist to ensure that this study provides explicit information about how it was conducted (Tong et al., 2007). To ensure transparency, a detailed description of the methods used to achieve the results is provided in Appendix 12.

4.2.2 Participants and Recruitment

Patients and healthcare professionals were recruited from outpatient clinics in Riyadh, Saudi Arabia, at King Abdullah bin Abdulaziz University Hospital (KAAUH). The patients considered eligible for the study were identified by the clinical teams (nurses) and the primary researcher, while they were waiting to see their family physicians or dietitians for their regular clinic appointments. The researcher met with potential healthcare professional participants during their breaks at their clinic. Contact information, brief details of the project, and the inclusion criteria were shared by asking interested volunteers to scan a QR code. Patients with high blood pressure and healthcare professionals interested in participating in the study contacted the primary researcher by email to obtain further information and ensure they met the eligibility criteria. A purposive sampling strategy was employed to capture as wide a variety of patients as possible with specific characteristics. Participants were purposefully picked in this sampling strategy because they have specific qualities that will allow for an in-depth examination and understanding of the primary themes associated with the phenomenon under investigation. Inclusion criteria were (1) individuals must be 18 years old or older, and have a systolic blood pressure reading between 130 mmHg and 159 mmHg and a diastolic blood pressure reading between 85 mmHg and 99 mmHg (Saudi Ministry of Health, 2023), (2) willing to read in the English language (the second language in Saudi Arabia), (3) willing to use a dietary smartphone app, (4) own an iPhone, and (5) have the desire to discuss and reflect on their DASH diet app experiences. Any individuals who had cognitive impairment or gestational hypertension (high blood pressure only during pregnancy) were excluded from the study.

Healthcare professionals were recruited through convenience sampling. The eligibility criteria for healthcare professionals' participation included having experience treating patients with high blood pressure, owning an iPhone, and being willing to discuss and reflect on their DASH diet app experiences. Recruiting participants continued until data saturation was reached, when new participants revealed no new information (Braun & Clarke, 2021).

4.2.3 Apps

The smartphone apps Noom and DASH To Ten, both of which are commercially available, were chosen for the study: Noom was available on Google Play Store and the Apple App Store, while DASH To Ten was only available in the Apple App Store. Both apps included the following interactive functionalities: dietary self-monitoring, goal setting, push notifications, and educational information (Alnooh et al., 2023); however, they differed in how they presented these features to users. In both apps, users could create individual profiles, set weight-loss goals, and set daily reminders for logging their meals. Both applications provided users with feedback on their dietary habits and self-reported weight.

4.2.4 Procedures

During an initial session, the researcher asked the participants to sign the consent form and complete a brief questionnaire concerning their personal information, such as age, sex, and education. Then, participants downloaded two smartphone applications. The Noom and DASH To Ten applications cost £15 for a two-week trial and £18 for one month, respectively. After downloading the apps, the participants created their profiles and were asked to use each app for a week to ensure exposure to its various features and functions. This approach allowed individuals to compare the apps, providing a deeper understanding of the user experience. A randomised allocation approach was adopted in which participants were assigned to either Noom or DASH To Ten for the first week; they then switched to the other app for the second week, to reduce order bias. During this session, the researcher used the observation technique to observe the participants' actions when they signed up for both apps. The study determined that one week was sufficient time for exploring the app's functions based on a previous study investigating users' experiences with a dietary smartphone application (Flaherty et al., 2019).

After two weeks, participants received an email from the researcher asking for confirmation of a convenient time to attend a focus group and/or interview. During the second visit, the primary researcher (GA, a female PhD student, an MPH graduate in public health with training in qualitative research methods of data collection and analysis) conducted a focus group and semi-structured interviews to better understand patients' and healthcare professionals' experiences and perceptions. The focus group and semi-structured interviews guides were developed based on the systematic review of the effectiveness of the DASH diet smartphone apps (Alnooh et al., 2022), along with an app review and content analysis of a commercial DASH diet smartphone app (Alnooh et al., 2023), as well as based on other relevant qualitative studies (Alessa et al., 2021; Hahn et al., 2021; Tang et al., 2015). The interview and focus group topic guides focused on the apps' interactive functions. The study also explored other areas of interest, including challenging aspects of dietary self-management, the benefits and challenges of dietary smartphone apps, suitable apps for Saudi content, and the reasons behind selecting the most suitable one (Appendix 13, 14).

The interview and focus group questions were reviewed to ensure they aligned with the study's objectives before they were translated into Arabic. With limited resources, the interviews were piloted in Saudi Arabia with one family physician, one dietician, and a focus group of hypertensive patients (Dworkin, 2012). The purpose of this pilot study was to establish that the questions were suitable and clearly phrased and to determine how long it would likely take the participants to answer them.

During the focus groups and interviews, participants were asked to look at the functions of both apps and verbalise their thoughts and feelings about each function to gain more information and understand the participants' experience. During the focus groups and interviews, the researcher obtained the participants' consent to take notes and audio-record the sessions. While audio recordings are considered more precise (Pope & Mays, 2020), the researcher also opted to take notes because certain aspects, such as body language, cannot be fully captured via audio.

Although the DASH To Ten and Noom apps are only available in English, all questionnaires, focus groups, and semi-structured interviews were conducted in Arabic because people felt more confident when speaking their first language. The participants had no prior relationship with the interviewer before the study commenced, and the duration of the interviews and focus groups ranged from 30 to 45 minutes and from 75 to 90 minutes, respectively.

4.2.5 Data Analysis

The focus groups and semi-structured interviews were recorded and transcribed verbatim, and then the audio files were compared with the transcriptions to ensure accuracy. Anonymised transcriptions were created and analysed by the researcher. The participants did not check the transcripts. Mero-Jaffe (2011) highlighted that interview transcripts frequently exhibit a lack of coherence in the discourse, which can be unexpected for the interviewees. Researchers encounter several challenges in dealing with this issue. Some interviewees may express a desire to modify sections of the transcript, leading to concerns regarding the reliability of the data. To ensure accuracy, the researcher had anonymised quotations translated into English by a qualified translation service in Saudi Arabia. The researcher intentionally refrained from translating the data into English immediately after transcription, in order to first identify the meanings and themes in Arabic. This allowed for a more precise analysis because Arabic is the principal researcher's first language. According to Bryman (2016), translating data from one language to another incurs the risk of losing vital information due to cultural differences.

Framework analysis was used to analyse the semi-structured interviews and focus groups. The researcher selected framework analysis because of its distinct structure and systematic approach, which make it ideal for novice researchers (Goldsmith, 2021). This method is effective for analysing extensive and intricate qualitative data sets and was also chosen for its suitability in addressing the research questions relevant to this study (Goldsmith, 2021; Ward et al., 2013). The MAXQDA (version 12, VERBI GmbH, Berlin, Germany) software program was selected for the analysis because it supports the Arabic language.

Framework analysis involves the following five steps: (1) familiarisation, (2) identification of a theoretical framework, (3) indexing, (4) charting, and (5) mapping (Ritchie et al., 2013). In the first data analysis phase, the researcher immersed herself in the data to become familiar with them. Through the familiarisation process, notes were taken using MAXQDA to identify recurring ideas in the data. These recurring ideas were then grouped into similar themes to create a framework (Furber, 2010). Inductive and deductive approaches were used to analyse the data. The first part of the framework was developed using the topic guide of the interviews and focus groups as well as familiarisation with the data. Participants' attitudes towards hypertension self-management strategies and dietary self-management apps were examined in the first part of the framework, while the interactive functions in the apps and the participants' attitudes towards both apps were explored in the second part of the framework. Indexed transcripts were examined whenever a new theme or sub-theme was added to identify any potentially relevant information. Upon completion of the indexing, the framework was reviewed to ensure that only relevant information was incorporated into its themes and sub-themes. After indexing the data, they were organised into framework matrices. A separate matrix was created for each theme. Following discussions with supervisors, the researcher reviewed the findings of the final analysis stage and implemented changes based on their feedback. Afterwards, the data were mapped and interpreted. Each theme and contrary findings and differences among subgroups were described in depth (e.g. healthcare professionals and patients). All of these factors were considered when mapping and interpreting the data to identify potential explanations.

4.2.6 Ethical Considerations

Ethical approvals were granted by the ethics committees at the School of Health and Related Research (SCHARR) of the University of Sheffield, Princess Nourah bint Abdulrahman University (PNU), and King Abdullah bin Abdulaziz University Hospital (KAAUH) (reference # 049904, #22-0490 # 22-0054, respectively). See Appendix 15.

4.3 Results

4.3.1 Participants Characteristics

This study recruited 20 patients. However, three withdrew because they had difficulties dealing with technology, and two were excluded because they were below the body weight at which the apps would accept them. Therefore, 15 participants took part. Four focus groups were conducted, each consisting of three to four patients. Ten patients had systolic blood pressure between 140 mmHg and 159 mmHg and diastolic blood pressure between 90 mmHg and 99 mmHg, and five had systolic blood pressure between 130 mmHg and 139 mmHg and diastolic blood pressure between 85 mmHg and 89 mmHg. Ten healthcare professionals (5 family physicians and 5 dietitians) were interviewed. Tables 4-1 and 4-2 illustrate the participants' characteristics

Table 4-1: The patients' Characteristics (N = 15)

Characteristics	
Mean age, years (range)	43 (35-65)
Gender, n (%)	
Female	7 (45)
Male	8 (55)
Marital status, n (%)	
Single	2 (13)
Married	13 (87)
Education status, n (%)	
High school diploma	1 (7)
Bachelor's degree	11 (73)
Master's degree and above	3 (20)
Participants with blood pressure readings from 130/85 mmHg to 139/89 mmHg, (Prehypertension), n (%)	5 (33)
Participants with blood pressure readings from 140/90 mmHg to 159/99 mmHg, (stage 1 hypertension), n (%)	10 (67)
Duration of stage 1 hypertension, n (%)	
Less than three years	4 (26)
More than three years	6 (40)

Table 4-2: Healthcare Professionals' Characteristics

Characteristics	
Mean age, years (range)	36 (26-52)
Gender, n (%)	
Male	4 (40)
Female	6 (60)
Work experience, n (%)	
1-5 years	2 (20)
5-10 years	3 (30)
More than 10 years	5 (50)
Profession, n (%)	
Resident doctor	1 (20)
Consultant doctor	4 (80)
Specialist dietitian	4 (80)
Consultant dietitian	1 (20)

4.3.2 Overview of the DASH diet smartphone apps for dietary tracking

Table 4-3 presents the themes and subthemes from the study framework, followed by a description of the results. For more quotations, see Appendix 16.

Table 4-3*:* Identified themes and subthemes through framework analysis.

Theme	Sub-theme	Initial codes
Managing hypertension [a]	***Hypertension self-management strategies***	Walking, salt reduction, a healthy diet and taking medicine, weight reduction, drinking water, sleeping well, following a low-cholesterol diet, and reducing stress.
	Barriers to dietary self-management	Busy life, irregular meals, lack of commitment and motivation, a weak will, the high cost of healthier foods, lack of awareness and skills, dietary habits, and patients' needs.
Dietary apps' potential and current reach	**Potential users**	Simple smartphone application. Educated young adults.
	Awareness of dietary app benefits	Help users to achieve their goals, provide dietary assessments, commitment, increase motivation, and accessibility.
	Awareness of dietary app challenges	Lack of commitment, cost, language, lack of time, accuracy of information.
Comparison of apps	***Interactive app functions***	Sign-up process Dietary self-monitoring, tracking and feedback. Blood pressure self-monitoring Push notifications Goal setting Educational features Social communication
Comparison of Apps [a]	***Visual design***	Home screen, colour, font, and language
Overall app assessment	***App preference***	Reasons for selecting the app.
	Recommendation	Translation, training, reducing the cost, and calculating sodium and potassium intake automatically.

a A priori themes are indicated in italics

1) Managing hypertension

Hypertension self-management strategies

Patients and professionals alike acknowledged that healthcare professionals play an essential role in encouraging patients to adopt healthy habits to control their blood pressure, including a healthy diet and a low-salt (sodium) regimen, physical activity, and weight reduction. Formulating smart objectives with overweight and obese patients is important because a realistic action plan could boost the confidence of patients regarding effectively self-managing their condition.

> *Regarding weight loss (if necessary), I always set patients a reasonable and achievable goal (a smart objective). I always start with a target of three to five kilos for the follow-up visits and inform them of the target and the effects of losing weight* [*to lower their blood pressure*]. *Of course, this is all in addition to medication and monitoring blood pressure.* [Family physician, male]

> *In the early stages of my prehypertension, the doctor focused on reducing the salt and fat in my food and advised me to lose weight.* [Focus group 2, male]

Barriers to dietary self-management

Many barriers affect patients' commitment to dietary self-management. According to the patients and professionals, the most common were a lack of motivation; a busy life, which led them to eat fast food; social life, for instance when they invite their friends to eat at a restaurant; and the high price of healthy foods, such as granola, avocado, and salmon.

> *Frankly, I lack motivation. I mean, I've followed many diets, and I was committed at first, but I didn't continue as a result of a weak will and bad eating habits.* [Focus group 2, female]

The healthcare professionals and patients indicated that insufficient support from household members was one of the reasons for not committing to a diet. For example, mothers cooked for all their family members and ate with them; they found it difficult to convince their families to eat healthily.

When I eat healthy food, my family does not commit to it, so it is hard for me to cook two meals, one for myself and another for my family. This is the thing that makes us not commit. [Focus group 1, female]

Some patients and family physicians reported that some patients were aware of healthy food and what their bodies needed but required a human coach to assist them in changing their dietary behaviour.

We need behavioural therapy. Our problem is not the knowledge itself, which hospitals focus on. Our problem is changing dietary behaviour, and this is the hardest thing. We stick to diets for a month or up to six months; then we return to bad habits. [Focus group 1, female]

2) Dietary apps' potential and current reach

Potential users

Healthcare professionals noticed that many patients use simple smartphone apps to manage chronic disease, such as monitoring blood pressure or blood sugar levels. However, they emphasised that dietary smartphone apps are complicated to use because they require users to change their behaviour. As a result, younger people tend to be more engaged with these apps than older people, as they are more familiar with technology.

The smartphone apps we use are simple – for example, those for measuring blood sugar. But the dietary applications are too complicated because they involve behavioural change. [Family physician, male]

Awareness of the dietary app benefits

Both the healthcare professionals and the patients expressed awareness of the benefits of using smartphone apps. Most of these apps have helpful functions, such as goal setting, feedback, and reminders. These apps also help healthcare professionals review the patient's condition and make it easier for patients to record their diets.

The benefit of this app is that it allows you to set a goal and facilitates keeping a record of your daily habits; then, after some time, you can check whether you achieved your goal. [Family physician, male]

The benefit is to review the patient's diet during the previous days, especially if some of them forgot a meal they ate. In addition, if the application records blood pressure readings, this will help me review the patient's blood pressure. [Family physician, male]

Furthermore, these apps might increase patients' motivation and commitment and meal regularity.

It helps with organising meals; for example, the application sends notifications to organise and follow my diet. [Focus group 1, male]

I can gain motivation; it helps people to record their meals.[Focus group 2, male]

These apps also offer healthy recipes and food plans. Regarding this aspect, one patient stated the following:

They are easier and more comprehensive in terms of nutritional options. Sometimes you say, I would like to eat, but I don't know what I should eat. The app gives you a healthy option to try based on healthy choices. [Focus group 1, female]

In addition, a wide range of patients can benefit from these apps, including those who reside in remote villages, which will reduce their travel burden. These apps can also increase patients' awareness of healthy food.

We live in the vast Kingdom of Saudi Arabia. There are no nutrition clinics in the villages. I expect that using these applications in hospitals will be significantly effective. [...] *It is difficult for a patient who comes every week or 10 days to follow up with a dietician.* [Focus group 2, female]

It gives you more time to understand what you have never learnt from the dietitian, who has limited time. The application helps you calculate your calories. [Focus group 2, male]

Awareness of the dietary app challenges

Most healthcare professionals and patients believed that, while these apps had the potential to be helpful, they might only have a small impact because they would not reach the people who needed them the most. This could be due to low motivation, lack of commitment, level of education, the fact that they are not free, or the lack of support in Arabic. Some professionals also reported that explaining dietary apps to patients requires extra effort, time, and attention.

> *I think that my patients come to the clinic to obtain free treatment, so it is difficult for me to advise them to use a mobile application that costs money.* [Family physician, male]

> *I do not have enough time. In the space of 10 to 14 minutes, I have to review the medication with the patient and understand their health condition and other things. So, I have no time to explain to them how to use the technology.* [Family physician, male]

Additionally, dietitians expressed concerns about dietary apps' effectiveness in changing dietary behaviours and the reliability of their content.

> [*I do not recommend the app to my patients*] *because I am quite concerned about the content and efficacy of these apps.* [Dietitian, female]

Some patients mentioned that the apps asked for information from them and that when they entered incorrect data, the patient plan was affected. Thus, the apps cannot be used without being monitored by dietitians.

> *The only defect is that the patient might enter the wrong information, in which case the application makes the plan according to this incorrect data, so the dietitian must still help.* [Focus group 2, female]

3) Comparison of Apps

Interactive Functionality

A detailed description of each feature, screenshots, and participants' opinions is provided in Appendix 17.

Sign-up process

Both apps – Noom and DASH To Ten – require completion of a registration process. DASH To Ten asks for preliminary information, including name, sex, height, and weight. In contrast, there are six registration steps with Noom, each of which includes several questions, including a demographic profile, weight-loss goal, behavioural profile, eating habits, health and fitness, and behavioural change, as well as a quiz. All the patients preferred signing up with DASH To Ten because it was easy. Most patients were unhappy with the Noom registration process because it took a long time (one hour on average). Despite this, they believed that the amount of information required by Noom was needed to understand users and that the app asked them logical questions to build a good plan.

> *DASH To Ten was easy and quick, and I immediately understood it; it took 10 minutes.* […] *It didn't ask me for any information about myself. The only problem was that it asked for weight and height in imperial units, and in Saudi Arabia, we use metric units! So, I had to convert them. This may be one of the obstacles with the DASH To Ten app, but the other features are excellent and fast.* [Focus group 1, female]

The dietitians and family physicians had different opinions regarding the user information and health history in the two apps. Most of the dietitians reported that they liked the Noom app because it uses the same type of assessment they employ in their clinics.

> *Noom is accurate; it asks almost the same details that we ask in our clinic, which is excellent for us, but possibly not for patients.* [Dietitian, female]

In the first session, four patients (two females and two males) faced a technical issue with Noom's registration and payment processes, which was resolved by deleting the app and downloading it again. The researcher also observed one participant asking the other patients in his group to explain some questions in the app.

Dietary self-monitoring, tracking and feedback

Both apps allow users to keep track of their daily food intake, but they differ in their approach. With Noom, patients can self-monitor their dietary intake by searching for food and drink in the application's database, which is comprehensive and includes a variety of different foods. For DASH To Ten users, calculating serving size is required to log dietary intake. Most patients reported that they preferred Noom because they selected their food from the app's database, which is more accurate and accessible. Healthcare professionals also liked Noom because it focuses on the type, not the quantity, of food and how patients cook.

> *In DASH To Ten, you don't know what the serving is. I don't have a background in nutrition, so I don't know how to calculate the serving and what the serving is.* [Focus group 1, male]

> *In my clinic, I care about the quality of the food more than the quantity, so I go with Noom.* [Dietitian, female]

Some patients liked calculating the serving sizes, though they admitted not knowing how to do so. They justified their choice by saying they did not have enough time to search in the database and that calorie counting is more complicated than calculating serving size.

> *If you are a busy and don't have time to search in the database, DASH To Ten is the best choice.* [Focus group 2, male]

Both apps use line charts to track weight-loss progress. For dietary intake feedback, DASH To Ten uses credits (points) to illustrate users' dietary intake. In contrast, Noom uses a colour system (orange, yellow, and green) to categorise foods based on their caloric density and to help users determine which ones are nutritious and which are not. In addition, Noom offers quizzes to its users and gives them feedback on their results. All the patients and healthcare professionals said that Noom's feedback was better than that of DASH To Ten because Noom provides users with information about their diets, instructions for improving healthy dietary behaviours, and reflections on their behaviours. Some patients noted that feedback could motivate them to change their behaviour.

It tells me that this food has these calories, which are unsuitable for me. It gives me feedback on the food I eat to avoid it; it's not just about food recording. [Focus group 2, female]

Blood pressure self-monitoring

Many healthcare professionals and patients consider the BP monitoring feature in the Noom app to be essential. Users can manually log their BP measurements in the app and receive feedback, making it a useful tool for monitoring their BP levels. However, many healthcare professionals did not explore it due to its unclear interface, while most patients did not use it because they lacked regular blood pressure monitoring or measuring devices.

Patients with chronic diseases can monitor their blood pressure and blood sugar using this app, but I couldn't find these features. [Family physician, female]

I didn't log the BP readings into the app because I do not have a BP monitoring device. [Focus group 1, male]

Push notifications

Noom pushes four daily notifications (breakfast, lunch, dinner, and reading articles), while DASH To Ten pushes only one daily notification to log food. Most patients and healthcare professionals liked Noom's notification feature as it motivated them to continue to use the app. One patient, however, had a different preference and preferred DASH To Ten, stating that downloading the app indicated a willingness to change behaviour, and they did not require multiple reminders.

Noom sends many notifications. I liked it when it sent [*a reminder to read*] *the articles. In addition to reminding you of logging meals and activities, it gives you something that encourages you to continue, while DASH To Ten reminds you only about meal logging.* [Focus group 1, female]

Goal setting

Both apps provide goal-setting features. Noom creates a practical action plan to avoid the underestimation/overestimation of abilities and determines the date for reaching the goal on this basis. Both the patients and the healthcare professionals liked Noom because it provides a realistic action plan and motivates users by reminding them of special events such as travel plans or social events.

For me, Noom [*is better*] *because it sets a specific goal; for example, a very important occasion for me. It constantly reminds me of the date of my friend's wedding and that I have to lose weight and take care of my food.* [Focus group 1, male]

Educational features

There are differences between the two apps in terms of the kind of information and the level of detail they provide. The participants had different opinions on whether the apps offer helpful, clear, and appropriate information. Most of them preferred Noom because it provides basic information on stress management, healthy eating, exercise, and sleep, as well as quizzes to help users remember what they have learnt. The app also offers guidance on altering behaviour and reminds users to read the articles. It even offers audio recordings for those who lack time to read.

The healthcare professionals liked Noom; however, they criticised it for focusing more on weight loss than the DASH diet or high blood pressure. They liked Noom for two reasons: its interactive nature and its breadth, which addresses a variety of elements, including social and mental factors.

DASH To Ten focuses on the DASH diet, but Noom emphasises general nutrition information. Noom is the one that considers all the factors, including psychological and social ones, as well as tracking and monitoring. The library is lovely. Noom is based on the concept of reinforcement, so it will conduct a review after you read something. The app is more interactive than DASH To Ten, and this interactivity made me access it more often daily. I want to access it. I mean, it's fun. [Family physician, male]

Some patients criticised the information feature in DASH To Ten, saying it was not clear. Many of them did not see it. One patient said,

Noom has articles and a listening feature and displays them daily, while the educational information in DASH To Ten was not clear. However, based on the pictures, I understood that we should eat fruit and vegetables. [Focus group 1, male]

Social communication

Only Noom enables users to share their weight-loss progress with their friends via social media platforms. Noom also allows users to chat with coaches in the app. Many of the patients and healthcare professionals liked this feature because it helped them contact coaches when they had questions about their diet or wanted to receive food exchange lists or advice on reducing sodium.

> *Exchanging experience between users is essential as it builds trust among the app's users.* [Family physician, male]

Visual design

Most patients liked DASH To Ten's simple language and design, which uses icons that help users understand the point without reading. In contrast, Noom uses scientific language, which forced some patients to translate terms and read about them in order to comprehend their meaning.

> *To be honest, DASH To Ten is a friendly app; I like its colours. Noom is more formal. DASH To Ten has icons, and even the options were easy. If you bring someone who cannot read and write, he can still use DASH To Ten*. [Focus group 1, female]

4) Overall app assessment

App preference

Most of the interviewed healthcare professionals and patients preferred Noom. They recommended this app for the following reasons: 1) it focuses on mental well-being to help people break bad behaviours by using a mindful eating approach; 2) it is comprehensive because it supports people's weight reduction, which will lower their blood pressure and blood sugar; 3) it is interactive because it offers reminders for activities and offers information through quizzes, as well as providing social support; 4) patients enter what they eat, which makes food logs easier, and the app also offers different units, such as grams and ounces; 5) it has a comprehensive food database, which helps patients select their food rather than calculate servings; 6) it helps patients to change their behaviour by sending feedback to them.

> *From my point of view, eating mindfully is the basis of the success of any diet plan. It's an essential element in any diet, so I chose Noom.* [Family physician, male]

Noom focuses on changing dietary behaviour, which I need. I know the information – for example, the effect of salt on blood pressure – but I do not have the commitment. [Focus group 1, female]

However, two family physicians and one dietitian preferred different apps based on the patient's age, level of education, and motivation. They would recommend Noom if the patient was younger, had self-efficacy and commitment, and liked reading. If the patient was elderly and less motivated, they would suggest DASH To Ten.

If the patient only needs to explain the DASH diet to increase awareness, I will select DASH To Ten. However, if they have self-efficacy, self-awareness, and mental readiness, and they have commitment and motivation, in that case, I will choose Noom. [Family physician, male]

Only one patient said she would choose DASH To Ten because she felt it was easier to use.

For me, DASH To Ten is straightforward, and everything in it is clear. You don't need to go deep, including the registration and information. So, I liked it more, and the app's simplicity encourages one to try it. [Focus group 1, female]

Recommendations

Most of the healthcare professionals and the patients thought that use of both apps requires some training. Some informants said that patients would need training depending on their age, education level, and background. The most common opinion was that one or two sessions to explore the apps' functions should be sufficient. One patient suggested that the apps could create short video tutorials, which could be shared among friends.

It depends on the person, their level of education and knowledge about technology, and how fast they are in understanding the app. Honestly, Noom was not easy or quick to learn. Exploring and understanding its functions requires an educational session. [Focus group 1, female]

The healthcare professionals and the patients offered suggestions for improving the functionality and content of the two apps. Some of these suggestions were common for both apps, including adding medication names, providing Arabic language versions, reducing the cost, and automatically calculating sodium and potassium intake.

> *They need to be in Arabic. The idea behind the two applications is great, but they need to be in Arabic to be easily accessible to the Arab population*. [Family physician, male]

Noom received specific suggestions, including adding articles and tips about high blood pressure and reducing the registration process. Meanwhile, DASH To Ten also received suggestions, including adding other metric units such as kilograms and meters, and monitoring blood pressure levels.

> *Noom should address the issue of the registration's complexity. To ensure continuity* [*of use*]*, it is very important that the patients find it simple*. [Family physician, male]

> [*DASH To Ten*] *should add a blood pressure monitoring function and the option to save the readings, so we can compare them.* [Focus group 1, male]

4.4 Discussion

4.4.1 Principal finding

This study aimed to explore patients' and healthcare professionals' experiences and perceptions of using two likely effective, high-quality, and secure DASH diet smartphone apps and to select which app is most appropriate in the Saudi context. Overall, participants agreed it was crucial to manage their hypertension through their diet. However, following the DASH diet can be challenging when combined with a lack of motivation and willpower, insufficient support from family members, and the high cost of healthy food. Although the use of simple smartphone apps, including those used to monitor BP, is increasingly common among patients, dietary apps need to be more user-friendly and accessible if they are to become more widely adopted. Participants highlighted interactive app functionality (e.g., a simple sign-up process), a comprehensive food database for dietary self-monitoring, individualised feedback, and the ability to set goals as the key features of nutritional apps. Overall, the participants thought the Noom app was more suitable than the DASH To Ten app for those in Saudi Arabia.

4.4.2 Comparison with prior research

The findings of this study have highlighted various hypertension self-management strategies and barriers when following a DASH diet. The main strategies identified in this study for managing hypertension include medication adherence, maintaining the DASH diet, salt restriction, and weight reduction. This is in line with usual care practices (Saudi Hypertension Management Society, 2018; Unger et al., 2020). However, patients and healthcare professionals also reported several barriers to following a DASH diet, including a lack of time to cook healthy food, the high cost of healthy food, food-related household responsibilities, including meal planning and cooking, the negative reaction from family members, and a lack of motivation and willpower. This finding aligns with the results of earlier qualitative studies, which have shown that these were essential barriers to DASH diet adherence among Black Americans with hypertension and chronic kidney disease (Bertoni et al., 2011; Tyson et al., 2023). Some patients acknowledged that although they had knowledge of healthy foods and the benefits of a nutritious diet, they struggled to change their behaviour and needed to implement additional strategies. Research has shown that interventions focusing solely on education have limited success, since knowledge about healthy eating does not necessarily translate into positive behaviour change (Samoggia & Riedel, 2020). These findings emphasise the need to identify effective strategies to help patients adopt healthy eating habits and follow the DASH diet.

Smartphone applications can be an effective source of information and can motivate users to change their dietary behaviour (DiFilippo et al., 2015). In the present study, many healthcare professionals reported that their patients use a simple smartphone app to monitor their blood pressure. This result aligns with a study by Alessa et al. (2021), which examined Saudi patients' and doctors' interest in using blood pressure self-monitoring apps. Nonetheless, due to language barriers and the potential difficulty of using nutritional apps, the healthcare professionals in this study emphasised that they would recommend dietary apps primarily to educated young adults with a high level of motivation. Based on a previous survey conducted in Saudi Arabia on weight-management apps, education and age were the main predictors of smartphone app use, since young adults are more familiar with mobile technology than older adults (Aljuraiban, 2019). In this study, healthcare professionals expressed their concerns regarding the app's content quality, usability, and cost. They also highlighted patients' willingness to use them and the time needed to review large amounts of data during time-constrained visits, all of which significantly decreased their willingness to recommend nutrition apps to their patients. Similarly, Lieffers et al. (2014) determined that factors such as content quality, usability, cost, and accessibility influence the use of apps by dieticians and how likely they are to recommend them to patients. This highlights the need for researchers to assess the content quality of commercial nutrition apps and their usability before suggesting that patients use them.

In this study, some patients reported that they did not use any dietary apps, due to a lack of dietetic monitoring by dietitians to review the apps' dietary plans, which is consistent with the results of a previous study, which revealed that overweight or obese respondents discontinued use of weight-management apps because of the absence of dietitian monitoring (Aljuraiban, 2019).

The participants explored the interactive features of both apps, which they found to be supportive in facilitating DASH diet self-management. Most patients and healthcare professionals preferred the registration process with DASH To Ten, because it was easier and quicker than the Noom app. This is supported by the findings of Alzahrani et al. (2022a), who concluded that signing up for a smartphone app should be a stress-free process, particularly when it is the user's first time interacting with the application. In addition, research has shown that health app developers should make apps more accessible and user-friendly for individuals with limited knowledge about health or mobile applications (Xie et al., 2018). In a systematic review conducted by König et al. (2021), it was emphasised that to improve an app's usability, the set-up process should be simple, long instructions should be avoided, and an easy-to-use interface should be used.

Self-monitoring is critical to improving clinical outcomes in patients living with chronic disease (Alzahrani et al., 2022a). Thus, many healthcare professionals recommend that patients with chronic diseases such as hypertension utilise health apps to monitor their physical activity and nutrition (Vasiloglou et al., 2020). Different dietary apps take different approaches to tracking users' food intake, such as calculating food portion sizes or having comprehensive food databases that include various types of food (Rusin et al., 2013). The Noom app was preferred by most patients and healthcare professionals in this study, because it has comprehensive food databases, making food tracking easier and more accurate. According to Vasiloglou et al. (2021), the ease of use of food databases was one of the primary criteria for selecting nutrition apps in an extensive web-based survey of European consumers. Studies have shown usability issues associated with tracking food intake may influence willingness to record food consumed (König et al., 2021; Ziesemer et al., 2020). Databases that contained errors and shortcomings, such as incorrect nutritional information, a failure to include local foods, or the omission of major foods, were less likely to be selected (Vasiloglou et al., 2021). The present study also found that patients were unfamiliar with the size of food servings, which may explain why some of them did not prefer the DASH To Ten app. To address this barrier, the most effective solution would be to simplify the input process by using common household items as a reference for portion sizes (König et al., 2021).

Providing timely and individualised feedback based on a person's performance and goals is crucial (Schembre et al., 2018). In our study, many patients confirmed that individualised feedback from Noom motivated them to use it. This is consistent with previous studies, which indicate that self-monitoring and personalised and detailed nutrition education and feedback features can be seen as encouraging factors for the continued use of nutrition apps (König et al, 2021; Lieffers et al, 2018)

Push notifications are a commonly used method for regularly engaging users' attention (Bidargaddi et al., 2018; Freyne et al., 2017). However, the timing, appearance, and frequency of these notifications need to be carefully considered (Bidargaddi et al., 2018). This study found that most patients preferred Noom notifications, as they were motivating. However, some patients found them annoying. This interesting result may be attributed to the phenomenon of task response times decreasing as the number of reminders increases (Freyne et al., 2017). In Pielot's study (2014), more notifications were associated with more negative emotions. Freyne et al. (2017) found that users tolerated receiving three daily diet app notifications, yet found low compliance with food recording. Consequently, further research on the frequency and timing of daily notifications is necessary to understand how compliance rates are impacted when using dietary apps.

Setting achievable goals is a promising method of facilitating behavioural change (van der Haar et al., 2023). In this study, most patients and healthcare professionals preferred the Noom app, as it provided achievable and realistic goals and action plans. This finding aligns with another study that found health professionals should set specific goals combined with a solid action plan to avoid unrealistic or unachievable fitness and dietary goals (Bossen et al., 2022). It is essential to address the setting of goals and action plans at the beginning of the intervention, as well as at different points throughout the intervention period (Bossen et al., 2022). In this study, users' goals were linked to significant events in the Noom app, which provided them with encouragement to continue to achieve their goals. In short, the key to maintaining sustained engagement with mHealth and well-being apps is to develop a sound action plan that identifies when, where, and how to complete specific tasks (Bossen et al., 2022). Moreover, setting clear goals and gradually increasing the frequency of specific behaviours can enhance success rates (Bossen et al., 2022; van der Haar et al., 2023). Success in performing these tasks can foster self-efficacy, which is closely related to healthy behaviour (Bossen et al., 2022).

Other interactive functions worthy of discussion are educational functions and social support. Most patients also preferred the Noom app because it provided a variety of methods for improving their knowledge of nutrition. These methods included quizzes, rewards, and automatic feedback, which patients confirmed motivated them to use the Noom app. This finding aligns with those of other studies. For example, in one study, it was found that quizzes that reward users with points rather than just providing information can be used to motivate digital behaviour change interventions (Rohde et al., 2019).

Coaches can facilitate support through a variety of online platforms with dedicated communities. The Noom app offers coaching support to improve users' knowledge of nutrition and also supports their communication with friends. This is vital, as evidence suggests that social support from friends, family, and peers is crucial for weight loss and physical activity (Alzahrani et al., 2022a; Bossen et al., 2022). The positive impact of such support can result in fewer unhealthy habits and improved adherence to treatment (Bossen et al., 2022). Combining mobile apps with in-person interactions, such as coaching sessions, interventionist feedback, and web-based chats with professionals, resulted in significantly greater weight loss than using mobile apps alone, according to a recent systematic review and meta-analysis (Antoun et al., 2022). In the present study, several patients emphasised the benefits of human coaches, who they felt might help them to change their dietary behaviour.

In terms of graphic design, the DASH To Ten app was popular among patients due to its simple interface and appealing design. This is significant: users generally prefer quick and simple apps which increase their awareness of their eating habits (Coughlin et al., 2015; Nour et al., 2018).

Many participants expressed interest in using the Noom and DASH To Ten apps but encountered various barriers, one of which was technical issues. Some patients in this study found it difficult to register and pay on Noom, which could have led to disengagement. These findings are supported by other studies that explain that technical problems can prevent users from adopting and utilising apps (Alzahrani et al., 2022b; König et al., 2021).

In the current study, both patients and healthcare professionals reported that a language barrier impeded their access to nutrition apps. Currently, these apps are only offered in English, which limits a large audience from accessing them in Saudi Arabia. To make these apps more widely available, participants highly recommended that they be translated into Arabic, a commonly spoken language in the Middle East. This recommendation aligns with the findings of Aljuraiban (2019), who established that the main reasons preventing Saudi women from using weight-management apps were language barriers, a lack of motivation, and difficulty using them. Barriers for non-English speakers can be minimised by designing apps in languages other than English (Lyzwinski et al., 2018). Both apps offered Western dietary plans or recipes, which can affect Arabs' readiness to use these apps, as they present unfamiliar dishes. Indeed, the results of the current study indicate that patients were hesitant to adopt a Western diet long-term. According to Kaur et al. (2022), diet and health messages tailored to culture, language, and race are more effective in addressing individuals' needs. Furthermore, culturally appropriate diets can help reduce the burden of preventable diseases by being easily integrated into the daily diet instead of employing a one-size-fits-all approach (Kaur et al., 2022). Moving forward, the development of culturally tailored behavioural apps will help encourage and promote sustained dietary change among individuals and groups from diverse cultures and regions.

Healthcare professionals and patients alike perceive financial cost as a major barrier when using nutrition apps. This finding aligns with a survey conducted among 2,382 European participants, in which 59.3% of respondents reported that whether a nutrition app was low cost or not was a critical factor in choosing it (Vasiloglou et al., 2021). Developers of nutrition apps should strive to provide affordable as well as user-friendly apps.

In this study, when healthcare professionals and patients explored the barriers and benefits of the two apps, the Noom app was identified as being suitable for people with high blood pressure. This is because it is a comprehensive app that helps users lose weight and, consequently, should assist in controlling their blood pressure. This reason was supported by several studies that have found that using the Noom app significantly reduces body weight, although no significant improvement in systolic blood pressure was observed after using the app in these studies (Cho et al., 2020; Ju et al., 2022). According to a recent systematic review and meta-analysis of thirty-five studies involving 3219 patients, it has been found that losing weight can significantly reduce blood pressure levels (Yang et al., 2023). These findings highlight the importance of weight management in managing blood pressure levels, which can significantly reduce the risk of cardiovascular diseases.

Mindfulness is a critical component of the Noom app, specifically regarding eating habits. Being mindful of one’s food choices involves understanding the difference between physical and emotional hunger, as well as fullness signals, and making healthy choices based on these signals (Warren et al., 2017). Mindfulness can help address unhealthy eating behaviours and difficulties with controlling food intake (Warren et al., 2017). For this reason, Noom was selected as the most suitable app by the healthcare professionals in this study. It is an interactive app offering motivational information that helps users to change their behaviour. For example, users receive helpful motivation feedback to achieve their weight-loss goals before important events (e.g. weddings). Van der Haar et al. (2023) confirmed that nutrition apps that provide new information and facts maintain user interest and engagement over a longer period of time.

In contrast, DASH To Ten was identified by some healthcare professionals and patients as a suitable app for older people and patients who often lack the motivation to use such apps. DASH To Ten's high level of usability may have made it a key facilitator in gaining acceptance among this target group. According to a recent qualitative study investigating mobile nutrition and fitness tool acceptance among German adults aged 50 and older, many apps were rejected due to their complex and time-consuming handling, as it was recognised that a high level of usability was a key facilitator contributing to a higher level of acceptance within the target group (Vietzke et al., 2023). Furthermore, some healthcare professionals identified DASH To Ten as an ideal information resource for increasing patients' knowledge of the DASH diet rather than a tool for changing dietary behaviour. This finding aligns with a previous study that found that most dietitians use health apps primarily as information resources in patient care within their practice (Chen et al., 2017). Further research is needed to investigate the extent to which older and less motivated Saudi patients are willing to embrace smartphone nutrition apps, and to identify the factors that facilitate or impede their acceptance.

Although both apps have user-friendly features, the healthcare professionals and patients in this study suggested providing training sessions and brief, precise video tutorials when setting up the app for users, to ensure that they understand the app's functions before using it. This is in alignment with other studies on dietary self-monitoring, which have shown that education and training sessions are necessary to understand how to use apps and calculate food portion sizes (Hales et al., 2016; Pellegrini et al., 2018). In another study, Australian, New Zealand, and British dietitians identified training, education and advocacy as factors for integrating health apps into dietetic practice (Chen et al., 2017). However, it is unclear how long these training sessions should be. Further research is needed to determine the optimal training session duration.

Moreover, most healthcare professionals have recommended that both apps include automatic sodium and potassium consumption calculations. Previous studies investigated the effectiveness of smartphone apps in monitoring and managing dietary sodium intake. The findings indicated that these apps accurately measure sodium consumption and demonstrated a positive association between app-recorded intake and 24-hour urine sodium levels (Jung et al., 2023; Kim & Chung, 2020).

4.4.3 Strengths and limitations

The main strength of this study lies in the fact that participants had sufficient time to become familiar with the apps. The professionals and patients involved evaluated each app's features thoroughly, compared them side-by-side, and then provided feedback. An observational technique was also employed to track participants' responses to the apps in real time. This approach yielded detailed data on specific usage problems and challenges. The interviews and focus groups provided insight into participants' personal needs, experiences, and perceptions of dietary and nutrition apps for high blood pressure patients in Saudi Arabia. In addition, the study interviewed a diverse group of professionals, with varying degrees of mHealth experience and differences in age, gender, and occupation. This provided a comprehensive understanding of their health-related perspectives, particularly with regard to nutrition and dietary applications. The use of a flexible framework analysis method, combining both inductive and deductive approaches, proved suitable for analysing the data and answering specific research questions. Finally, the study provides recommendations for nutrition app developers. It emphasises the need for further experimental research to evaluate the impact of certain interactive features, such as self-monitoring, feedback, goal setting, and reminders, in changing dietary behaviours.

This study has several limitations. Firstly, the results may not be generalisable. The sample was self-selected, meaning participants who were more interested and could use and compare two dietary apps were more likely to volunteer, which could have affected the findings. The study also focused on iPhone users, since the DASH To Ten app is only available in the Apple Store. This excluded many volunteers who owned Android phones. Furthermore, the study included a relatively small number of older participants. This may limit the generalisability of the findings, particularly since hypertension is more common among older people. Both apps only accept overweight or obese users, which resulted in many volunteers with ideal weights being excluded from the study, and this too may have affected the study's results. None of the identified apps were available in Arabic, meaning most participants had to be educated. The language barriers excluded certain groups from the study, which may also have affected the results. This is because studies have reported that mHealth systems that consider the end-users and the local context (e.g., language) are more likely to succeed and be accepted by their users (Aboye et al., 2024; Gong et al., 2019; Koumpouros, 2022). The study also had a small sample size; however, it was sufficient to explore the apps' functions and select the most appropriate app for patients with high blood pressure.

4.5 Conclusion

Through semi-structured interviews and focus groups, this study has gained insight into the experiences of individuals who use two likely effective, high-quality, and secure DASH diet self-management applications. Both patients and healthcare professionals in Saudi Arabia found the Noom app to be the most suitable option, as it encourages perseverance in dietary self-monitoring, increases motivation by setting realistic goals, and provides informative reminders, all of which result in better hypertension management. Mindfulness is one of the most critical components of the Noom app, particularly regarding eating habits. The app encourages users to be more mindful and aware of their food choices, and offers interactive features to help motivate and support positive behavioural change, and this was welcomed by participants. This study also sheds light on the challenges and needs of individuals with high blood pressure. Policymakers, practitioners, and app developers can use these findings to design, develop, and deploy nutrition apps and app-supported interventions that will help those with high blood pressure manage their diets. Further research is needed to determine the feasibility and acceptability of long-term use of the Noom app with a population in Saudi Arabia. The upcoming chapter will present the feasibility and acceptability of the Noom app with a Saudi Arabian population, the last study of the second phase of this research.

4.6 References

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Chapter 5 │ An investigation of the feasibility and acceptability of using a commercial DASH diet app in Saudi Arabia in people with high blood pressure: a mixed methods study

This is the last study in the second phase. The previous chapter selected the Noom app as the most suitable app for the Saudi context. The current chapter focuses on determining the feasibility and acceptability of using the Noom app to support DASH diet self-management among individuals with high blood pressure in Saudi Arabia. A mixed-methods approach was adopted, integrating quantitative and qualitative findings to comprehensively understand the app's feasibility and acceptability. This chapter is presented in a published format and has been accepted for publication at JMIR Formative Research.

Abstract

Background: The use of smartphone apps for dietary self-management among patients with high blood pressure is becoming increasingly common. Few commercially available Dietary Approaches to Stop Hypertension (DASH) diet apps have the potential to be effective, and only a few of these have adequate security and privacy measures. In previous studies, we identified two high-quality apps that are likely to be effective and safe. One of these, the Noom app, was selected as the most suitable app for use in the Saudi Arabian context based on healthcare professionals' and patients' preferences.

Objectives: This study aimed to determine the feasibility and acceptability of using the Noom app to support DASH diet self-management among people with high blood pressure in Saudi Arabia.

Methods: This study used mixed methods to evaluate the feasibility and acceptability of using the Noom app for people with high blood pressure in Riyadh, Saudi Arabia. Fourteen participants with high blood pressure were recruited and asked to use the app for eight weeks. The quantitative outcome measures were DASH diet adherence and self-efficacy. Feasibility and acceptability were assessed during and after the intervention via a user engagement with the Noom diet-tracking questionnaire, the system usability scale, and semi-structured interviews.

Results: Most participants logged their meals for three to five days a week; snacks were the most commonly forgotten eating occasion to be recorded. The interviews revealed four main themes: (1) acceptance, (2) app usability, (3) technical issues, and (4) suggestions for improvement. Most participants found the Noom acceptable, and most had no difficulties integrating it into their daily routines. The results of this feasibility study provided insights into the app's educational content, some of which was deemed unsuitable for Saudi Arabian users. App usability was identified as a critical theme: the app and its database were easy to use, convenient, and valuable to most participants. Despite this, some participants reported difficulties in identifying some foods because of a lack of local options. Technical issues included the app freezing or responding slowly. Most participants also suggested translating the app into Arabic and simplifying the method of logging food in the app. The participants showed some improvement in self-efficacy and adherence to the DASH diet, although these increases were not statistically significant. The self-efficacy score increased from (mean+/-SD) 18 ± 4.7 to 20 ± 6.3, and the DASH diet score increased from 3.4 ± 1.4 to 4.3 ± 1.1.

Conclusions: The use of the app was feasible and acceptable among the participants who completed the study. Further studies are needed to examine the potential for smartphone apps to improve adherence to the DASH diet among people with high blood pressure in Saudi Arabia and to evaluate their effects on the blood pressure levels of individuals with hypertension.

Keywords: Hypertension; blood pressure; DASH Diet; Dietary Approaches to Stop Hypertension; self-efficacy; mHealth; Saudi Arabia.

5.1 Introduction

High blood pressure (hypertension) is the most preventable cause of cardiovascular disease (CVD) and all-cause mortality around the globe (Mills et al., 2020), affecting 1.28 billion people worldwide (World Health Organization, 2023). Lifestyle risk factors for hypertension include unhealthy diets, tobacco use, and a lack of physical activity (World Health Organization, 2023). Hypertension is a significant public health concern in Saudi Arabia and contributes significantly to mortality rates (Al-Kadi, 2022; Alshammari et al., 2023). The Saudi Ministry of Health reported in 2023 that two out of five Middle Eastern adults suffer from hypertension (Saudi Ministry of Health, 2023b). A recent systematic review and meta-analysis evaluating the prevalence and awareness of hypertension in Saudi Arabia revealed that 23% of Saudi adults have hypertension but that less than half of them (42.8%) were aware of their condition and, as a result, did not seek treatment (Alshammari et al., 2023). Undiagnosed, untreated, or uncontrolled hypertension can lead to severe health consequences, such as heart failure, coronary heart disease, and renal failure (World Health Organization, 2023). These diseases burden the healthcare system, and mortality rates related to hypertension-induced CVD are expected to rise (Bromfield & Muntner, 2013).

The Dietary Approaches to Stop Hypertension (DASH) diet is an effective blood pressure-lowering plan (Chiavaroli et al., 2019; Epstein et al., 2012; Sacks et al., 2001). The DASH diet encourages the consumption of fruit, vegetables, whole grains, nuts, lean meat, fish, dairy, and limited consumption of sodium, saturated fat, sugar-sweetened beverages and sweets (Appel et al., 1997; Steinberg et al., 2017). A low consumption of fruits and vegetables and high consumption of fast foods containing saturated fats, high energy density, and sodium has been associated with obesity and elevated blood pressure in adults and children in Saudi Arabia (Alshaikh et al., 2018; Amer et al., 2022; Elbashir et al., 2020). These data show that addressing Saudis' dietary habits may help to reduce a significant risk factor for prevalent CVD and hypertension in the Saudi population (Al Khathaami et al., 2019; Alkhunaizi et al., 2013; Alshaikh et al., 2018; Amer et al., 2022; Elbashir et al., 2020; Saeedi et al., 2017).

Adherence to the multiple components of the DASH diet plan can be difficult (Rodriguez et al., 2019). Self-efficacy is one of the core concepts of social cognitive theory and describes people's confidence in their ability to engage in specific behaviours or achieve desired outcomes (Zhao et al., 2021). Increasing self-efficacy for healthy eating has been associated with positive behaviours, including increased fruit and vegetable consumption (Bracken &

Waite, 2020). Self-monitoring is a technique for raising awareness of an individual's behaviour through recording details about the behaviour performed (Bandura, 2004; Bracken & Waite, 2020). By receiving feedback on self-monitoring behaviours, such as calories consumed daily, one may be able to change their behaviour (e.g., reducing caloric intake) to achieve desired results.

Mobile phone apps have been shown to improve nutritional habits and medical care (Samoggia & Riedel, 2020). Using apps to improve diet and nutrition can be a valuable and low-cost intervention strategy (Samoggia & Riedel, 2020). Dietary smartphone apps can estimate changes in eating behaviour (e.g., self-reported food intake, energy, micro and macronutrient, fruit, and vegetable intake) and outcomes (e.g., body weight, blood pressure, blood glucose levels, physical activity, and quality of life) (Samoggia & Riedel, 2020).

As part of the 2030 vision of Saudi Arabia, there is a push to leverage mobile health applications in the healthcare sector to enhance patient care (Abu-Elenin et al., 2023). The Saudi Ministry of Health has introduced multiple mobile applications, such as the Sehhaty app, to streamline user administrative procedures (Young et al., 2021). This app provides convenient access to medical consultations, enables users to update their medication information, and allows for monitoring vital health indicators such as blood pressure, body mass index, waist circumference, and blood glucose levels (Alkhalifah et al., 2022). According to Alrowaily et al. (2024), primary healthcare doctors are taking a leading role in the adoption of telehealth, as they increasingly utilise the Sehhaty mobile application, thereby influencing the general population's acceptance of this technology. Additionally, several studies reported that Saudi users accept app-based interventions, and diet-tracking apps are convenient and more accessible than other tracking methods (Aljuraiban, 2019; Alnasser et al., 2019; Zaman et al., 2021).

A systematic review assessing the effectiveness of smartphone apps to support DASH diet self-management found weak emerging evidence of a positive effect of apps in enhancing dietary self-management (Alnooh et al., 2022). A recent systematic search of commercial app stores and content analysis of DASH diet apps found that only a limited number of high-quality apps support DASH diet self-management, and only 2 apps (Noom and DASH To Ten) were deemed to be high-quality, potentially effective and to offer adequate security and privacy protection (Alnooh et al., 2023). A subsequent study (unpublished), conducted in Saudi Arabia, explored family physicians', dietitians', and patients' perceptions of the two apps, confirming the apps' potential effectiveness, high quality, and good security and privacy measures. When the participants were asked to select their preferred app, the Noom app was considered the most suitable. Healthcare professionals and patients widely accepted Noom because it has interactive functions, a comprehensive food database that helps patients track their food, and mindful eating strategies.

Noom's smartphone app promotes healthy behaviour change (Earl et al., 2024; Mitchell et al., 2021). This app includes features aligned with social cognitive theory, such as setting manageable goals, monitoring daily progress, receiving feedback, participating in social support, and problem-solving (Alnooh et al., 2023; Kim et al., 2017; Mitchell et al., 2021; Sysko et al., 2022). A broad range of behavioural strategies are included in the Noom programme, such as promoting a healthy lifestyle, and suggesting food (Sysko et al., 2022). Furthermore, published evidence from a study conducted in the US supports the usability and effectiveness of the Noom app to reduce weight and high blood pressure (Toro-Ramos et al., 2017). However, it is important to note that the study had a small sample size and only focused on individuals aged 40-50 years.

Before evaluating the effectiveness of an app in a new setting, it is critical to examine its feasibility and acceptability among end users and their willingness to use it (Bowen et al., 2009; Inal et al., 2020). This step is essential because systems that are difficult to use may yield low goal-achievement efficiency or result in users neglecting or rejecting the technology (Inal et al., 2020). Considering the chosen context of this study, the research will investigate the feasibility and acceptability of the adopted Noom app to ensure that it is well-suited to a new context, specifically for people with high blood pressure in Saudi Arabia.

Study Aim

This study aimed to determine the feasibility and acceptability of using the Noom app to support DASH diet self-management among people with high blood pressure in Saudi Arabia.

Objectives

To determine the use of the app, adherence to the DASH diet and self-efficacy and to investigate the patient experience and satisfaction with the app (including ease of use, technical and problems encountered).

Research Questions

RQ: Is it feasible and acceptable to use the Noom app to encourage people with high blood pressure to improve their dietary habits?

5.2 Methods

5.2.1 Research Design

In this study, a one-group pre-post-trial design was adopted to investigate the feasibility of an eight-week intervention to determine whether patients with high blood pressure living in Saudi Arabia can use the Noom app to manage their diets. A mixed methods approach was employed. The adherence to the DASH diet and self-efficacy were evaluated using objective quantitative measures, while both quantitative and qualitative methods were employed to assess patient satisfaction with the Noom app. The CONSORT guidelines for feasibility trials were followed to report this study (Eldridge et al., 2016)(Appendix 18).

5.2.2 Study setting

All participants were enrolled and followed remotely for eight weeks.

5.2.3 Participants

Patients with high blood pressure attending outpatient clinics at the King Abdullah bin Abdulaziz University Hospital in Riyadh, Saudi Arabia, who had participated in an earlier qualitative study (unpublished) and who had agreed to be contacted for future research were sent an electronic message through social media (WhatsApp) inviting them to take part in this study. The earlier study received approval from the School of Health and Related Research of the University of Sheffield, Princess Nourah bint Abdulrahman University and King Abdullah bin Abdulaziz University Hospital (reference # 049904, #22-0490 # 22-0054, respectively). The clinical team (nurses) and primary researchers identified eligible patients for the earlier study during regular clinic appointments. The inclusion criteria were as follows: (1) Individuals with systolic blood pressure range from 130 mmHg to 159 mmHg and diastolic blood pressure range from 85 mmHg to 99 mmHg (Saudi Ministry of Health, 2023a), (2) aged 18 years or older, (3) with a body mass index of 25 or above, (4) who were willing to read in the English language since the Noom app is not in Arabic, and (5) who owned a smartphone and were willing to receive monthly text messages. Individuals who (1) have a systolic blood pressure of 160 mm Hg or higher and diastolic blood pressure of 100 mm Hg or higher (Saudi Ministry of Health, 2023a), (2) have CVD, (3) have a history of renal diseases, or (4) were pregnant or planning to become pregnant while the study was ongoing were excluded from the study. Twelve participants were considered an adequate sample size for feasibility study (Julious, 2005). The purpose of this study was not to detect effects using inferential statistical tests, so power calculations were not performed (Leon et al., 2011).

5.2.4 Study Procedure

Figure 5-1 summarises the study procedure. The eligible individuals were asked to review and sign a consent form sent via email. They then completed a self-reported demographic survey, a self-efficacy questionnaire, and a 3-day food record. Subsequently, in the first online orientation session, they were instructed to download and purchase the app. Each participant received the equivalent of £112 to cover the cost of this. The DASH diet and various app functions and features were reviewed with them, and the participants were asked to use the app daily for 8 weeks and to use it to enter all the food and beverages they consumed. After four weeks, participants were sent an email asking them to complete the engagement with the Noom diet-tracking questionnaire. At the end of the intervention, all the participants received an email asking them to complete questionnaires, including those on Noom diet-tracking engagement, self-efficacy, a 3-day food record, and the System Usability Scale (SUS). Finally, the researcher conducted qualitative, online semi-structured one-to-one interviews with the participants to gain insights into their experiences and the acceptability of using the app. The interviews also investigated the perceived impact of the app on DASH diet adherence and identified any technical problems encountered in using the app.

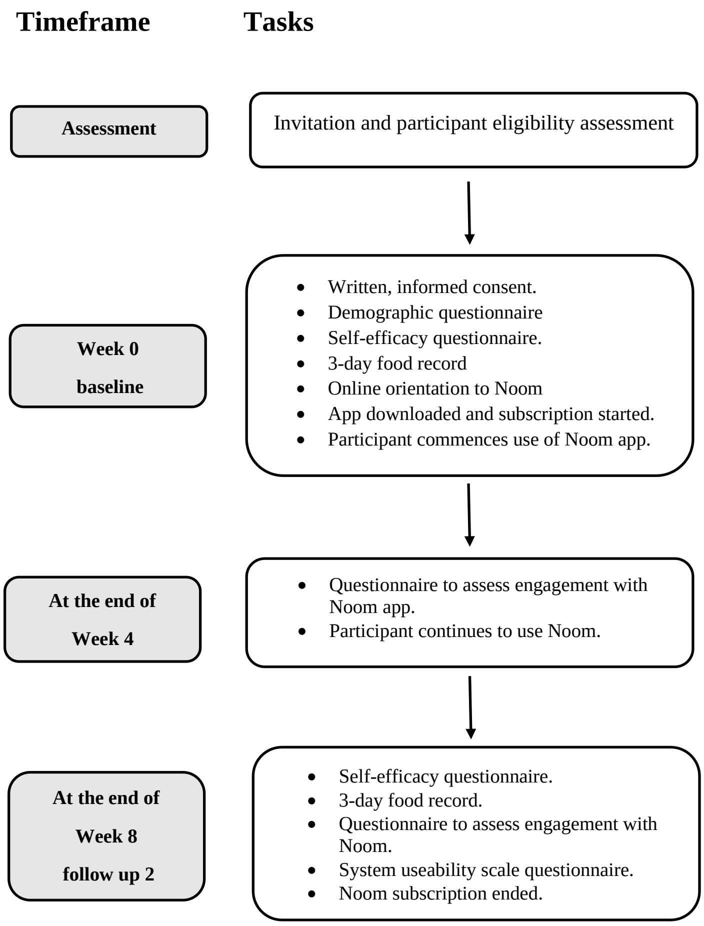

Figure 5-1: An overview of the timeframe of the study and the tasks involved in the study protocol.

5.2.5 Description of The Noom App

The app has the following features: 1) a tool to track dietary intake using comprehensive food databases and an intelligent recognition system to identify food barcodes, the Noom app created its food database, and it uses reliable government sources, such as the USDA's food database, or directly consults the nutrition labels of packaged foods to provide its users with the most accurate information (Noom, 2024,); 2) a daily log to record blood pressure, weight, blood sugar, and exercise can be recorded manually or automatically by syncing with Fitbit; 3) feedback on the diet and activities recorded; 4) a daily reminder to log their diet and other activities, such as physical activity, and reading daily articles; 5) Social communication: participants can communicate with others to share their experience. They can also communicate with a human coach via in-app messages. Furthermore, the app offers comprehensive content written by nutritionists, physicians, and psychologists to assist its users in achieving and maintaining a healthy lifestyle. With a focus on developing healthy eating habits, increasing physical activity, and building skills for overcoming obstacles, the courses cover various topics, including calorie balance, staying active, overcoming unhealthy behaviours, and seeking support from family and friends. Additionally, the app emphasises the importance of regular eating, getting enough sleep, and managing stress. All this content is delivered in short, easy-to-understand segments daily to help users achieve their goals.

5.2.6 Measures

5.2.6.1 Baseline assessment

This study measured various demographic variables. Standard survey questions used in the previous study were used to collect demographic measures at baseline (Aljuraiban, 2019). This included age, sex, marital status, educational achievement, and whether they had ever used a dietary smartphone app outside of the research. Participants were asked to self-report their height and weight, from which body mass index (BMI) was calculated using the formula: weight (kg) / $[\text{height (m)}]^2$ (NHS, 2023).

5.2.6.2 Quantitative outcomes

The quantitative outcomes of this study were DASH diet adherence and participants' self-efficacy, which were assessed at baseline and at the end of the intervention. To evaluate the change in DASH diet adherence, macro- and micronutrient intakes were assessed using a 3-day food record pre-and post-intervention (Appendix 19). Nutritics dietary analysis software (version 5.95, Dublin, Ireland) was used to analyse reported intake to determine the changes in adherence to the DASH diet (Nutritics, 2022). Participants were asked via email to complete a 3-day food record before week one and the end of week 8. We calculated a nutrition-based DASH index score, similar to Mellen et al.'s DASH index score (Mellen et al., 2008). The score for DASH diet adherence was computed based on nine target nutrients: total fat, saturated fat, protein, fiber, magnesium, calcium, sodium, potassium, and cholesterol. A value of 1 was given to participants who met the DASH target for a nutrient, 0.5 if they met the intermediate target, and 0 if neither target was met. Thus, the range of scores is 0 to 9, with higher scores indicating greater adherence, while a score of 9 means full adherence (Steinberg et al., 2020).

To measure DASH diet self-efficacy, this study adopted Zhao's six-item diet self-efficacy scale (Zhao et al., 2021). Participants rated each item on a 5-point Likert scale ranging from 1=not confident at all to 5=completely confident. Total scores for the scale range from 6 to 30, with a higher score indicating greater self-efficacy.

Feasibility and Acceptability

Feasibility was indicated by adherence to the DASH diet and engagement with Noom app. Acceptability was indicated by assessing participants' satisfaction and their perception of the app's usability, measured by the System Usability Scale (SUS).

This study could not automatically track user engagement, so it assessed it by asking participants to respond to the Noom diet tracking questionnaire comprised of five questions about frequency, timing, days of logging, and missing meals. These questions were adapted from previous studies that evaluated engagement with dietary smartphone apps (Garcia et al., 2022; Langlet et al., 2020).

Participants completed the SUS for usability testing of the app (Bangor et al, 2009). For about 30 years, the SUS has been frequently used to measure usability in commercial and research projects (including mobile apps) (Tong et al., 2019). The participants were asked to rank the statements on a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). A final score ranging from 0–100 is yielded with the SUS, with higher values indicating better usability. Acceptability ranges classify a product's SUS score to determine whether it has an ‘acceptable’ SUS score or needs more attention and continuous improvement. For example, a score of not acceptable (0–50), a score of low/high marginal (51–69), and a score of acceptable (70 and above) (Bangor et al., 2008).

5.2.6.3 Qualitative Measures:

Semi-Structured Interviews

Feasibility and Acceptability were also evaluated using one-to-one semi-structured online interviews using Google Meet. The interview guide was developed based on previous studies (Bentley et al., 2020; Meinert et al., 2020) and was informed by social cognitive theory (Bandura, 2004). It included detailed questions about participants' experiences with the Noom app for dietary self-management, as well as questions about the benefits and barriers they encountered when using the app. The interview explored factors influencing app engagement, such as self-monitoring, feedback, goal setting and motivational strategy. The interview guide was thoroughly tested with a single volunteer to guarantee clarity for the participants*;* the interview guide can be found in Appendix 20. The interviews were conducted online as online meetings provide greater flexibility and allow participants to schedule the meeting around their busy schedules and personal commitments, as opposed to traditional methods (Irani, 2019). To minimise bias, the interviewer clarified to the participants that they could express their views freely without pressure during the online interview. In addition, audio recordings and concurrent notes were taken during the interview, which lasted approximately 25 minutes; the minimum duration was 20 minutes, and the maximum duration was 35 minutes.

5.2.7 Data Analysis

5.2.7.1 Quantitative Evaluation

SPSS version 26 (SPSS Inc., Chicago, IL, USA) was used for all the statistical analyses. Descriptive statistics were used to describe all variables; frequency and mean with standard deviation were reported.

5.2.7.2 Qualitative Analysis

Participant interviews were digitally recorded, transcribed verbatim in their language (Arabic), and coded using the MAXQDA (version 12, VERBI GmbH, Berlin, Germany) qualitative analysis software (Rädiker, 2020). Despite the participants being able to read and write in English, the interviews were in Arabic because people feel more confident speaking their first language. A thematic framework analysis was performed to identify the key themes within the data (Gale et al., 2013; Ritchie et al., 2013). The thematic framework was developed through a combination of inductive and deductive approaches. A framework analysis was selected for its effectiveness as a tool for qualitative content analysis. This method provides a systematic approach to organising and mapping data (Gale et al., 2013). It is valuable for analysing interview data, comparing themes within and between cases, and managing large datasets by offering a structured data summary (Gale et al., 2013). Inductive methods involved identifying and categorising emerging ideas into preliminary themes, while deductive methods mapped these themes based on the social cognitive theory (Bandura, 2004). Two researchers, GA and JA, independently analysed and explored the transcript data, taking notes on pre-existing and emerging themes. These notes were used to create a coding framework applied to the transcript data within MAXQDA. The data within each theme were then thoroughly examined and summarised, including differences between participants, to create summaries of each theme and identify similarities and differences between themes. Following discussions with EW and MH regarding the final analysis stage results, GA implemented some adjustments based on these discussions. In this study, quantitative and qualitative data were analysed separately (O'Cathain et al., 2010). In the final interpretation of the results, the quantitative data complemented the qualitative data (Creswell & Creswell, 2017; O'Cathain et al., 2010). For example, in the case of missing data, interviews may show why one point of measurement has more missing data than another. The study used an integration matrix to compare data obtained from different methods. The integration matrix can be found in Appendix 21.

5.2.8 Ethical Considerations

This study received approval from the University of Sheffield's ethics committee (reference #053461) and Princess Nourah Bint Abdul Rahman University (reference #23-0453) (Appendix 22). The study details were communicated to participants through information sheets sent to all eligible individuals by email (participants' emails were obtained from the previous study). A researcher (GA) contacted eligible participants to provide additional information about the study (e.g., study protocol and duration) and obtain electronic informed consent. The study data was anonymised, de-identified, and stored securely in a password-protected file in a secure filestore. No compensation was provided to participants.

5.3 Results

5.3.1 Recruitment and Retention Rate

Fourteen individuals with high blood pressure took part in the feasibility study. Their average age was 43 years, ranging between 35 and 65. Of the group, 57% were male, and 71% held a bachelor’s degree. Most participants had systolic blood pressure between 140 mmHg and 159 mmHg and diastolic blood pressure between 90 mmHg and 99 mmHg. The demographics of the participants are illustrated in Table 5-1.

All 14 participants completed the baseline questionnaire. Two participants withdrew during the trial: one in week two and one in week 5. Both participants voluntarily reported that their reasons for withdrawal were that they found the research too burdensome, especially the required dietary log. Nine of the remaining 12 participants completed all of the data collection points.

Table 5-1: Baseline demographic characteristics of participants (n=14) with high blood pressure recruited to the study.

Characteristic	
Age (Years), mean (Range)	**43 (35–65)**
Sex, n (%)	
Male	**8 (57)**
Female	**6 (43)**
Marital status, n (%)	
Single	**2(14)**
Married	**12 (86)**
Education, n (%)	
High school diploma	**1 (7)**
Bachelor's degree	**10 (71)**
Master's degree and above	**3 (21)**
BMI (kg/m2), mean (SD)	**30.7 (5.54)**
participants with BMI 25-30 kg/m^2, n (%)	**6 (43)**
participants with BMI 30-39.9 kg/m^2, n (%)	**8 (57)**
Participants with blood pressure readings from 130/85 mmHg to 139/89 mmHg, n (%)	**5 (36)**
Participants with blood pressure readings from 140/90 mmHg to 159/99 mmHg, n (%)	**9 (64)**
Blood pressure medications self-reported, n (%)	**9 (64)**
Users of nutrition smartphone apps, n (%)	**2 (14)**

n: number of participants with high blood pressure in Saudi Arabia

BMI: Body Mass Index

kg/m^2: kilogram body mass/ height in metres square

mmHg: millimetres of mercury

5.3.1 Engagement with the Noom App

Table 5-2 summarises the participants' engagement during weeks 4 and 8. All participants logged their food using the app. Most participants (62%) logged their food 3–5 days a week, with the frequency of food logging increasing with longer periods spent using the app. The meal record of each user was used to measure their engagement with the app over the two months. During the first month, one participant spent 31–45 minutes per day on the app, six participants spent 16–30 minutes per day on the app, and six others spent 1–15 minutes per day. In the following month, one participant spent roughly 30 minutes, while most users' sessions decreased to 1–15 minutes. Throughout the two months, most participants logged their meals at the end of the day, with snacks being the most frequently forgotten foods recorded.

Table 5-2: Self-reported frequency of engagement and food logging with the Noom App assessed at follow-up appointments in week 4 and week 8 using a questionnaire.

Engagement measure	Weeks 1-4 (n = 13)	Weeks 5-8 (n =12)
Number of days food was logged on the Noom app		
7 days a week	3	5
3–5 days a week	8	6
One day	2	1
App use, no. minutes per day		
31–45 min	1	0
16–30 min	6	1
1–15 min	6	11
Daily meal recorded, no.		
One meal	1	1
Most meals	9	6
All meals	3	5
Time of day for food logging		
At the end of the day	9	6
Meal by meal	4	6
Missing meals, no.		
Breakfast	3	1
Lunch	2	2
Dinner	3	1
snacks	5	8

a: Participants were asked to report the frequency they had engaged with the Noom food logging over the previous 4 weeks. This included documenting the frequency of logging, such as the number of days, minutes, daily meals recorded, missing meals, and the time of day for food logging.

5.3.3 DASH diet Adherence and Self-Efficacy

As shown in Table 5-3, over the 8-week follow-up period, participants tended to increase their DASH diet score. Participants also reported decreased total fat, saturated fat, cholesterol and sodium levels and increased calcium, magnesium, and protein intake.

In addition, the self-efficacy score, measured out of 30, reflects a higher score, indicating higher self-efficacy. The mean (SD) self-efficacy for participants was 18 (4.7) at the baseline (n =14) and 20 (6.3) at the 8-week follow-up.

Table 5-3: Change in DASH adherence score and DASH score components among participants with high blood pressure from baseline to follow-up

Nutrient	Mellen's DASH Index (Mellen et al., 2008) [b]		Baseline, mean (SD) [a] (n = 14)	8 weeks, mean (SD) (n = 12)
	DASH score target	Intermediate target		
DASH score	**0–9**		3.4 (1.4)	4.3 (1.1)
Total fat (% total Kcals)	**27% of energy**	**32% of energy**	35.9 (8.1)	28.2 (6.5)
Saturated fat (% total Kcals)	**6% of energy**	**11% of energy**	11 (4.1)	9.3 (5.4)
Protein (% total Kcals)	**18% of energy**	**16.5% of energy**	17.9 (3.3)	21.3 (3.4)
Cholesterol (mg / 1000 kcal)	**71.4 mg/1000 kcal per day**	**107.1 mg/1000 kcal per day**	245 (206)	230 (167)
Fiber (g / 1000 kcal)	**14.8 g/1000 kcal per day**	**9.5 g/1000 kcal per day**	13.1 (5.7)	12 (5.6)
Magnesium (mg / 1000 kcal)	**238 mg/1000 kcal per day**	**158 mg/1000 kcal per day**	138 (78)	146 (66)
Calcium (mg / 1000 kcal)	**590 mg/1000 kcal per day**	**402 mg/1000 kcal per day**	360 (185)	506 (130)
Potassium (mg / 1000 kcal)	**2238 mg/1000 kcal per day**	**1534 mg/1000 kcal per day**	1632 (705)	1489.5 (474)
Sodium (mg)	**1143mg/ 1000 kcal per day**	**1286mg/ 1000 kcal per day**	1503 (772)	1181(637)

[a] Mean and Standard Deviation. [b] DASH Index: Each participant receives one point for meeting the target, 0.5 points for meeting the intermediate target, and 0 points for not meeting either target.

5.3.4 System Usability Scale

Based on the SUS questionnaire, it was found that most respondents had a positive experience with the Noom app (see Table 5-4). with an overall mean (SD) SUS score of 73.33 (8.07) (range 62.5-87.5) indicating that the Noom app is acceptable. The question with the most favourable answer revealed that users found the app to be consistent and not cumbersome. However, one question received a mix of negative and neutral responses, where users felt they needed to learn a lot before using the Noom app.

Table 5-4: Participant responses to the System Usability Scale (SUS) questionnaire and total SUS score after 8 weeks of using the Noom app

SUS Questions	Positive responses, n	Neutral responses, n	Negative responses, n
Q1: I think that I would like to use the Noom app frequently.	11	1	-
Q2: I found the Noom app unnecessarily complex.	11	1	-
Q3: I thought the Noom app was easy to use.	10	2	-
Q4: I think that I would need the support of a technical person to be able to use the Noom app.	9	3	-
Q5: I found the various functions in the Noom app were well integrated.	9	3	-
Q6: I thought there was too much inconsistency in the Noom app.	12	-	-
Q7: I would imagine that most people would learn to use the Noom app very quickly.	7	3	2
Q8: I found the Noom app very cumbersome (inconvenient)to use.	12	-	-
Q9: I felt very confident using the Noom app.	10	2	-
Q10: I needed to learn a lot of things before I could get going with the Noom app.	6	3	3
SUS scores mean (SD)	73.33 (8.07)		

5.3.5 Qualitative Results

The interviews were conducted with 9 participants who completed the study. The data analysis revealed four overarching descriptive themes concerning the Noom app's usage over the previous eight weeks, including (1) acceptance, (2) app usability, (3) technical issues, and (4) suggestions for improvement. The thematic framework analysis is provided in Appendix 23.

1) Acceptance

The Noom app was generally well accepted and liked among the participants who completed the study. Most participants generally found the Noom app easy to use, and as a result of consistently tracking their behaviour, most participants were able to re-evaluate their dietary choices and break old habits, as shown in the quantitative data, most participants had improved their DASH diet scores.

> *Generally, I am a busy person; when I started using the app and noticed the positive feedback, it satisfied me because I was trying to modify my dietary behaviour.* [participant 4 male, 35, Bachelor's degree]

> *[The* Noom *app] helped me change my dietary behaviour. Every morning, I was feeling that I needed to use the application.* [participant 6, male, 49, Bachelor's degree]

Most participants experienced positive changes in their behaviour due to self-monitoring and receiving regular feedback through the app. The app colour-coded positive and negative energy balances in green, yellow, and orange, which helped them become more aware of their dietary habits and encouraged them to reflect on their behaviours. Furthermore, the feedback allowed them to make improvements, eventually increasing their self-efficacy and DASH score, as evidenced by the quantitative data.

> *Upon the appearance of green colour, I felt that I reached my goal. And by receiving red colour I felt this was a compelling reason to stop eating unhealthy food, especially upon logging your meals on time*. [Participant 8, female, 45, Bachelor's degree]

Many of the female participants were able to positively impact their children's eating habits by incorporating more fruits and vegetables into their diets, eating healthy snacks, and having dinner earlier. One of the participants even suggested that her friend try using the Noom app.

My awareness increased, and I tried to modify my children's behaviours; I became keen on increasing the amount of fruit and vegetable intake, and we had our dinner early. [Participant 9, female, 44, Bachelor's degree]

There were mixed opinions regarding the reminders (sent through the app) for logging food and reading articles. Some found these messages helpful and promptly acted on them, while others ignored them but still appreciated receiving them because they helped them record their missing meals. However, some participants did not find the reminders helpful, and they disabled the notifications because they received them at inconvenient times and found them annoying.

Because I was busy during the day, I turned off all notifications, except the last notification of the day, to remind me to log my meals. [Participant 4, male, 35, Bachelor's degree]

The notifications are useful, especially when the person is lazy or forgetful. They remind the person and help him adhere to the application's instructions. [Participant 6, male, 49, Bachelor's degree]

Most participants reported that effective app use required self-motivation to change behaviours. They were self-motivated to continue using the app due to positive outcomes, health concerns, and daily goals such as calorie limits. Moreover, some participants reported that the app provides daily motivational messages that motivate them to continue using it.

The motivation is that I became able to control food quantity, especially since I am at risk of developing diabetes. [Participant 5, male, 41, Master's degree]

Motivating messages and easiness of application usage such as when you forget to log my meal, I received a message saying that don't worry you still have a chance and time has not finished yet. I also remember that at the beginning of the course, I received a message saying, 'Starting is very difficult, but ends are very pleasing'. These phrases give me the desire and motivation to continue. [Participant 7, female, 40, Bachelor's degree]

Participants had differing opinions about using the app if they were busy or on holiday. The app benefited some since it allowed them to manage their food intake during the holidays, specifically during Eid ul-Adha ('Festival of Sacrifice'), while others did not utilise the app during this time. This reason could explain the differences in-app engagement.

> *Eid ul-Adha significantly influenced us, during which we ate lots of meat and sweets, but the application helped me to control the food quantity; I ate only one piece of meat instead of two.* [Participant 2, male, 43, Bachelor’s degree]

> *During the holidays, I use the application notifications to remind me to adhere to eating healthy food, but I do not log my meals onto the application due to difficulty in logging meals every day.* [Participant 6, male, 49, Bachelor’s degree]

Participants felt they benefited both psychologically and behaviourally from the app’s educational component. Most participants felt that the Noom app provided them with information to increase their confidence in selecting healthier food, monitor their dietary intake, and incentivise eating healthy food.

> *The educational information is beneficial, especially psychologically, in controlling meal selection and diplomatically behaving with your family or friends regarding choosing healthy food. The application directs you to the best choice, showing its health advantages. The application also gives you new information about the quality, quantity, and time of food and method of eating, for example, how you can chew.* [Participant 1 male, 65, Bachelor’s degree]

However, all participants expressed their dissatisfaction with some of the Noom app's suggestions and language. Some of the app's recommendations cater more towards Westerners and do not consider Arab and Muslim cultural differences. For instance, some users found it odd that the app suggested limiting alcohol consumption to only one cup. Furthermore, the app incorporates American slang, which can be confusing for some users who are not familiar with the language (e.g. ‘listen to your gut’, ‘take the plunge’, and ‘veggies’).

> *The application has a simple defect: it talks about American culture. No doubt, there is a comprehensive food database that contains Arab and international meals from other countries. But it deals with me as an American and gives me advice appropriate to their culture, such as eating pork and drinking alcohol, and practicing American sports, such as dancing*. [Participant 1, male, 65, Bachelor’s degree]

2) App Usability

Most participants reported that the Noom database contained a variety of foods and was easy to use, convenient, and valuable. However, participants reported difficulties identifying certain foods due to missing local options such as local restaurant foods and traditional cuisine. Mixed dishes like *Kabsah* and homemade foods also challenged some participants. Despite the option for users to add their foods to the database, only a few participants found this helpful in entering their foods. Some users expressed concerns about the accuracy of food information in the database after adding their food.

> *The food database needs to be more accurate, but it is better than nothing [for dietary self-monitoring].* [Participant 1, male, 65, Bachelor's degree]

> *There is an advantage which satisfied me: the ability of the user to enter his meals and to be available to others, but my question is there someone who reviews our meals entering because it is possible that our estimation of elements is not accurate, therefore the database is not accurate.* [Participant 5 male, 41, Master's degree]

Some participants reported that they were unable to incorporate the app into their daily routine quickly, which was supported by their SUS score question 7.

> *In the beginning, I was upset, and the application didn't satisfy me, because I searched in a database which required further time and effort but after a period of time, I have adapted to it.* [Participant 4, male, 35, Bachelor's degree]

3) Technical Issues

Participants reported technical errors, including the app frequently freezes or responds slowly; this happened to four participants. They solved this issue by uninstalling and reinstalling the app.

> *Technical problems causing the suspension of the application once or twice a week and I have to uninstall the application and reinstall it.* [Participant 1, male, 65, Bachelor's degree]

When participants encountered technical problems, they generally did not contact the primary researcher. These problems were usually only discovered during the interviews. Some participants hesitated to trouble the researchers with technical issues stemming from their slow internet connections. On the other hand, a few participants preferred to contact the Noom app support team to address the technical problems, as they believed they were accountable for such matters.

> *There is a simple technical problem that the application didn't respond may be due to internet weakness.* [Participant 6, male, 49, Bachelor's degree]

> *I contacted* Noom *app support about this issue, and they replied they were aware of the issue and were working to resolve it.* [Participant 5, male, 41, Master's degree]

4) Suggested Improvements

There were some suggestions to improve the Noom app. These suggestions include translating it into Arabic, reviewing its content, and deleting any recommendations unsuitable for the Arab and Muslim populations.

> *"Please develop the application [The Arabic version] to reflect our Arabic culture. It would be best to remove any inappropriate content, such as references to alcohol consumption, to make it more suitable for the Arab user."*[Participant 6, male, 49, Bachelor's degree]

> *"To be honest, I wish there was an option like the Arabic language in the language settings because not everyone can read and understand English."* [Participant 7, female, 40, Bachelor's degree]

Furthermore, participants believed that adding some traditional Saudi and Arab cuisine would be useful addition because people from all backgrounds and ages would benefit from this, as it would make it more appealing to users from these regions. Participants also suggested that it could be used offline, and the subscription prices should be reduced. These changes would improve the app's accessibility and usefulness for all users.

> *I want an Arabic version of the* Noom *application that is in line with the Arab and Middle Eastern cultures, also its price is inexpensive.* [Participant 4, male, 35, Bachelor's degree]

> *To add some traditional Arab cuisine to its database and to work without internet, because sometimes I have no internet and find it difficult to log meals after returning home.* [Participant 2, male, 43, Bachelor's degree]

A final suggestion was to find a method to make logging food easier. Although the Noom app has barcode scanners that identify the food, the app seems unable to recognise some of the local Saudi products.

> *Sometimes I feel lazy or forget what I ate for breakfast and lunch, so I did not log my meals. I would like it if there was an easier way to log my meals on time.* [Participant 5, male, 41, Master's degree]

5.4 Discussion

5.4.1 Principal Findings

This study examined the feasibility and acceptability of using the Noom app to assist people with high blood pressure to improve their dietary behaviours. After an eight-week intervention, this study found it feasible and acceptable to use a commercially available app to support DASH diet self-management among people with high blood pressure in Saudi Arabia. Moreover, there was a positive trend toward an increase in DASH scores and self-efficacy, but these results were not statistically significant.

The Intervention's Feasibility and Acceptability

The study recruited 14 people with high blood pressure. The nine participants who completed the interview expressed positive opinions about the intervention. Many participants reported significant benefits from the intervention in terms of their motivation to change their dietary behaviour and their psychological or physical well-being. Most participants found the Noom app easy to use, and most had no difficulties integrating it into their daily routines.

However, two participants withdrew from the study, and three did not complete the interview. Some found the app overwhelming when monitoring their diet. This feedback was based on patients' reasons for withdrawal. The findings indicate that dietary smartphone apps may be more effective for individuals with high motivation and willpower. Consequently, the intervention based on dietary smartphone apps may not reach less motivated and willing patients. Similarly, a previous study assessed the use of the My Fitness Pal app for weight loss (Laing et al., 2014). It concluded that Clinicians may not necessarily recommend the app to every overweight patient with a smartphone unless they are motivated to lose weight and track their calorie intake. For those patients, the app could be a helpful tool (Laing et al., 2014). However, the current study’s findings should be interpreted cautiously due to the small sample size and short study period.

The dietary smartphone app has been found to be a promising intervention for supporting DASH diet self-management (Alnooh et al., 2022). The current study found that this smartphone app appeared to improve adherence to the DASH diet after eight weeks. These findings are consistent with a recent randomised control trial conducted in Iran, which revealed that smartphone apps improved adherence to the DASH diet plan (Darabi et al., 2024). Most participants in this study suggested that personalised feedback, motivational reminders, and knowledge were essential to increase participants' DASH adherence and app engagement. This aligns with the principles of behaviour change theories, which emphasise the importance of goal setting, feedback, and knowledge for successful self-management and behavioural control (Bossen et al., 2022; Villinger et al., 2019).

Most participants in this eight-week study tracked their diet for approximately three to five days per week. During the following month, the number of days people used the app generally increased, while the time spent per day on it decreased. The results of this study contradict Laing et al. (2014), who found that the use of My Fitness Pal, a popular app for diet tracking, decreased considerably after the first month (Laing et al., 2014). In the present study, it is possible that the motivational reminders and feedback provided by Noom, the need to record skipped meals, additional meals and saving favourite meals encouraged the participants to maintain a higher frequency of engagement. In addition, one possible explanation for the decrease in time spent per day engagement is the app's time-saving features, which, for instance, allow users to save their favourite meals and foods (Franco et al., 2016). Ziesemer et al.(2020) reported that fixed daily reminders and logging skipped meals could increase the awareness and the number of logged eating events in the short term. However, the long-term effects of fixed reminders remain unknown. Moreover, most participants acknowledged that perceived missed events were likelier to be snacks than main meals because they logged their food at the end of the day, forgot snacks, were busy or had no Wi-Fi. Similarly, a previous study found that snacks were more likely to be missed (Ziesemer et al., 2020). The most common reasons were obstacles related to devices (e.g., the absence of a device at hand), multitasking or situational barriers (Ziesemer et al., 2020). Further research is needed to identify events that are likelier to be missed and to determine the reasons for such omissions.

Moreover, studies show that individuals who practise self-monitoring tend to experience greater success in changing their health behaviours (Bracken & Waite, 2020; Tang et al., 2015). The Noom app includes information on calorie balance, which helped participants confidently estimate the calories in foods. Furthermore, participants' feelings towards certain types of food were influenced by Noom. This led to heightened awareness among the participants, increasing their consumption of fruits and vegetables and decreasing their consumption of unhealthy snacks, fast food, soft drinks, and high-fat foods such as red meat. Some participants also found the tool helpful in regulating their food intake. Engaging in self-monitoring behaviour can help users gain knowledge about which foods are beneficial or detrimental to their diet, ultimately improving their ability to achieve their goals (Bracken & Waite, 2020).

Additionally, some mothers decided to increase the amount of fruit and vegetables they served their children after using Noom. This positive influence from Noom aligns with the systematic review results (Zarnowiecki et al., 2020), which emphasise the effectiveness of digital interventions in promoting nutrition for parents and improving outcomes for both parents and children.

Another factor that positively influenced the acceptance of the Noom app was the positive feedback and motivational information provided in the educational information. Participants who used the Noom app reported feeling more motivated and capable of improving their dietary habits. They also experienced an increase in their ability to set and achieve dietary goals. Bozorgi et al.(2021) demonstrated that using a mobile application-based- education improved adherence to low-fat and low-salt diets among patients with high blood pressure. Participants' self-efficacy level was also increased during the study. Our findings are consistent with prior research showing that diet apps can improve self-efficacy or improve individuals' belief that they can engage in healthy eating behaviours (West et al., 2017). The findings of our study are theoretically supported by social change theory, which argues that individuals' confidence that they can consume healthy food daily, despite challenges, is often a major determinant of their ability to adhere to a healthy diet (Bandura, 2004). From a psychological perspective, positive or negative consequences for the individual's health are essential factors influencing behaviour (König et al., 2021). Thus, when developing nutrition apps, it is crucial to avoid encouraging feelings of shame by keeping the information positive.

Although the Noom app was considered an acceptable tool, some of its educational content proved unsuitable for individuals with elevated blood pressure in Saudi Arabia. Participants refused to adopt some of the app's suggestions that did not align with their cultural beliefs. For instance, the app recommended having a nightcap before sleep, which was not well received. Empirical studies have shown that health and diet promotion initiatives considering culture, ethnicity, and language are more effective in motivating individuals to adopt healthy behaviours (Coughlin et al., 2016). Thus, it is crucial that personalised nutrition advice and messaging are provided, along with tailored recommendations for affordable and accessible meals and recipes that align with an individual's daily diet (Nordström et al., 2013). As König et al. (2021) pointed out, besides technological factors, the characteristics of a potential user, the interaction between the user and technology, and the social environment also play a role in the usage of nutrition apps. Alzahrani et al.(2023) developed an app called Sehhaty Wa Daghty to cater to the cultural and social norms of Saudi Arabia, the motivational needs of male and female Saudi citizens, and their hypertension management needs. This app allows for easy tracking of blood pressure, physical activity, and a healthy diet and has reminders for medication intake, and water consumption. Most of their participants found the Sehhaty Wa Daghty app easy to use and acceptable. There are notable differences between this intervention and our intervention. The research team developed its app rather than using a commercially available one. Consequently, it underwent prototype testing, and the researchers had to consider many user design aspects more appropriate for the Saudi population. Nonetheless, it is worth noting that the Sehhaty Wa Daghty app is limited only to the study population, while the Noom app is accessible to the general public. Alzahrani et al. (2023) discuss valuable insights on the development of a smartphone app for self-management of hypertension among Saudi patients. They emphasise the significance of considering cultural and social norms when creating digital health programs in Saudi Arabia. Our findings add to that evidence and suggest that commercial dietary smartphone apps have the potential to be used effectively among the Saudi population.

The accuracy of the food database is crucial to the Noom app's acceptance. Although the app offers a comprehensive food database including data from government sources, such as the USDA’s food database, international restaurant chains and some Arab cuisines, it lacks many traditional Saudi cuisines, which affects food tracking. Many Saudi participants reported that food data entry was complex, as they estimated portion sizes, calories, fat, and protein content. They were also concerned about the food database's accuracy and reliability. A previous systematic review has demonstrated that issues related to the usability of food intake tracking can affect a user's willingness to record their food intake (König et al., 2021). The systematic review also emphasised that nutrition apps that allow users to add entries are prone to human error (König et al., 2021). Consequently, nutritional values are likely incorrect, and their sources could be uncertain (König et al., 2021). Therefore, using simpler input mechanisms, such as household items to indicate portion sizes or photo-based food recording, reduces the user's burden (König et al., 2021). To increase users' trust, creating opportunities to enhance transparency about food data sources is crucial if human error cannot be avoided completely (König et al., 2021).

The Noom app itself worked well most of the time. Nevertheless, the most challenging technical issue was freezing and slow response times. The support team assured users that they were working on a solution. These technical issues within the app, such as app malfunctions, can cause user disengagement (König et al., 2021). Therefore, these issues must be resolved prior to a future study for the app to be widely used.

Most participants followed the DASH diet but could not fully adhere to it. Steinberg et al. (2020) found that lower-intensity approaches that focused only on dietary behaviour slightly affected adherence to the DASH diet. Moreover, it has been challenging to achieve complete adherence, even in DASH trials that have included intensive behavioural interventions (Hinderliter et al., 2014). In the PREMIER trial, a comprehensive and multicomponent behavioural intervention was used to improve the adoption of DASH. The intervention consisted of group meetings and frequent face-to-face counselling with a registered dietitian (Appel et al., 2003; Svetkey et al., 2003). The intervention included sodium reduction, increased physical activity and weight loss (Appel et al., 2003). Although the intervention effectively improved DASH adherence, it did not lead to full adoption. Although the DASH recommendations are comprehensive, their full adoption may be challenging when the focus is on multiple behaviours simultaneously. A previous study indicated that although full adherence was optimal, partial adherence to DASH could lower blood pressure (Steinberg et al., 2020).

5.4.2 Recommendations

Although the Noom app may be suitable for individuals with high blood pressure in Saudi Arabia, not all participants were satisfied with some of its content. Our results suggested that the Arabic version of the Noom app needs to be more suitable for Arab users; content not in line with Saudi cultural values needs to be removed.

According to our results, the food tracker method should be simplified due to the burden of text-based data input being too much. Despite the Noom app including barcode scanning, some participants could not find their food, or some food did not come with barcodes. To promote continuous use of the app, participants in this study suggested using voice technology. Previous research has indicated that logging diets using voice is more effective and more user-friendly than text-based method (Chikwetu et al., 2023). Furthermore, adding an offline mode so that users can monitor their food intake and maintain access to the app even without a connection to the internet is recommended (Lieffers et al., 2018).

5.4.3 Strengths and Limitations

One strength of the feasibility study was that it evaluated the Noom app over two months in individuals who experienced high blood pressure in real-life conditions. To our knowledge, no previous research has used a commercial dietary app to support people with high blood pressure in Saudi Arabia.

Several limitations of this study should be noted. First, similar to previous dietary studies, the results of this study may have been limited by the accuracy of the data collected, which may have been influenced by recall and response biases (Subar et al., 2012; Subar et al., 2001). Some participants may have overestimated or underestimated their dietary intake because they knew their diet data would be collected. In addition, all measurements were self-reported, which could have resulted in inaccuracies and biases. Second, the study population consisted of well-educated individuals who read and spoke English and were familiar with technology. Therefore, further research is needed to determine whether these findings are generalisable to less highly educated people. Finally, because some participants dropped out or did not complete their interviews, we may have missed some valuable insights regarding the usability and acceptance of the intervention.

5.5 Conclusions

The results of the current feasibility study showed that using dietary smartphone apps among people with high blood pressure in Saudi Arabia is both feasible and acceptable. There was an apparent improvement in DASH diet adherence and self-efficacy, supporting the need for a larger trial. The results indicate that the food tracker method should be simplified (e.g., adding voice technology for food tracking). Furthermore, this study provided insights into the app's educational content, which was not always suitable for Saudi users, and highlighted the need for a culturally appropriate Saudi Arabian version of the app prior to a full trial.

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Additional Information Regarding the Feasibility of Conducting Randomised Controlled Trials on the Impact of Noom App

Background to the Study

The importance of definitive randomised controlled trials (RCTs) to address crucial questions of causation and elucidate mechanisms cannot be overstated (Campbell et al., 2000). However, conducting one at this time is not recommended due to the lack of research on the impact of commercial Dietary Approaches to Stop Hypertension (DASH) diet self-management applications (apps) in Saudi Arabia (Campbell et al., 2000). The absence of data on improving DASH diet adherence and reducing blood pressure among individuals with high blood pressure necessitates the identification of essential feasibility indicators, such as recruitment, retention, and adherence, as well as acceptability, including satisfaction with trial methods and intervention components. This information is crucial for conserving valuable research resources and increasing the likelihood of successful definitive RCTs (Campbell et al., 2000; Thabane et al., 2010).

Aim of the Study

This pilot single-arm study aimed to evaluate the feasibility of an RCT, including components such as recruitment, retention, adherence, and data completeness, as well as acceptability, defined as satisfaction with the trial procedures and the intervention.

Research Questions

Based on the above, the following two research questions were formulated:

Q1: Is it feasible to conduct a full-scale trial in the future to investigate the effectiveness of the intervention?

Q2: Are the outcome measures acceptable for use in a full-scale assessment of the Noom app?

Methods

The earlier section fully describes the study design, setting, recruitment, and procedures (see 7.2).

Measures

Feasibility

Data on the number of eligible participants with high blood pressure who were recruited, adherence and retained in the study were collected in order to assess feasibility. The retention rate was calculated based on the number of participants who completed all assessments and interviews.

Acceptability

Participants shared their perspectives on the acceptability of trial methods, such as their satisfaction with assessments and procedures. These perspectives were gathered through semi-structured interviews conducted at the conclusion of the trial.

Results

Translation of the Noom Application

The researcher contacted the developers of the Noom app to propose a collaboration on an Arabic translation of the app. Unfortunately, the researcher did not receive a response to her email request. Consequently, the researcher opted to conduct a feasibility and acceptance test of the English version among high blood pressure patients in Saudi Arabia. However, during the recruitment process for the qualitative study (Chapter 4), she encountered several challenges, including finding participants who could read and understand English, were motivated to change their dietary behaviour, and were interested in using technology. Due to time constraints, the researcher chose to contact the participants from this previous qualitative study. Participants in the qualitative study provided informed consent and agreed to be contacted for participation in the feasibility and acceptance study. While this study could not fully evaluate the recruitment process and sample size, it successfully highlighted several key points, such as retention rate, acceptability, and reasons for withdrawal.

Recruitment and Attrition Rate

Once the research had received ethical approval, 15 participants were asked to review the information sheet and sign the consent form via email. Only 14 returned the informed consent form, all of whom had completed the baseline questionnaire (Figure 5-2). However, two participants withdrew during the trial, and three did not complete their interviews.

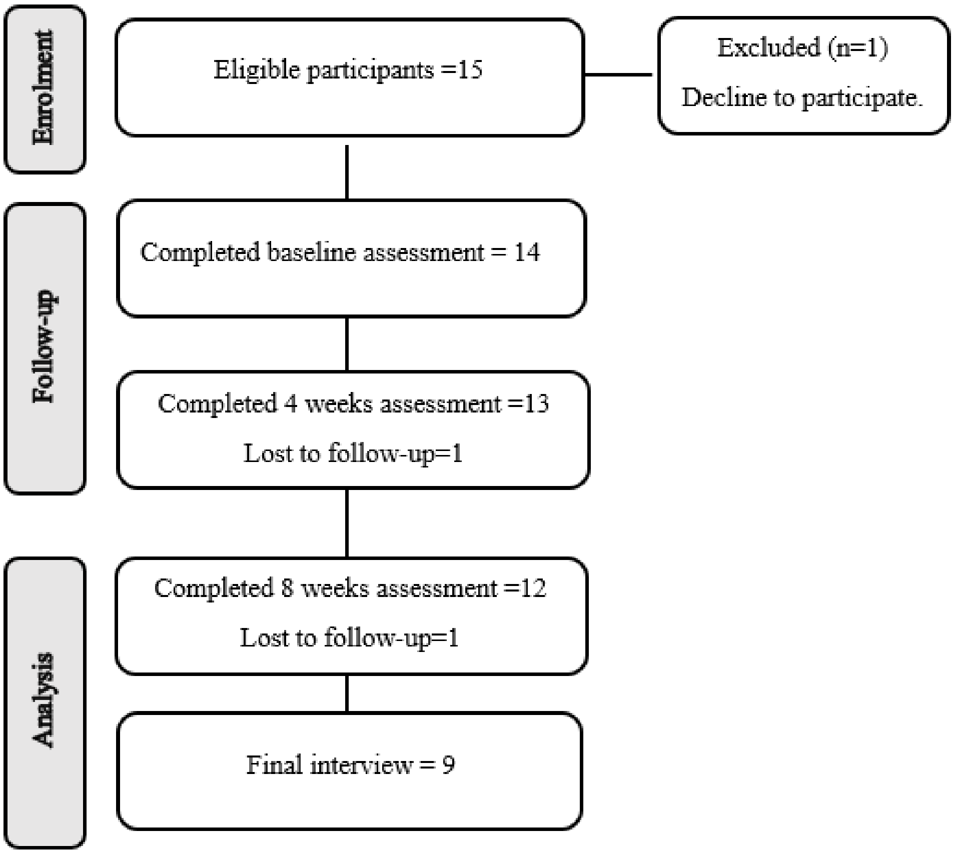

Figure 5-2: Participant Flow Diagram

Withdrawal from the Study

Two participants withdrew from the study – one two weeks after commencement and the other between Follow-up 1 and Follow-up 2. Only 9 of the remaining 12 participants completed all the data collection points. The participants voluntarily provided their reasons for withdrawing. The first two participants withdrew because they found the research too burdensome, particularly the required dietary log. Of the three participants who did not complete their interviews, one withdrew due to family circumstances, while the other two did not provide reasons for their withdrawal.

Qualitative Results

Theme 1: Study Design, Conduct, and Processes.

This theme focuses on the implementation and design of the study. Participants appreciated the trial's usefulness and the skills they acquired, demonstrating its positive impact. After the study ended, one participant renewed his two-month app subscription. Furthermore, most participants expressed their willingness to continue participating for six months if the study were extended to include a six-month follow-up, as illustrated by the following quotations.

> *This project is significant for Saudi males and females due to their bad dietary behaviours. Educating parents about food quantity and quality will reflect on their children so that they can live a healthy life.* [Participant 1, male, 65, bachelor's degree]
>
> *For me, I feel that it was a beautiful experience, and I have learned a new thing. I have achieved my weight loss goal at home without visiting the nutrition clinic, so I have renewed my subscription.* [Participant 6, male, 49, bachelor's degree]

However, one participant expressed his unwillingness to participate in a six-month follow-up if the study were to be extended.

> *No, [using the app] continuously for six months is difficult because it's hard for a person to commit to entering his food information for six months.* [Participant 3, male, 40, bachelor's degree]

Most participants were generally satisfied with the questionnaires and the time required to complete them. However, the self-reported 3-day food record posed considerable difficulties in terms of compliance. Participants found the record time-consuming since they had already recorded their food on the app, which caused delays in returning the records to the researcher.

> *Most questionnaires were straightforward to complete, except for the three-day food record, which was quite time-consuming.* [Participant 4, male, 35, bachelor's degree]

Discussion

This study evaluated the feasibility and acceptability of utilising the Noom app to enhance adherence to the DASH diet over a two-month period. The dropout rates posed a challenge to the study's feasibility, indicating that modifications to the study design and methods may be required to enhance participant retention. During the study, two individuals withdrew, and three did not complete the interview. This outcome may be due to some participants wanting to modify their dietary habits but being unwilling to put in the effort required to self-monitor their food consumption. During the screening phase, all participants expressed interest in changing their diet, but their readiness for change or level of motivation was not explicitly assessed. The attrition rate of the study participants suggests that some individuals may have been unwilling to dedicate the necessary time to self-monitoring. Future research should take into account evaluating potential participants' readiness and motivation levels during the screening phase (Laing et al., 2014). However, despite the high dropout rate, participants who completed the study found it to be feasible, acceptable, and sustainable.

Implementing health promotion messages to enhance participants' motivation and increase the likelihood of behavioural change is also recommended (Coughlin et al., 2016). Moreover, providing compensation to participants could be a successful strategy to enhance retention in future studies (Amagai et al., 2022). However, it is important to consider that the app's effectiveness may not be accurately demonstrated if participants are overcompensated (Amagai et al., 2022). Consequently, the research findings may not be generalisable. Finally, several studies have uncovered the potential benefits of algorithms that adjust daily and weekly goals based on past achievements. These algorithms promise to enhance user retention (Ghelani et al., 2020).

Most participants expressed satisfaction with the study measurements, although a few noted significant challenges in completing the self-reported 3-day food record. To address this issue, collaborating with the developer of the Noom app could be beneficial. This could involve exporting the food records from Noom as participants enter and analyse them. Also, using an online dietary assessment tool, such as myfood24, which overcomes the limitations of traditional pen-and-paper dietary assessments. This software includes 2016 types of Arabic foods (Bawajeeh et al., 2021). However, researchers need to consider the cost of myfood24.

Conclusion

In conclusion, an RCT is feasible with certain modifications.

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Chapter 6 | General Discussion and Conclusion

This chapter presents a general discussion of the research, along with a conclusion, including an overview of the main findings and a reflection on the results. The strengths and limitations of the research are considered, and recommendations for future dietary app development and further research are provided. Following this, the overall conclusion ties all the findings together and highlights their significance.

6.1 Overview

Hypertension is a significant health concern worldwide. Adherence to the Dietary Approaches to Stop Hypertension (DASH) diet is an effective strategy for controlling high blood pressure. Saudi dietary behaviour is poor, and there is a need to raise awareness and identify effective interventions to change their dietary behaviour. Dietary smartphone apps offer significant potential for supporting dietary self-management. Commercial dietary apps are becoming increasingly widely available; there are examples in the literature of them being used to enhance dietary self-management, which leads to healthier living. However, no evidence in the literature indicates which DASH diet app is most suitable for helping patients improve their dietary self-management in order to control their blood pressure.

The overall aim of this research was to contribute to this gap in knowledge through a systematic staged process to investigate the potential for using mHealth apps to support DASH diet self-management among individuals with high blood pressure in Saudi Arabia. Four primary studies were conducted in two phases, presented in Chapters 2 to 5. The first phase aimed to establish whether DASH diet apps effectively support self-management of the DASH diet, and to identify widely available apps suitable for this purpose. It involved conducting a systematic review of the existing literature examining DASH diet apps targeted at people with high blood pressure, and an app store review assessing the potential effectiveness, theoretical underpinning, quality, privacy, and security of commercially available DASH diet smartphone apps. The second phase aimed to select and test the most suitable DASH diet app for people with high blood pressure in Saudi Arabia. In the first phase, two suitable apps were identified, apps considered to be high quality, and likely to be effective and to display adequate privacy and security features. A qualitative study was then conducted to explore the experiences and perceptions of people with high blood pressure and professionals (family physicians and dietitians) using these apps. This enabled the further selection of the most appropriate of the two apps for the Saudi Arabian context. Subsequently, the feasibility and acceptability study was conducted to assess the selected app in Saudi Arabia, marking the final step of the second phase. This chapter offers a thorough summary and reflection on the main findings discussed in Chapters 2 to 5. The conclusions presented in those chapters are reinforced, and this chapter provides an in-depth understanding of the utility of dietary smartphone apps in general, particularly the Noom app in Saudi Arabia.

6.2 Summary of results

6.2.1 Phase one – Identification of DASH diet smartphone apps

Study 1: Systematic review

This study (Chapter 2) aimed to assess the existing evidence for the effectiveness of smartphone apps that support self-management to improve DASH diet adherence and reduce BP. This study identified weak emerging evidence for the positive effect of using DASH smartphone apps. However, the evidence is inconclusive. The three RCTs evaluated were deemed to be of low quality primarily due to the absence of blinding for both participants and assessors. One study did not publish its study protocol, and missing information compromised the validity of another study. Furthermore, all studies had relatively short durations. Given the nature of dietary intervention studies and the use of apps, achieving blinding was not feasible across these interventions. As a result, most studies were assessed as having a high or unclear risk of bias in this regard. This limitation was considered during the overall evaluation of evidence quality, ultimately diminishing confidence in some of the findings. Although the efficacy of DASH smartphone apps in promoting adherence to the DASH diet and lowering BP has not been definitively demonstrated in the literature, these apps are user-friendly, feasible, and well-received. This review observed that all five apps had similar functionality: three out of the five apps combined three main features, educational information, feedback, and messages (reminders or motivations), with other functionalities. Nevertheless, the results were similar between apps with different functionalities, which made determining which features were most effective difficult. According to the analysis, there was no difference between the characteristics of commercial apps and those of non-commercial apps. The interventions utilised the mobile application alone or in conjunction with other communication tools such as telephone calls, chats through the application, or text messages. Although it was impossible to determine whether combining an app with other modalities increased its effectiveness based on our results, a systematic review found that apps are most effective when combined with other tools (Schoeppe et al., 2016).

During the updated search of the literature conducted as part of this systematic review, it was discovered that an under-review RCT, which was included in our systematic review, had recently been published (Darabi et al., 2024). This RCT study's results demonstrated that smartphone apps led to a significant reduction in SBP, DBP, and BMI. While no new studies have been published, the existence of published RCT protocols indicates that research activities in this field are on the rise (Miller et al., 2021; Zou et al., 2020).

Study 2: App store review

A systematic search and content analysis (Chapter 3) were conducted of all DASH diet apps available on Google Play and the Apple App Store in the UK. This study also conducted an electronic search of the most popular app stores – the Apple App Store for iPhone and Google Play for Android – in Saudi Arabia. The search used Arabic and English keywords to identify apps supporting the DASH diet. However, no DASH diet apps supporting the Arabic language were found. DASH diet apps that provided dietary self-management were found to be limited. Only seven apps met the inclusion criteria, including providing dietary self-monitoring and feedback that enhances diet outcomes. While some apps were considered potentially effective, their effectiveness was assessed by identifying BCTs and likening them to the theoretical domain framework (TDF) mechanisms of action rather than relying on RCTs. In the present study's review, only two apps (Noom and DASH To Ten) were deemed to be of high quality and likely to be effective, and displayed sufficient privacy and security measures. One of these apps (Noom) has previously been evaluated for effectiveness in a trial.

6.2.2 Phase two – The selection and testing of the most suitable app

Study 3: Experiences and perceptions of healthcare professionals and patients with high blood pressure accessing commercial DASH diet apps: A qualitative study

In Chapter 3, Noom and DASH To Ten were identified as high-quality apps with the potential to be effective and secure. A qualitative study (Chapter 4) conducted in Saudia Arabia explored the experiences and perceptions of patients with high blood pressure and professionals (family physicians and dietitians) after using each app for a week, in order to select the most suitable app for the Saudi Arabian context.

The results highlighted many barriers to adopting a DASH diet, including a lack of motivation, a busy lifestyle leading to fast food consumption, the high cost of healthy foods, and insufficient support from household members. Some patients acknowledged that they knew about healthy food choices but needed extrinsic motivation, such as a human coach. Both patients and professionals were aware of the benefits of dietary smartphone apps. However, there were some barriers to using them; for example, dietary apps may not reach people with low motivation, lack of commitment, or low education levels. Additionally, people with a busy life may find it difficult to use these apps consistently, and those who do not speak English may be limited in their ability access to such support and resources. Additionally, some professionals reported that explaining dietary apps to patients requires extra time, effort, and attention.

After comparing the functionalities and characteristics of both apps, participants suggested that an app with a straightforward sign-up process, an extensive food database for dietary self-monitoring, feedback, goal setting, and reminders was essential to enhancing DASH diet adherence. Participants perceived the Noom app to be more suitable in the Saudi context. The Noom app was deemed to support DASH self-management due to its strong emphasis on mindfulness, specifically regarding eating habits. Furthermore, it supports weight reduction, which helps lower blood pressure. Participants also found the Noom app highly interactive, offering motivational information, reminders, personalised feedback, realistic goals, and a comprehensive food database. However, participants made several recommendations for improving the app, including a simpler sign-up process, Arabic language support, automatic sodium and potassium consumption calculation, and lower costs for the user. Participants also expressed a desire for training in using the app.

Study 4: An investigation of the feasibility and acceptability of using a commercial DASH diet app in Saudi Arabia in people with high blood pressure: a mixed methods study

Chapter 5 investigated the feasibility and acceptability of using the Noom app to support DASH diet self-management among people with high blood pressure in Saudi Arabia within eight weeks. Using the Noom app was found to be feasible and acceptable among participants. Most participants who completed the study reported that the app was easy to use, and most had no difficulty integrating it into their daily routines. Most participants reported that they would be willing to continue the study for a six-month trial. This study also found that there was a positive trend towards an increase in DASH scores and self-efficacy among participants. Chapter 1 highlighted that motivation is a significant factor affecting health behaviour. The feasibility study confirmed that dietary smartphone apps may be more effective for individuals with high motivation and willpower. Conversely, interventions based on dietary smartphone apps may not engage less motivated and willing patients.

Despite the Noom app having a comprehensive food database, some users were concerned about its accuracy because it allows them to create their own meals, a feature which is prone to human error. Some participants faced technical issues with the app, including freezing and slow response times. This study assessed the educational information given in the app and provided suggestions to improve the app's suitability for Saudi and Arab users.

The methods adopted within the study would need to be modified if a future RCT were to be conducted. Some participants found it time-consuming to complete the self-reported three-day food record questionnaire. Using online dietary assessment and collaborating with the Noom app developer potentially addresses this issue.

6.3 Main findings and reflections

6.3.1 The effectiveness, quality, privacy, and security of DASH diet smartphone apps

A systematic review (Chapter 2) found that only limited studies with methodological weaknesses have been conducted on the effectiveness of DASH diet smartphone apps (Alnooh et al., 2022). Additionally, it was found that most researchers had developed their own apps for these studies, which are often not available in the app marketplaces. In contrast, hundreds of DASH diet apps are commercially available, but there is no evidence that they are effective (as shown in Chapter 3). This poses a significant challenge for potential users and healthcare professionals looking for reliable resources to guide their decision-making when selecting (and buying) a suitable app.

Academic research and commercial app development differ in terms of the pace of their progress. Jake-Schoffman et al. (2017) found that academic research moves more slowly than commercial app development. Consequently, effective apps may not yet be available to the public (Riley et al., 2013). Developing a commercial mobile application involves various skills, including content creation, programming, and design expertise (Jake-Schoffman et al., 2017; Riley et al., 2013). Additionally, the app must be continuously hosted, updated, and supported with customer service and technical assistance (Jake-Schoffman et al., 2017; Riley et al., 2013). To ensure success in the market, an app requires significant resources and expertise (Jake-Schoffman et al., 2017). As a result, researchers who do not have these resources will face challenges in launching their apps in the marketplace.

App developers are not obligated to seek regulatory clearance from agencies like the US FDA or the European Union before launching their apps (Fallaize et al., 2019; Gordon et al., 2020). This contrasts with the pharmaceutical or medical device industries, where validation is typically required (Alexander & Joshi, 2016). This absence of regulation can call into question the validity and reliability of nutrition and diet apps. For example, many nutrition-related apps may need to accurately assess specific nutrient intake, such as total energy and micronutrients (Fallaize et al., 2019). The validity of nutrition-related apps available for commercial download is often unclear, especially given the lack of transparency about the sources of nutritional data used by app developers and the lack of a standard method for assessing the validity of health-related apps, which poses significant challenges for health organisations and researchers considering their use (Fallaize et al., 2019). To address these issues, it is essential to establish validation models to help patients and healthcare professionals differentiate between those apps worth using and those not (Gordon et al., 2020). Such models should include quality and safety measures such as effectiveness, patient satisfaction, and potential adverse effects (Gordon et al., 2020). Collaboration between developers and researchers may also improve the quality and effectiveness of apps[1] (Alexander & Joshi, 2016). Integrating research-based development and the resources required to make these apps widely available could provide prospective users with better access to high-quality and effective apps (Akbar et al., 2020; Jake-Schoffman et al., 2017).

In health systems, user-centred design (UCD) is an effective approach for successful product or system design (Norman & Draper, 1986). UCD involves end-users in design processes, contributing to product effectiveness, acceptance, and success (Hermawati & Lawson, 2014). To implement UCD, it is essential to understand users, tasks, and environments clearly. It is also necessary to identify the context in which users will use a system (Hermawati & Lawson, 2014). Additionally, multidisciplinary skills and perspectives, including those of non-technical specialist experts, end-users, and relevant stakeholders, should be incorporated during the design and development of a system (Hermawati & Lawson, 2014). For example, De Luca et al. (2021) used a UCD approach to develop a regional digital service for managing hypertension. Based on interviews with patients and health professionals, the system's functional requirements and use cases were defined. Some DASH diet apps included in the

[1] It is important to note that the Noom app has developed its food databases using credible sources, as detailed in Chapter 5. Fallaize et al. (2019) conducted a study to assess the accuracy of various nutrition-related apps in measuring energy, macronutrients, and micronutrients compared to a UK reference method (Dietplan6). They discovered that Noom, which focused on energy measurement only, provided the most reliable results. Another study examined the Noom app's effectiveness in measuring dietary sodium intake and found a strong correlation between the data recorded by the app and estimates based on 24-hour urine sodium levels (Jung et al., 2023). These findings underscore the importance of further research to determine whether the Noom app can accurately measure dietary sodium and other micronutrient intakes, such as potassium and calcium.

systematic review (Chapter 2) were developed with the input of multidisciplinary teams, such as nutritionists, dietitians, and end users during the development process (Mann et al., 2014); obtaining feedback from end users at an early stage is crucial to ensure the quality and usefulness of content (Choi et al., 2021; Gabrielli et al., 2017). However, Chapter 3 observed that commercial DASH diet apps are often designed without the involvement or consultation of users or healthcare professionals. Therefore, these apps may not meet users' characteristics and needs (Hermawati & Lawson, 2014) and may not comply with the latest research evidence, reducing their usability, effectiveness, quality, and safety (Alessa et al., 2019; Alexander & Joshi, 2016; Vasiloglou et al., 2020). This project embraced a collaborative approach. It engaged healthcare professionals and prospective users in the selection and assessment process, ensuring that the app selected aligned with the actual needs and preferences of patients and healthcare professionals, as detailed in Chapter 4.

Chapter 5 explored the Noom app's feasibility and acceptance among people with high blood pressure in Saudi Arabia. The findings align with previous studies, which have also found that the Noom app is user-friendly and accepted (Cho et al., 2020; Keum et al., 2021). Despite the limitations of commercial apps, including limited participation of end users in the development process, these apps are often professionally designed and developed to meet high standards of functionality and aesthetics (Jake-Schoffman et al., 2017). The research findings underscore the potential of utilizing commercial apps to advance research in the mHealth sector, both in Saudi Arabia and worldwide. However, researchers must adhere to a systematic selection process to guarantee the choice of high-quality, likely effective, and secure apps that resonate with end users' preferences. Although this research could not collaborate with the Noom app developer to translate the app into Arabic, the results are still useful, and the Noom developers may be able to use them if they launch an Arabic version.

Additionally, this research identified issues with the security of many commercial DASH diet apps, which have not specified the measures taken to ensure data security, potentially putting users' data at risk. Adequately monitoring the safety of commercially released apps is crucial (Gioia et al., 2023; Hutton et al., 2018). In response to similar general concerns, the Apple App Store has required developers to create a privacy label when submitting new apps or app updates since December 2020 (Li et al., 2022). However, more than half of all apps in the US still lack a privacy label (Li et al., 2022). Moreover, smartphone users often lack awareness about security (Mylonas et al., 2013). While some attempt to review app privacy policies, they struggle to understand the content, possibly due to language barriers (Al-Ameen et al., 2020). This issue arises because English and the use of complex language may create significant barriers for app users whose native language is not English (Al-Ameen et al., 2020; Neal et al., 2023). To enhance app security, developers must be transparent about how their users' data are collected, used, and supported, and should supply resources to improve security (Alessa et al., 2019). Developers should also consider creating simple and easy-to-understand summaries of privacy information and ensuring that privacy policies are available in the official languages of all the countries where their apps are available (Neal et al., 2023). In addition, users should be more aware of privacy concerns in order to evaluate the safety of apps and should use tools to determine whether an app is likely to suit them (Alessa et al., 2019).

Selecting a suitable smartphone app for DASH self-management can be challenging, given the wide range of available DASH diet apps. This makes it difficult for researchers and users to make a selection. A systematic stage process was used to identify and select the most suitable DASH diet app for the Saudi context. In phase one, this research systematically identified two apps that met our criteria for effectiveness, theoretical underpinning, quality, privacy, and security by considering the criteria used by Alessa et al. (2021a) for evaluating hypertension mobile apps, which also focused on effectiveness, theoretical underpinning, privacy, and security. The present research also focused on app quality as an essential criterion for identifying high-quality DASH diet apps that meet patients' needs. Some users rely on subjective consumer ratings, such as star rating systems and annotated reviews of questionable credibility, when selecting an app (Choi et al., 2021). Consequently, users could not select apps offering features, content, and quality tailored to their needs (Choi et al., 2021). Thus, the present research used the App Quality Evaluation (AQEL) tool to assess the quality of the nutrition apps (DiFilippo et al., 2017). Previous studies have often used the Mobile App Rating Scale (MARS) to determine the quality of nutrition apps, such as those for the Mediterranean diet and weight management (Bardus et al., 2016; Choi et al., 2021; Geng et al., 2023; McAleese et al., 2022). However, DiFilippo et al. (2017) argue that the AQEL tool is more suitable for assessing nutrition apps. It allows for the modification of items based on the targeted age group and emphasises evaluating the app's ability to support education for increasing nutritional knowledge and behaviour change. Interestingly, a recent study assessed the Noom app using the MARS tool; it scored 4.2 on a 5-point scale (Ebrahimi et al., 2023), which is in line with our finding that the Noom app has a high quality level. However, it is important to note that privacy and security are not part of the AQEL or MARS assessments, as they mainly focus on content quality and usability without considering security, privacy, or ethical issues (Grundy, 2022).

Most published studies have also primarily focused on evaluating the quality of popular nutrition apps, and there is a limited number of systematic reviews that include the privacy policies of commercial dietary apps (Gioia et al., 2023). The lack of consensus on the criteria and instruments to use indicates that research in this field is still in its early stages. Further exploration is required, including experimentation with different criteria and instruments, in order to formulate a more definitive and universally accepted approach to evaluating the quality of these interventions. This underscores the need to develop a comprehensive quality, privacy, and security assessment tool rather than standalone instruments.

In the second phase of this research, which focused on the selection and testing of app, emphasis was placed on the importance of direct user engagement. Rather than relying solely on app descriptions, it was deemed essential for end users to interact with the apps themselves to determine their suitability. This hands-on approach aimed to provide deeper insight into the functionality and usability of each app. Furthermore, the research evaluated the feasibility and acceptability of the apps to ensure they were appropriate for end users. This systematic stage process enables researchers to make well-informed, evidence-based decisions when selecting dietary apps for research and clinical applications.

6.3.2 Healthcare professionals' and participants' experience and attitudes regarding DASH diet-related smartphone applications

Gathering user insights through qualitative research is essential to ensuring that digital interventions meet users' needs and preferences (Vo et al., 2019; Yardley et al., 2016). In phase two, Chapters 4 and 5, the qualitative research explored patients' and healthcare professionals' perceptions of apps in general and two high-quality, likely effective, and secure apps in particular, to select the most suitable app and then test its feasibility and acceptability among people with high blood pressure in Saudi Arabia.

Participants' perceptions of the apps' features changed over time. For instance, in the case of self-monitoring of dietary intake, which is essential for nutrition apps (as seen in Chapter 4), most participants favoured the Noom app due to its comprehensive food database, which helped them locate their meals. However, after using the Noom app for eight weeks in the feasibility study, some participants encountered difficulties entering data and recommended simplifying the food tracking methods. Recent studies have utilised photo-based food records or automated diet logging through speech recognition technology to alleviate the user's burden when logging their food (Schembre et al., 2018; Chikwetu et al., 2023). While these methods have shown potential, they are still in the early stages of development and have yet to be widely tested for everyday use. Further research is necessary to determine the most effective methods of collecting nutritional data using smartphone apps to improve the quality and accuracy of health research data.

Push notifications are a notable feature of the Noom app; most participants preferred it because it sends three or more notifications daily. However, after eight weeks, some participants opted to turn off the notifications, as they found them bothersome. This shift in perception highlights that many factors influence users' receptivity to prompts (e.g., timing, frequency); one of the most important factors is the content of the prompt. According to Bidargaddi et al. (2018), frequent app users are significantly more responsive to notifications containing insights derived from their data than suggestions containing strategies and tips. In general, users are more likely to respond to prompts that contain exciting and persuasive content (Schneider et al., 2013). A recent meta-analysis involving 11 studies found that computer-tailored health communication is an effective strategy for increasing vegetable and fruit intake among adults > 40 (Misir et al., 2023). This approach is particularly beneficial due to its affordability and ease of implementation (Misir et al., 2023). Therefore, app developers should consider personalised notification content.

Additionally (as seen in Chapter 4), healthcare professionals expressed concerns about patients' lack of motivation and commitment, which can impede the adoption of health apps. In the feasibility study (Chapter 5), two participants withdrew, despite their interest in participating and in using an interactive app that includes personalised feedback, motivational information and reminders. Results from RCTs have shown that people who only employed smartphone apps did not achieve significant weight loss (Allen et al., 2013; Laing et al., 2014). However, considerable weight reduction has been observed when mHealth was combined with counselling (Stephens et al., 2017), regardless of the intensity of the counselling (Allen et al., 2013). This highlights the importance of human coaches who can help patients sustain engagement and adherence to the smartphone app through feedback and tailor-made advice (Chen et al., 2017). Healthcare professionals who have established a strong trust and rapport with their patients can be vital in increasing their motivation and commitment to sticking with the app (Schroeder et al., 2021).

This research has significant implications for research, policy, and industry. When smartphone apps are combined with evidence-based behaviour change techniques to improve DASH diet eating patterns, the potential for reducing blood pressure at population level increases (Miller et al., 2021). However, it is important to note that the systematic review (Chapter 2) found limited studies with poor methodological quality. Nevertheless, the findings of this research provide a solid basis for developing a high-quality RCT of a widely available DASH diet app, since this study carefully identified and selected a commercial DASH diet app, and evaluated its feasibility, usability, and acceptability among individuals with high blood pressure in Saudi Arabia. The Noom app is supported by evidence-based behaviour change techniques, including daily dietary tracking, feedback, goal setting, healthy diet education, skills training, and motivation messages to improve adherence to the DASH eating patterns. However, conducting an RCT in Saudi Arabia may face challenges if the app is not adapted to address participants' recommendations, particularly concerning the need to enhance its educational content to better align with the needs of Saudi users. Implementing these adjustments would facilitate a more accurate and meaningful assessment of the app's impact.

This research pinpointed the interactive features of dietary apps, explored them based on end-users' (people with high blood pressure) and health professionals' experience (including dietitians and family physicians) and supported by a literature review. This research's insights and suggestions will benefit researchers and developers, enabling them to craft more efficient and user-friendly dietary applications.

Chapter 4 highlights the importance of training patients to use health apps effectively, which could be integrated into daily life. Researchers recommend that dietetic associations offer patients and healthcare professionals training and education (Chen et al., 2017; Vasiloglou et al., 2020). By providing this training, healthcare professionals and patients can improve their ability to engage with and utilise these apps in their practice (Chen et al., 2017; Vasiloglou et al., 2020). This increased proficiency has the potential to lead to better patient health outcomes.

The findings around what the barriers are to adopting the DASH diet can contribute to improving food policies. Chapter 4 identified several barriers to adopting the DASH diet in Saudi Arabia. These barriers include the high cost of healthy food, a busy lifestyle, and insufficient family support. Using apps such as Noom alone may not significantly change dietary behaviour. The promotion of healthy eating behaviour requires a combination of effective policies and interventions (Wendt et al., 2023). For dietary apps to be effective, the food strategy must facilitate behavioural changes and not hinder them.

Implementing education campaigns promoting healthy food habits, such as opting for frozen fruit and vegetables instead of pricey fresh ones, is essential, as discussed in Chapter 1. Several studies have suggested that government programmes and consumer organisations should use inclusive language to promote all types of fruit and vegetables, such as fresh, frozen, dried, and 100% juice, to meet the fruit and vegetable recommendations (Askelson et al., 2018; Storey & Anderson, 2018). This can facilitate the effectiveness of dietary interventions, encouraging individuals to make more nutritious food choices (Askelson et al., 2018). In addition, dietary apps seem more effective when paired with educational or counselling sessions than when used in isolation (Chen et al., 2018).

6.4 Researcher Reflection and Positionality

It is crucial to acknowledge a researcher's positionality, which encompasses their existing knowledge and philosophical stance, when conducting qualitative research (Sikes, 2004). It determines the research aim and methodology. Interpreting qualitative data requires an understanding of the researcher's experiences, beliefs, and values. I thus aimed to demonstrate awareness of my position and to reflect on it. In addition to disclosing my background and relevant personal history, I discussed with my supervisors how these details might influence the study results. This research was refined through valuable supervisor feedback and strengthened by debates about the research (Shenton, 2004).

My background as a nutritionist and teaching assistant in health education at PNU might have impacted the study process, including my interpretation of the data. In addition, my master's dissertation on female Saudi students' knowledge and perception of Saudi dietary guidelines and how their knowledge influences their dietary behaviour might have influenced my interpretation of the data results owing to my pre-existing knowledge about the barriers to following dietary guidelines despite having good knowledge about them.

My background as a Saudi and Arab citizen and my knowledge of Saudi and Arab culture helped me to interpret participants' responses and ask relevant follow-up questions, which enabled me to understand their views and experiences regarding dietary habits. Working with an Arab researcher could have helped the participants feel at ease, leading to a shared understanding that could have encouraged them to share aspects of their experiences that they might have been hesitant to share with a non-Arab researcher.

In addition, my gender was likely significant in the data collection process, in a conservative culture where gender segregation is common. Despite the increasing number of Saudis working in mixed-gender environments in recent years, I was aware that gathering data from male participants might be challenging, as they might feel less comfortable speaking openly to a woman, especially in one-on-one situations, which might pose some difficulties. I used ice-breaking questions and more appropriate probing questions with the male participants in order to minimise this risk. Moreover, I was aware that women are not expected to speak freely about their dietary habits with groups of men in Saudi Arabia. Accordingly, the focus groups were divided into two groups along gender lines.

It is also possible that participants felt pressured to give answers that they perceived that I wanted to hear, rather than their true thoughts about the DASH diet. For example, they might have claimed to eat healthier food, or they desired to use nutrition apps. For fear of appearing unfriendly to the researcher, some participants might have been reluctant to admit their lack of experience with dietary apps or might not believe in the effectiveness of the apps in improving their dietary behaviour. To minimise bias, it was stressed that there were no right or wrong answers during the interviews and focus groups.

At the beginning of the research process, I had some preconceived notions and personal beliefs about the significance of patients utilising nutrition apps for dietary self-management to control hypertension, and about the selected apps. My personal preference for the Noom app may have influenced the interviews. However, I recognize that this preference could introduce bias in various aspects of the study, including how I framed interview questions, interacted with participants, and interpreted their responses.

To address this potential bias, I took deliberate steps to ensure the credibility of the research. First, I created a structured interview guide to remain neutral and open-ended, allowing participants to share their perspectives without leading questions or assumptions. My supervisors reviewed this guide to minimize unintentional bias in further phrasing questions. During the interviews and foucs groups, I maintained a neutral demeanour and refrained from expressing personal opinions about Noom. I focused on active listening to ensure that participants felt their views were valued and not overshadowed by my perspective.

Additionally, during the analysis phase, I employed strategies such as reflexive journaling to critically examine how my positionality might shape my interpretation of the data. By implementing these measures, I aimed to minimize the impact of my personal preferences on the study, ensuring that the findings genuinely reflect the participants' experiences and insights rather than my preconceived notions.

Researchers' backgrounds can affect qualitative study results (Patton, 2014) because researchers may have similar experiences and attitudes as participants. Regular discussions with my supervisors helped address this bias.

6.5 Methodological considerations

The previous chapters have discussed study-specific methodological considerations in detail. This section discusses this thesis' research strengths, limitations, and challenges.

6.5.1 Thesis strengths, limitations, and challenges

This research exhibits several strengths, including the multi-stage mixed-methods approach of using different methodologies, such as systematic review, systematic selection, qualitative methods, and mixed methods, to answer the research questions (Creswell & Clark, 2016). Although no published framework or guideline was followed, the approach shares similarities with existing frameworks for developing and evaluating healthcare interventions, such as the MRC model. The multi-stage mixed-methods approach employed in this research provided diverse perspectives, which enhanced accuracy and detail while reducing bias.

A systematic selection process was used to identify suitable smartphone apps. Potentially effective, quality, privacy, and security must be considered when identifying an app. These criteria are supported by a previous study assessing hypertension smartphone apps to identify the suitable one (Alessa et al., 2021a). Alessa's study focuses on effectiveness and safety as the most critical aspects. Quality was also identified as one of the most essential criteria because it ensures information reliability for the targeted population, recommended use, and usability (DiFilippo et al., 2017; Singh et al., 2016).

Qualitative methods were employed to engage with healthcare professionals and patients to understand their experience and perceptions of using two high-quality, likely effective, and safe DASH diet self-management apps and, thus, to select the most suitable app for the Saudi context. These are the two most critical stakeholders in mHealth interventions, offering valuable and unique insights into how the app might integrate into patients' lives (Wright et al., 2007).

Additionally, a mixed-methods pre-post trial was conducted to explore the feasibility and acceptability of the Noom app. Through a unique evidence-based approach, this research provides a valuable contribution to both the practical and research fields by rigorously identifying and evaluating the most suitable commercially available app for high blood pressure patients.

The content analysis of DASH diet apps in Chapter 3 was based on the 93-item taxonomy of BCTs and linked to the TDF domains. This analysis was used to understand how mHealth interventions can affect behaviour change (Michie et al., 2014; Michie et al., 2013). The behaviour change wheel also assists researchers in connecting these TDF domains and BCTs with intervention functions (Michie et al., 2014). Future researchers and developers will be able to use these findings to understand how TDF mechanisms of action promote user engagement, along with the most efficient methods of utilising BCTs in support of dietary self-management.

Additionally, this research used an app that has been commercially available since 2011. The research benefits from over 13 years of continuous app design, development, and refinement, which has resulted in a highly polished interface and reliable functionality for participants.

Although this research has several strengths, there are also some limitations. There is a lack of research examining the effectiveness of DASH diet smartphone apps to support dietary self-management. Consequently, the systematic review presented in Chapter 2 could not conclude that the apps were effective, primarily due to the limited availability of studies (only five studies were available) and the poor methodological quality of these studies. Furthermore, the review could not identify any specific combinations of app functionalities, that are likely to be more effective. For instance, a systematic review evaluating the effectiveness of apps in reducing blood pressure found that apps with three or more functionalities are more likely to be effective in lowering BP compared to apps with only one or two functionalities (Alessa et al., 2018). In contrast, the current research identified the BCTs for each app as an indicator of its potential effectiveness. This approach was informed by Michie et al. (2009), who suggested that interventions aimed at increasing healthy eating and physical activity were more effective when self-monitoring was combined with one or more BCTs, including goal setting, behaviour goals review, and feedback on behaviour.

This research has followed a structure in which the results of preceding chapters have been used to guide subsequent chapters. In one instance, due to certain constraints, this was not possible: in evaluating the Noom app, it was not possible to implement the recommendations provided by healthcare professionals and patients, including translating the app into Arabic, automatic sodium and potassium consumption calculation, and adding more articles about the DASH diet (Chapter 4). The Noom app is a commercial app, and the researcher had no control over its design. The researcher has been sending many emails to the developer of the Noom app in order to collaborate with them, but has not received a response. Nevertheless, the results of this research could still provide valuable insights for the future development of the Noom app and other dietary apps.

Researchers have used different methods to assess DASH compliance because there is no unanimous agreement on the best approach (Kwan et al., 2013). The feasibility study (Chapter 5) utilised a 3-day food record to assess DASH diet compliance. This approach involved individuals self-reporting their dietary intake through dietary records, which were then compared to the recommendations. This method provides researchers with additional information on the quality of the overall diet, including the type and quantity of foods consumed by individuals. However, it is essential to note that this method has inherent limitations, such as response bias and recall bias (Lee & Nieman, 2003.). A systematic review that assessed DASH diet compliance recommended that combining objective assessments (e.g., urinary excretion) with subjective assessments (e.g., three-day food record, FFQ) in a comprehensive evaluation (Kwan et al., 2013). While urinary excretion can provide insights into certain micronutrients such as sodium and potassium, it may not fully capture adherence to the DASH diet. Therefore, an objective measurement can serve as a validation check for subjective dietary evaluations (Kwan et al., 2013). However, the feasibility study (Chapter 5) only used dietary records due to limited resources and time. Considering the potential health benefits of compliance with the DASH diet, future research should identify the gold standard for measuring DASH compliance and examine barriers to adoption.

The importance of including potential users in healthcare research is increasingly recognised (Wright et al., 2007). In the present research, patients and professionals from KAAUH used two high-quality, likely effective, and secure DASH diet apps. They expressed their views, needs, concerns, and suggestions regarding use of these apps, and then they assessed the most suitable app in practice. However, the generalisability of the findings from these study populations in the qualitative and feasibility studies is limited, since most of the participants were educated and could read and understand English. Furthermore, most participants were motivated and engaged with the dietary self-management apps. Despite efforts to recruit a broad range of participants for the study, most of those who volunteered were likely already highly interested in changing their dietary behaviour. They were also willing to use technology. This may be a bias that could affect the generalisability of the results since use of the apps depends on the patient's willingness to engage with technology and their ability to read English, which is the most widely used language on the internet (West, 2015). Non-English speakers may find accessing digital information and services difficult (West, 2015). Even though this is a limitation of the current research, it is essential to recognise this potential barrier in this specific case as a possible barrier to technology-based healthcare interventions more generally.

Furthermore, it should be noted that the Noom app and the DASH To Ten app only focus on overweight users. In Chapter 4, some individuals who were interested in using dietary apps withdrew from participating because they already had an ideal weight. Franco et al. (2016) state that most nutrition-related apps focus on weight loss and calorie counting, as evidenced by their titles. However, it is essential to note that nutrition-related apps should not be limited to catering to overweight individuals seeking to lose weight. While this is one of the main motivations for using such apps, it is crucial to consider a broader range of nutritional needs and goals. For example, it is essential to consider the dietary requirements of individuals with other chronic diseases, such as high blood pressure, to help enhance their dietary behaviour. In light of this, dietary app developers could benefit from information about the limitations of current apps and consider users' diverse nutritional needs.

Another limitation of this research is that the researcher encountered the difficulty of travelling to conduct interviews for the feasibility study (Chapter 5). Fortunately, technological advancements solved this limitation (Stewart & Shamdasani, 2017). Virtual interviews now allow participants and researchers to join from any location at a convenient time, making it much more convenient for researchers to collect valuable data.

Each method, face-to-face interview and online interview, has advantages and disadvantages. For example, during face-to-face interviews, the interviewer can easily detect non-verbal cues such as body language and facial expressions (Saarijärvi & Bratt, 2021). Similarly, in online interviews conducted with a camera, the interviewer can observe the interviewee through the camera and interpret their non-verbal signals to a certain extent (Saarijärvi & Bratt, 2021).

However, participants may be hesitant to consent to video recording due to concerns about privacy and safety, as videos inherently include identifiable information (de Villiers et al., 2022). According to Saudi Arabian cultural and societal norms, participants in this study who were participating online were not asked to turn on their cameras. Furthermore, the researcher did not obtain ethical approval to record video interviews. Although video recording can provide valuable insights, the ethical implications and potential impact on participant privacy and safety should be considered (de Villiers et al., 2022).

Finally, in healthcare research, RCTs are considered the gold standard, as they enable researchers to establish causal relationships and minimise potential sources of bias (Milne-Ives et al., 2020). However, conducting RCTs can be time-consuming and expensive (Milne-Ives et al., 2020). Due to limited time and resources, the feasibility study was conducted quasi-experimentally. Nevertheless, this research considered various factors related to the feasibility of conducting an RCT, including the acceptance of outcome measures.

Several other challenges were encountered. One of the critical hurdles was the inability to secure the cooperation of the Noom developer. This led to the inability to incorporate recommendations provided by healthcare professionals and patients, including translating the app into Arabic. This translation was crucial for improving access to the app for Arabic-speaking users, particularly those with high blood pressure, which would have made it easier to recruit participants for a feasibility study (Chapter 5). Furthermore, the feasibility study (Chapter 5) could not gather information on real-world users' engagement with the application because of the lack of collaboration with the Noom app developers. Another major challenge was the recruitment process. Finding participants who were proficient in English and willing to use technology and participate in the study proved to be quite difficult. Some who could understand English were not interested in using dietary smartphone apps. Therefore, the feasibility study recruited participants who had participated in the previous study (see Chapter 5 for details). Moreover, the focus group method was effective in gathering insights and opinions from individuals (Stewart & Shamdasani, 2017). However, it has a significant drawback when it comes to time limitations. In the research for Chapter 4, coordinating a convenient date for all participants posed challenges to the researcher. Some participants were busy with daily routines, unavailable at comparable times, or had other reasons that made participation in a focus group at a fixed location (e.g., KAAUH) difficult. In addition, during online interviews, a reliable internet connection, a good microphone, and reliable technology are essential (de Villiers et al., 2022). One of the interviews in the feasibility study was rescheduled due to the participant's voice being unclear, emphasising the importance of having the appropriate equipment in conducting effective online interviews.

6.6 Future work

Research on using DASH diet apps to promote dietary self-management and lower blood pressure is limited; therefore, further research is needed. Based on the results of previous chapters, potential research directions were identified, and this section aims to identify additional areas that need attention.

6.6.1 Recommendations for further research

The research indicates that the current approach for selecting the most suitable dietary self-management app requires further refinement. Prior to this study, no established guidelines or evidence were available to select the most suitable dietary self-management app. The study by Alessa et al. (2021a) employed specific criteria to identify the most suitable hypertension self-management application, emphasising effectiveness, privacy, and security. The present research used these criteria to identify suitable DASH diet apps. Additionally, app quality was included as an extra consideration in this research. Future studies could consider the usability of the apps and the accuracy of information related to the DASH diet and general dietary advice provided by the apps (Chen et al., 2015). By incorporating these additional criteria, dietary self-management apps can be evaluated in a more comprehensive manner.

The research findings indicate that the selected app shows promise in the Saudi context regarding feasibility and acceptability. However, a full-scale study with longer follow-up periods would be required to assess the app's effectiveness directly. Conducting an RCT in Saudi Arabia may face challenges if the app is not adapted to address participants' recommendations, particularly concerning the need to enhance its educational content to better align with the needs of Saudi users. Implementing these adjustments would support a more accurate and meaningful assessment of the app's impact. The primary outcome of the full-scale study will be to evaluate adherence to the DASH eating pattern over six months, and the secondary outcome is to assess systolic and diastolic blood pressure, self-efficacy, and user engagement with the app. The feasibility and acceptability study (Chapter 5) provided valuable insights into participant attrition rates, along with suggestions to improve the app. A full-scale trial may require modifications to the study protocol. For example, amendments to outcome measures may be necessary, such as using an online dietary assessment tool, such as myfood24, to overcome the limitations of traditional pen-and-paper dietary assessments. Real-world evaluation approaches may also be integrated within the full-scale trial through collaboration with the Noom developer to gain insights into app usage and participants' dietary details. In addition, translating the Noom app into Arabic could facilitate the recruitment process and ensure that a broad cross-section of potential users can test the app.

This research did not explore how TDF mechanisms of action support user engagement. For example, two participants withdrew from the feasibility study in this research due to the required diary log, which may have led to negative emotions. There is a need for further research to examine the factors influencing engagement with dietary smartphone apps and to relate these factors to the components of the COM-B and TDF mechanisms of action. This information could benefit stakeholders in public health, policymakers, researchers, and developers of digital behaviour change interventions, as it can enhance app engagement. In addition, this research did not address the effective use of BCTs to support dietary self-management. For instance, the research revealed varying opinions on app notifications, with some users finding them bothersome while others found them helpful. Researchers and developers will need to tailor the use of BCTs according to users' characteristics. Monitoring how participants interact with the BCTs and their outcomes will also be crucial, as this will enable adjustments based on the most effective techniques for promoting dietary self-management. BCTs, such as prompts and reminders, should be flexible over time to improve adherence and motivation.

Moreover, the research could not identify the characteristics of users who consistently engage with dietary smartphone apps; for instance, comparing the use of dietary smartphone apps by a housewife and a working woman. Further research is needed to investigate the relationship between user characteristics and their level of engagement in dietary self-management. Qualitative research can help researchers understand why some individuals are prone to either immediate or gradual disengagement during an intervention (Kay et al., 2022).

It is worth noting that the study participants were all well-educated and proficient in reading and comprehending English. Due to language barriers and the complexity of dietary apps, this study did not include older or less educated individuals. A study of 1,079 people in the Netherlands found that those who use mobile health apps are typically younger, more educated, and have better e-health literacy skills (Bol et al., 2018). This is likely because younger individuals, particularly millennials, are more familiar with smartphones in their personal and professional lives than older age groups (Granger et al., 2016). However, despite older Malaysians' lack of familiarity with m-health, they demonstrated a positive attitude towards its adoption. They expressed a willingness to use m-health for health management but highlighted the need for further education and training (Lee et al., 2020). There is a pressing need for additional research to uncover the challenges that less educated and older users may face when using dietary smartphone apps. This study will provide valuable insights into the obstacles they may encounter, thereby paving the way for a more inclusive app design. Involving these users in a co-design process could help identify features that can enhance the usability and accessibility of these apps for this demographic, ultimately improving the overall user experience for these individuals (Tong et al., 2022).

Recent research highlights the importance of family-centred interventions and mHealth applications in managing hypertension effectively. Engaging family members in healthcare initiatives has been found to improve health literacy, enhance communication, and promote lasting behavioural changes that positively impact individuals across generations (Woods et al., 2024). Meta-analyses of 16 RCTs further revealed that self-management strategies incorporating mHealth applications can significantly reduce blood pressure among those with hypertension (Zhou et al., 2024). These insights point to the potential for future studies to explore the combination of family-based educational interventions with mobile technologies. Such a strategy could enhance self-management practices by offering accessible and personalised solutions that harness familial support while integrating evidence-based clinical guidance.

Finally, while the research provides valuable insights into the feasibility and acceptance of dietary apps in Saudi Arabia, it is essential to acknowledge that the findings may not apply to other healthcare contexts. Future studies should expand their selection process to encompass various regions and healthcare settings. This approach could lead to the selection of different apps, such as the DASH To Ten app, instead of the Noom app. Future studies should also explore the use of the Noom app in different regions and healthcare settings in order to gain a more comprehensive understanding of its effectiveness and potential for broader adoption. The results of such research might help improve the Noom app and increase its accessibility worldwide.

6.6.2 Recommendations for policy, practice, and app developers

In Saudi Arabia, studies have shown that the population is willing to use mHealth apps to manage chronic conditions like obesity, diabetes, and high blood pressure (Alessa et al., 2021b; Alnasser et al., 2019; Alturki & Gay, 2019; Jabour et al., 2021). However, there are several barriers to using commercial dietary smartphone apps, such as language, cost, and concerns about their content. To address this, it is necessary to collaborate with smartphone app developers to develop culturally adapted and evidence-based Arabic smartphone apps to promote dietary self-management.

Potential users and experts should be involved during the app development process to ensure that the apps meet users' needs and provide maximum benefits in self-managing their conditions (Wykes & Schueller, 2019). Researchers' and developers' roles should not end with an app's release; guiding its incorporation into regular healthcare processes would improve its effectiveness.

Once apps are released, researchers will assess them for usability, which includes user performance and satisfaction, and acceptability, which measures users' willingness to use them. It is essential to conduct campaigns to promote them among the target population. As an example of a successful promotion campaign, Public Health England's Change4Life 'Be Food Smart' campaign encouraged parents to control their children's eating habits (STEED, 2017). The Food Scanner app, a part of this campaign, saw greater interest and downloads when famous people were used to support campaign messages (STEED, 2017). Thus, a well-planned and well-executed promotional campaign can significantly increase an app's uptake and make it a valuable self-management tool for chronic diseases.

Finally, Saudi Arabia's digital health researchers face significant challenges in securing sufficient funding. This has led to a lack of research in this area. One solution to promote mobile and digital health in the country is to establish research centres within key medical and academic institutions. These centres would serve as focal points for research, education, and training on the latest developments in mHealth. They would provide a dedicated space for researchers, medical professionals, and students to collaborate and innovate. By facilitating such collaboration, researchers can accelerate progress towards a more efficient, patient-centred healthcare system. Furthermore, these centres may be able to attract funding and partnerships from industry and government, thus enhancing their impact and reach.

6.7 Conclusion

This thesis highlights that weak emerging evidence suggests a potential positive impact of using DASH smartphone apps to support self-management, which may improve DASH diet adherence and help lower blood pressure. Finding high-quality, secure commercial apps to promote the DASH diet is challenging, however. Even though hundreds of such applications are available, most are of poor quality or suffer from privacy and security concerns. The study participants emphasised that dietary apps should be user-friendly, contain a comprehensive food database, provide individualised feedback, set realistic goals, and offer motivational information to encourage users to adhere to the DASH diet. Many participants recognised the benefits of dietary self-management apps, but several barriers remain to their wide adoption. These include difficulty of use, preference for dietetic monitoring, lack of support for local languages, and high cost. Despite these challenges, this research identified potentially suitable DASH apps, and healthcare professionals and patients agreed that the Noom app was the most suitable option for the Saudi context. Although using the Noom app was deemed feasible and acceptable, several improvements could be made to meet users' varying needs, expectations, and preferences. A full-scale trial to assess the app's effectiveness may require some modifications to the study protocol.

This research has practical implications for the field of mHealth. It employed a systematic, staged approach to identifying and selecting commercial dietary apps, which may guide researchers in making informed decisions when identifying and selecting dietary applications. This approach provides a solid basis for developing a high-quality RCT for a widely available DASH diet app. This research carefully identified and selected a commercial DASH diet app and evaluated its feasibility, usability, and acceptability among individuals with high blood pressure in Saudi Arabia. Dietitians can use these findings to recommend two high-quality, potentially effective, and secure apps to their patients, helping them manage the DASH diet. This research also explored the interactive features of dietary apps based on the end-user experience (people with high blood pressure) and health professionals, which may enable researchers and developers to create dietary applications that are more efficient and user-friendly. In Saudi Arabia, the findings of this research may contribute to further study in the field of mHealth through the use of commercial smartphone apps.

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Appendices

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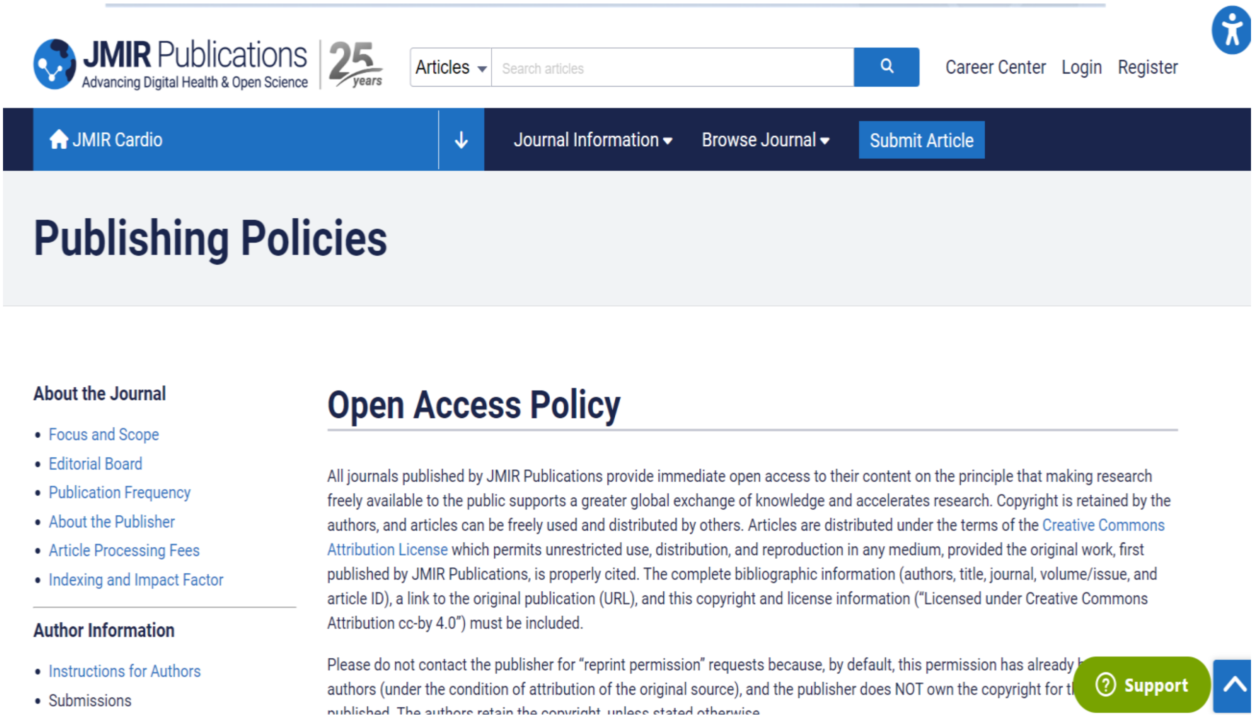
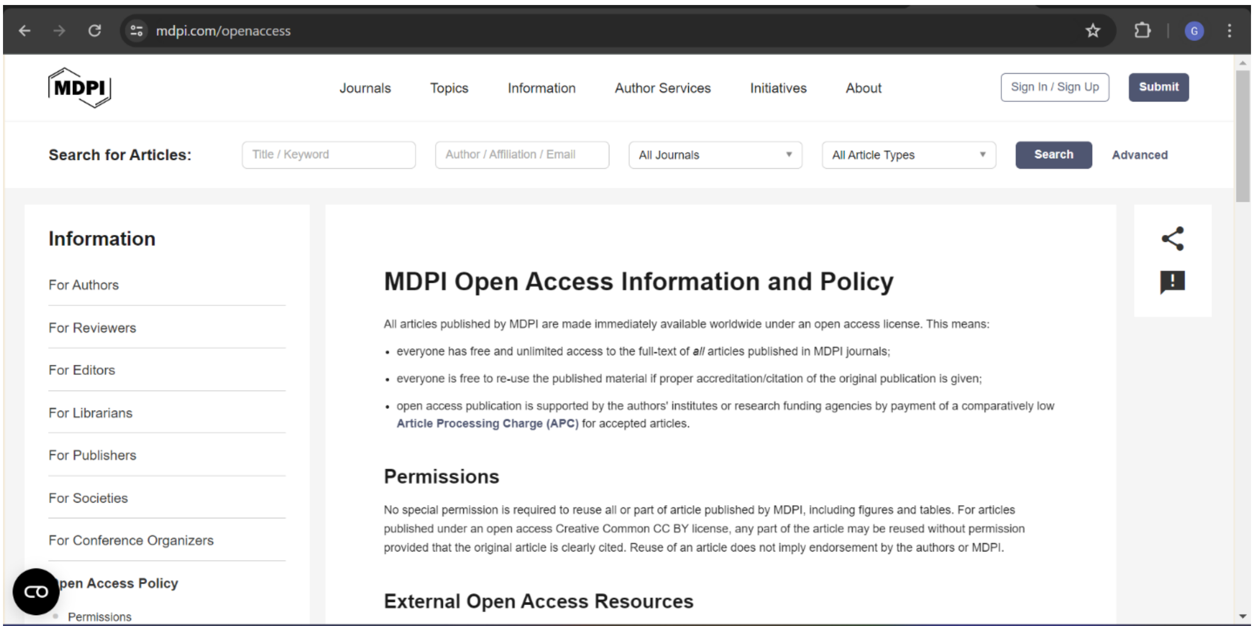
Permission to include published articles

JMIR (Publisher of the **systematic review and feasibility study**)



MDPI Nutrients (Publisher of the **App Store review**)



Appendix 2: Information Sheet

Participant Information Sheet for Patients

Experiences and perceptions of healthcare professionals and patients with prehypertension or hypertension accessing publicly available DASH diet apps for dietary self-management in Saudi Arabia: Qualitative study

You are being invited to take part in a research project. Before you decide whether or not to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. This project forms part of a PhD that will be submitted to The University of Sheffield, UK.

Thank you for reading this

1. What is the project's purpose?

This study aims to understand the experiences and perceptions of prehypertension or hypertension patients who have used the two high-quality Dietary Approaches to Stop Hypertension (DASH) diet self-management apps (Noom and DASH to Ten) to support DASH self-management and to identify the characteristics and functions of these apps that users find valuable and engaging. This research will be used to inform the selection of an app for use with a group of people with hypertension living in Saudi Arabia.

2. Why have I been chosen?

You have been asked to participate because you can read English, you have pre-hypertension or hypertension, and you have an iPhone. It is important to us to hear the views of patients on the DASH diet self-management apps and whether they could be used to support dietary self-management in Saudi Arabia.

3. Do I have to take part?

No, it is up to you to decide whether or not to participate. If you choose to participate, you will be given this information sheet to keep (and be asked to sign a consent form). You may withdraw at any time without any negative consequences. You do not have to give a reason. If you wish to withdraw from the research, please contact the student researcher to inform her.

4. What will happen to me if I take part? What do I have to do?

At visit one, you will be asked to sign a consent form. The researcher will then ask you to download both apps (DASH to Ten and Noom) using an iTunes voucher provided by the researcher. This 1st meeting is expected to last 30 minutes. You will be asked to use each smartphone app for one week to explore the characteristics and functions. After two weeks, during visit two, we will conduct a focus group. The researcher will ask you to complete a brief questionnaire concerning your personal information, such as age, gender, and education. The focus group discussion will consist of a range of 4–6 participants. The focus groups will be conducted in Arabic and divided by gender to respect Saudi culture. The researcher will ask you about the characteristics and functions of both apps and help you to compare both apps to select the most suitable one for the Saudi context. This discussion will last roughly 90 minutes and be recorded. Your discussion's audio recording will only be used for transcription.

You can withdraw your consent at any time before the recording. Your name will be removed from the list, to ensure your confidentiality. Due to the nature of the focus groups, data cannot be withdrawn during or after the focus groups. The recording will be kept on the University of Sheffield's secure online server in a password-protected folder. The Arabic recordings will be converted into an anonymous transcript by the researcher. This anonymous transcript will be converted into English by a qualified translation service in Saudi Arabia. After the PhD project is finished, the recording will be deleted.

5. What are the possible disadvantages and risks of taking part?

Taking part in this research carries no known risks. The utilisation of your time in participating is the sole drawback.

6. What are the possible benefits of taking part?

There are no immediate benefits for the people participating in the project, the hope is that this study will contribute to the advancement of knowledge regarding the use of DASH diet smartphone apps. Your participation will help select the most suitable app for patients by assisting in the understanding of patients' experiences with and impressions of using the DASH diet smartphone apps. This may eventually prove advantageous to them.

7. Will my taking part in this project be kept confidential?

All the information that we collect about you during the research will be kept strictly confidential and will only be accessible to members of the research team (the student researcher and her supervisors). You will not be able to be identified in any reports or publications unless you have given your explicit consent for this. All focus group participants are asked to respect the confidentiality of their fellow participants and to not repeat what was discussed in the focus group. However, we are not able to guarantee that all participants will adhere to this request. Instead of using your name, you will be identified by a number and not by name (e.g., participant 1, participant 3). Security will be established for any audio recordings and associated notes.

8. What is the legal basis for processing my personal data?

According to data protection legislation, we are required to inform you that the legal basis we are applying in order to process your personal data is that 'processing is necessary for the performance of a task carried out in the public interest' (Article 6(1)(e)). Further information can be found in the University's Privacy Notice .'

As we will be collecting some data that is defined in the legislation as more sensitive (information about health), we also need to let you know that we are applying the following condition in law: that the use of your data is necessary 'for archiving purposes in the public interest, scientific research purposes or statistical purposes' (9(2)(j)).

9. What will happen to the data collected, and the results of the research project?

Only the study team (the student researcher and her supervisors) will have access to the collected data (including personal information and transcripts), and they will process and analyse it in reports. All data will be stored on a secure university drive that only members of the research team at the University of Sheffield will be able to access. After the PhD study is finished, all audio recordings will be destroyed. After three years have passed and all publications have been completed, anonymous transcripts will be deleted. The study's results will be presented in the report. The findings could be presented at conferences or published in journals. You will not be identifiable in any published results.

10. Who is organising and funding the research?

The study is funded by Saudi Culture Bureau (Princess Nourah bint Abdulrahman University) in Saudi Arabia. The study is carried out by the PhD student at the School of Health and Related Research (ScHARR), University of Sheffield, UK.

11. Who is the Data Controller?

The University of Sheffield will act as the Data Controller for this study. This means that the University is responsible for looking after your information and using it properly.

12. Who has ethically reviewed the project?

This project has been ethically approved via the University of Sheffield's Ethics Review Procedure, as administered by the School of Health and Related Research (ScHARR), and Princess Nourah bint Abdulrahman University ethics committee.

13. What if something goes wrong and I wish to complain about the research or report a concern or incident?

It you are dissatisfied with any aspect of the research and wish to make a complaint, you can contact the researcher [Ghadah Alnooh; gsaalnooh1@sheffield.ac.uk; Phone: +966555490332]. If you wish to raise a complaint, please contact the main supervisor [Prof: **Mark Hawley;** mark.hawley@sheffield.ac.uk ; Phone: +44 114 222 0682] in the first instance. If you feel your complaint has not been handled in a satisfactory way you can contact the Head of the Department of the School of Health and Related Research (ScHARR) [Prof: **Mark Strong**; **m.strong@sheffield.ac.uk;** Phone:**+44 114 222 0812**]. If the complaint relates to how your personal data has been handled, please contact The University of Sheffield Data Protection Officer [Luke Thompson; data protection@ sheffield.ac.uk]. Also, you will find information about how to raise a complaint in the University's Privacy Notice: https://www.sheffield.ac.uk/govern/data-protection/privacy/general.

If you wish to make a report of a concern or incident relating to potential exploitation, abuse or harm resulting from your involvement in this project, please contact the project's Designated Safeguarding Contact [Prof: **Mark Hawley;** mark.hawley@sheffield.ac.uk ; Phone: +44 114 222 0682]. If the concern or incident relates to the Designated Safeguarding Contact, or if you feel a report you have made to this Contact has not been handled in a satisfactory way, please contact the Head of the Department the School of Health and Related Research (ScHARR) [Prof: **Mark Strong**; **m.strong@sheffield.ac.uk;** Phone:**+44 114 222 0812**]. and/or the University's Research Ethics & Integrity Manager (Lindsay Unwin; l.v.unwin@sheffield.ac.uk).
In Saudi Arabia, if you are dissatisfied with any aspect of the research and wish to make a complaint, you can contact the Research Ethics Manager at Princess Nourah bint Abdulrahman University Dr. Amal Fayed,(irb@pnu.edu.sa: Phone: +966594395059).

14. Contact for further information

For further information about this study please contact the

1. Student researcher: Ghadah Alnooh **Email**:gsaalnooh1@sheffield.ac.uk
   Phone:07377698476/ +966540072708
2. Supervisor: Mark Hawley **Email:** **mark.hawley@sheffield.ac.uk**
   Phone: **+44 114 222 0682**
3. Co supervisor: Elizabeth Williams **Email:** **e.a.williams@sheffield.ac.uk**
   Phone: **+44 114 215 9065**

Thank you very much for reading this

Participant Information Sheet for healthcare professionals (Family physicians and dietitians):

Experiences and perceptions of healthcare professionals and patients with prehypertension or hypertension accessing publicly available DASH diet apps for dietary self-management in Saudi Arabia

You are being invited to take part in a research project. Before you decide whether or not to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. This project forms part of a PhD that will be submitted to The University of Sheffield, UK.

Thank you for reading this

1. What is the project's purpose?

This study aims to understand the experiences and perceptions of healthcare professionals (family physicians and dietitians) who have used the two high-quality Dietary Approaches to Stop Hypertension (DASH) diet self-management apps (Noom and DASH to Ten) to support DASH self-management and to identify the characteristics and functions of these apps that users find valuable and engaging. This research will be used to inform the selection of an app for use with a group of healthcare professionals living in Saudi Arabia.

2. Why have I been chosen?

You have been asked to take part because you are a healthcare professional, you have experience dealing with pre-hypertension or hypertension patients, and you have an iPhone. It is important to us to hear the views of healthcare professionals on the DASH diet self-management apps and whether they could be used to support dietary self-management in Saudi Arabia.

3. Do I have to take part?

No, it is up to you to decide whether or not to participate. If you choose to participate, you will be given this information sheet to keep (and be asked to sign a consent form). You may withdraw at any time without any negative consequences. You do not have to give a reason. If you wish to withdraw from the research, please contact the student researcher to inform her.

4. What will happen to me if I take part? What do I have to do?

For visit one, the researcher will meet you at the hospital during break, where they will explain the study and give you the information sheet so you can read about the study. The researcher will ask you to sign the consent form. The researcher will then ask you to download both apps (DASH to Ten and Noom) and use each one for one week to explore the characteristics and functions. The researcher will provide an iTunes voucher to purchase both apps. The 1st meeting is expected 30 minutes. After two weeks, the researcher will conduct an interview in Arabic during visit two. First, the researcher will ask you to fill in your personal data, such as age, gender, and work experience in years. The researcher will then ask you questions about how your patients manage their hypertension, whether you have encouraged your patients to follow the DASH diet, and if you have previously used a smartphone dietary app. The researcher will then ask you about the features of both apps and compare them to help you select the best one. This discussion will last no more than 60 minutes and be recorded. Your discussion's audio recording will only be used for transcription.

You can withdraw your consent at any time prior to the analysis of the data (approximately 1 month after the 2^{nd} interview). If you decide to withdraw then all data will be deleted, to ensure your confidentiality. The recording will be kept in the University of Sheffield's secure online server in a password-protected folder. The Arabic recordings will be converted into an anonymous transcript by the researcher. This anonymous transcript will be converted into English by a qualified translation service in Saudi Arabia. After the PhD project is finished, the recording will be deleted.

5. What are the possible disadvantages and risks of taking part?

Taking part in this research carries no known risks. The utilisation of your time in participating is the sole drawback.

6. What are the possible benefits of taking part?

There are no other immediate benefits for the people participating in the project, the hope is that this study will contribute to the advancement of knowledge regarding the use of DASH diet smartphone apps. Your participation will help select the most suitable app for patients by assisting in the understanding of healthcare professionals' experiences with and impressions of using the DASH diet smartphone apps. This may eventually prove advantageous to them.

7. Will my taking part in this project be kept confidential?

All the information that we collect about you during the research will be kept strictly confidential and will only be accessible to members of the research team (the student researcher and her supervisors). You will not be able to be identified in any reports or publications unless you have given your explicit consent for this. Instead of using your name, you will be identified by a code. Security will be established for any audio recordings and associated notes.

8. What is the legal basis for processing my personal data?

According to data protection legislation, we are required to inform you that the legal basis we are applying in order to process your personal data is that 'processing is necessary for the performance of a task carried out in the public interest' (Article 6(1)(e)). Further information can be found in the University's Privacy Notice https://www.sheffield.ac.uk/govern/data-protection/privacy/general.'

As we will be collecting some data that is defined in the legislation as more sensitive (information about health), we also need to let you know that we are applying the following condition in law: that the use of your data is necessary 'for archiving purposes in the public interest, scientific research purposes or statistical purposes' (9(2)(j)).

9. What will happen to the data collected, and the results of the research project?

Only the study team (the student researcher and her supervisors) will have access to the collected data (including personal information and transcripts), and they will process and analyse it in reports. All data will be stored on a secure university drive that only members of the research team at the University of Sheffield will be able to access. After the PhD study is finished, all audio recordings will be destroyed. After three years have passed and all publications have been completed, anonymous transcripts will be deleted. The study's results will be presented in the report. The findings could be presented at conferences or published in journals. You will not be identifiable in any published results.

10. Who is organising and funding the research?

The study is funded by Saudi Culture Bureau (Princess Nourah bint Abdulrahman University) in Saudi Arabia. The study is carried out by the PhD student at the School of Health and Related Research (ScHARR), University of Sheffield, UK.

11. Who is the Data Controller?

The University of Sheffield will act as the Data Controller for this study. This means that the University is responsible for looking after your information and using it properly.

12. Who has ethically reviewed the project?

This project has been ethically approved via the University of Sheffield's Ethics Review Procedure, as administered by the School of Health and Related Research (ScHARR), and Princess Nourah bint Abdulrahman University ethics committee.

13. What if something goes wrong and I wish to complain about the research or report a concern or incident?

It you are dissatisfied with any aspect of the research and wish to make a complaint, you can contact the researcher [Ghadah Alnooh; gsaalnooh1@sheffield.ac.uk; Phone**:** +966555490332]. If you wish to raise a complaint, please contact the main supervisor [Prof: **Mark Hawley;** mark.hawley@sheffield.ac.uk ; Phone: +44 114 222 0682] in the first instance. If you feel your complaint has not been handled in a satisfactory way you can contact the Head of the Department of the School of Health and Related Research (ScHARR) [Prof: **Mark Strong**; **m.strong@sheffield.ac.uk;** Phone:**+44 114 222 0812**]. If the complaint relates to how your personal data has been handled, please contact The University of Sheffield Data Protection Officer [Luke

Thompson; dataprotaction@ sheffield.ac.uk]. Also, you will find information about how to raise a complaint in the University's Privacy Notice: https://www.sheffield.ac.uk/govern/data-protection/privacy/general.

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In Saudi Arabia, if you are dissatisfied with any aspect of the research and wish to make a complaint, you can contact the Research Ethics Manager at Princess Nourah bint Abdulrahman University Dr. Amal Fayed,(irb@pnu.edu.sa: Phone: +966594395059).

14. Contact for further information

For further information about this study please contact the

15. Student researcher: Ghadah Alnooh **Email**:gsaalnooh1@sheffield.ac.uk
    Phone: 07377698476 / +966540072708

16. Supervisor: Mark Hawley **Email:** **mark.hawley@sheffield.ac.uk**
    Phone: **+44 114 222 0682**

1. Co supervisor: Elizabeth Williams **Email:** **e.a.williams@sheffield.ac.uk**
   Phone: **+44 114 215 9065**

Thank you very much for reading this

Participant Information Sheet

Feasibility of a Commercial DASH Diet Smartphone App in Improving Dietary Self-Management among People with Raised Blood Pressure in Saudi Arabia: A Single-Arm Feasibility Study

You are being invited to take part in a research project. Before you decide whether or not to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. This project forms part of a PhD that will be submitted to The University of Sheffield, UK.

Thank you for reading this

1. What is the purpose of the project?

The DASH diet has been shown to be effective in lowering blood pressure. We aim to assess the feasibility and acceptability of using the NOOM app to support DASH diet self-management among people with raised blood pressure. Additionally, we will explore the feasibility of conducting a full-scale trial in the future to assess the app's effectiveness. The goal of using the NOOM app is to promote adherence to the DASH diet.

2. Why have I been chosen?

You have been asked to participate because you can read English, are prehypertensive or hypertensive, have a body mass index (BMI) of 25 or above, and have a smartphone. Additionally, you are willing to participate and be able to use the NOOM app for two months, fill out online questionnaires, and participate in an online interview.

3. Do I have to take part?

No, it is up to you to decide whether or not to participate. If you choose to participate, you will be given this information sheet to keep (and be asked to sign a consent form). You may withdraw at any time without any negative consequences. You do not have to give a reason. If you wish to withdraw from the research, do not hesitate to contact the student researcher to inform her, you can find the contact information on page 5.

4. What will happen to me if I take part? What do I have to do?

If you are interested in participating in this study after reading this information sheet, we will ask you to sign the informed consent form to confirm your willingness to participate.

After that, a researcher will send you three questionnaires via email and ask you to complete them. The questionnaires include a self-reported demographic questionnaire, a self-efficacy questionnaire, and the 24-hour dietary recall. Subsequently, the researcher will ask you to download the NOOM app and sign up to it. This app is free to download but with in-app purchases. To sign up for the app, please provide your name and email address. After that, the researcher will invite you to attend online training for 30–45 minutes to describe the potential benefits of the DASH diet and demonstrate how to use the NOOM app. The online training will consist of the trainer (the researcher) and five trainees. During the online session, you will receive details of a prepaid debit card via email to be used to pay for the NOOM program. The NOOM app instruction manual will be emailed to you with the principal researcher's contact details.

In week 1, we will ask you to use the app daily and to enter all the food and beverages you consume. **At the end of week 4,** you will receive an email requesting you to complete the Engagement with Diet Tracking questionnaire and a text message to remind you to complete the questionnaire. **After week 8 of the intervention**, we will require you to stop using the app and complete the 24-hour dietary recall, self-efficacy questionnaire, system usability scale (SUS) questionnaire (to evaluate the app's usability), Engagement with Diet Tracking questionnaire, and anthropometric information (a part of the demographic questionnaire). Also, we will send a text message to remind you to complete the questionnaires.

Finally, the researcher will conduct online interviews to gain insights into your experiences and the app's acceptability. The interviews will also investigate the perceived impact of the app on DASH diet adherence. We will identify any technical problems encountered using the app and determine what you liked and disliked about the study procedure. This discussion will last roughly 90 minutes and be recorded using Google Meet. We will interview you by phone if you do not have a Google account. The audio recording of the discussion will only be used for transcription purposes. The recording will be kept in a password-protected folder on the University of Sheffield's secure online server. The researcher will transcribe the Arabic recordings into an anonymous transcript. This will be analysed and the anonymous quotations will be translated into English by a qualified translation service in Saudi Arabia.

You can also withdraw your consent to participate in the study anytime. If you decide to withdraw, all data gathered from you will be deleted to ensure your privacy. After the PhD project is finished, the recordings and the questionnaires will be deleted.

5. What are the possible disadvantages and risks of taking part?

The risks associated with participating in the study are negligible. During the study, you will be asked about your experience using the NOOM app and your dietary habits. These questions may result in feelings of distress, upset, or discomfort. In our procedures, we conduct interviews and discussions following the intervention, and you may be asked questions you find uncomfortable to answer. If you are distressed, you can request that the researcher take a break or conclude the interview.

6. What are the possible benefits of taking part?

Evidence shows that smartphone DASH diet apps can enhance adherence to a diet and control blood pressure. Thus, you may be able to change your eating habits using the dietary smartphone app in this study. The benefits of the DASH smartphone app will be achieved if you maintain healthy dietary behaviours after the completion of the study. Additionally, your responses will assist us to improve study procedures in the future and in exploring technical issues.

7. Will my taking part in this project be kept confidential?

All the information we collect about you during the research will be kept strictly confidential and only accessible to members of the research team (the student researcher and her supervisors). You cannot be identified in any reports or publications unless you have given your explicit consent for this. Instead of using your name, you will be identified by number (e.g. participant 1, participant 3). Security will be established for any audio recordings and associated notes.

8. What is the legal basis for processing my personal data?

According to data protection legislation, we are required to inform you that the legal basis we are applying in order to process your personal data is that 'processing is necessary for the performance of a task carried out in the public interest' (Article 6(1)(e)). Further information can be found in the University's Privacy Notice .'

As we will be collecting some data that is defined in the legislation as more sensitive (information about health), we also need to let you know that we are applying the following condition in law: that the use of your data is necessary 'for archiving purposes in the public interest, scientific research purposes or statistical purposes' (9(2)(j)).

9. What will happen to the data collected, and the results of the research project?

Only the study team (the student researcher and her supervisors) will have access to the collected data (including all questionnaires and transcripts), and they will process and analyse it in reports. All data will be stored on a secure university drive that only members of the research team at the University of Sheffield will be able to access. After the PhD study is finished, all audio recordings and all questionnaires will be destroyed. After three years and all publications have been completed, anonymous transcripts and all Excel sheets will be deleted. The study's results will be presented in the report. The findings could be presented at conferences or published in journals. You will not be identifiable in any published results.

10. Who is organising and funding the research?

The study is funded by Saudi Culture Bureau (Princess Nourah bint Abdulrahman University) in Saudi Arabia. The study is carried out by a PhD student at the School of Health and Related Research (ScHARR), University of Sheffield, UK.

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13. What if something goes wrong and I wish to complain about the research or report a concern or incident?

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14. Contact for further information

For further information about this study please contact the

1. Student researcher: Ghadah Alnooh **Email**:gsaalnooh1@sheffield.ac.uk
   Phone: +966508250235/07377698476
2. Supervisor: Mark Hawley **Email:** **mark.hawley@sheffield.ac.uk**
   Phone: **+44 114 222 0682**
3. Co supervisor: Elizabeth Williams **Email:** **e.a.williams@sheffield.ac.uk**
   Phone: **+44 114 215 9065**

Thank you very much for reading this!

Appendix 3: Consent form

Patients Participant Consent Form

Experiences and perceptions of healthcare professionals and patients with prehypertension or hypertension accessing publicly available DASH diet apps for dietary self-management in Saudi Arabia

Please tick the appropriate boxes	**Yes**	**No**
Taking Part in the Project		
I have read and understood the project information sheet dated January /2023 or the project has been fully explained to me. (If you will answer No to this question, please do not proceed with this consent form until you are fully aware of what your participation in the project will mean.)	☐	☐
I have been given the opportunity to ask questions about the project.	☐	☐
I agree to take part in the project. I understand that taking part in the project will include 1) downloading and using both apps for 1 week, in order to explore the apps characteristics and functions, 2) participation in this study will include focus group which will be recorded. The transcripts of the recording will be anonymous and will be translated by a Saudi Arabia professional translation center to ensure accuracy.	☐	☐
I understand that by choosing to participate as a volunteer in this research, this does not create a legally binding agreement nor is it intended to create an employment relationship with the University of Sheffield.	☐	☐
I understand that my taking part is voluntary and that I can withdraw from the study **at any time/before or during the focus group.** I do not have to give any reasons for why I no longer want to take part and there will be no adverse consequences if I choose to withdraw.	☐	☐
How my information will be used during and after the project		
I understand my personal details such as name, phone number, address and email address etc. will not be revealed to people outside the project.	☐	☐
I understand and agree that my words may be quoted in publications, reports, web pages, and other research outputs. I understand that I will not be named in these outputs unless I specifically request this.	☐	☐
I understand and agree that other authorised researchers will have access to this data only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I understand and agree that other authorised researchers may use my data in publications, reports, web pages, and other research outputs, only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I give permission for the [all data from brief questionnaire and focus groups] that I provide to be deposited in University of Sheffield for the duration of PhD research and for three years after the completion of all expected publications so it can be used for future research and learning.	☐	☐
So that the information you provide can be used legally by the researchers		
I agree to assign the copyright I hold in any materials generated as part of this project to The University of Sheffield.	☐	☐
Optional		
I give permission to members of the research team to contact me about being involved in future research activities. I understand that agreeing to be contacted does not oblige me to participate in any future activities.	☐	☐

Healthcare Professional Participant Consent Form

Experiences and perceptions of healthcare professionals and patients with prehypertension or hypertension accessing publicly available DASH diet apps for dietary self-management in Saudi Arabia

Please tick the appropriate boxes	**Yes**	**No**
Taking Part in the Project		
I have read and understood the project information sheet dated January /2023 or the project has been fully explained to me. (If you will answer No to this question, please do not proceed with this consent form until you are fully aware of what your participation in the project will mean.)	☐	☐
I have been given the opportunity to ask questions about the project.	☐	☐
I agree to take part in the project. I understand that taking part in the project will include 1) downloading and using both apps for 1 week, in order to explore the apps characteristics and functions, 2) participation in this study will include an interview which will be recorded. The transcripts of the recording will be anonymous and will be translated by a Saudi Arabia professional translation centre to ensure accuracy.	☐	☐
I understand that by choosing to participate as a volunteer in this research, this does not create a legally binding agreement nor is it intended to create an employment relationship with the University of Sheffield.	☐	☐
I understand that my taking part is voluntary and that I can withdraw from the study **at any time/before One week after my interview, before my data have been analysed**; I do not have to give any reasons for why I no longer want to take part and there will be no adverse consequences if I choose to withdraw.	☐	☐
How my information will be used during and after the project		
I understand my personal details such as name, phone number, address and email address etc. will not be revealed to people outside the project.	☐	☐
I understand and agree that my words may be quoted in publications, reports, web pages, and other research outputs. I understand that I will not be named in these outputs unless I specifically request this.	☐	☐
I understand and agree that other authorised researchers will have access to this data only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I understand and agree that other authorised researchers may use my data in publications, reports, web pages, and other research outputs, only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I give permission for the [all data from questionnaires and interviews that I provide to be deposited in University of Sheffield for the duration of PhD research and for three years after the completion of all expected publications] so it can be used for future research and learning.	☐	☐
So that the information you provide can be used legally by the researchers		
I agree to assign the copyright I hold in any materials generated as part of this project to The University of Sheffield.	☐	☐

Participant Consent Form

Feasibility of a Commercial DASH Diet Smartphone App in Improving Dietary Self-Management among People with Raised Blood Pressure in Saudi Arabia: A Single-Arm Feasibility Study

Please tick the appropriate boxes	Yes	No
Taking Part in the Project		
I have read and understood the project information sheet dated /JUNE /2023 or the project has been fully explained to me. (If you will answer No to this question, please do not proceed with this consent form until you are fully aware of what your participation in the project will mean.)	☐	☐
I have been given the opportunity to ask questions about the project.	☐	☐
I agree to take part in the project. I understand that taking part in the project will include 1) downloading and using **the NOOM app** for two months, to promote DASH diet adherence.	☐	☐
I understand that I will be interviewed and give my consent for it to be recorded. Furthermore, I agree that the transcripts will be anonymous, analysed by the researcher, and then translated by a professional translation center in Saudi Arabia.	☐	☐
I understand that by participating as a volunteer in this research, this does not create a legally binding agreement, nor is it intended to create an employment relationship with the University of Sheffield.	☐	☐
I understand that my taking part is voluntary and that I can withdraw from the study **at any time.** I do not have to give any reasons for why I no longer want to take part, and there will be no adverse consequences if I choose to withdraw.	☐	☐
How my information will be used during and after the project		
I understand my personal details such as phone number and email address etc. will not be revealed to people outside the project.	☐	☐
I understand and agree that my words may be quoted in publications, reports, web pages, and other research outputs. I understand that I will not be named in these outputs unless I specifically request this.	☐	☐
I understand and agree that other authorised researchers will have access to this data only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I understand and agree that other authorised researchers may use my data in publications, reports, web pages, and other research outputs only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I give permission for all data from questionnaires and interviews that I provide to be deposited in the University of Sheffield for the duration of PhD research and three years after the completion of all expected publications so it can be used for future research and learning.	☐	☐
So that the information you provide can be used legally by the researchers		
I agree to assign the copyright I hold in any materials generated as part of this project to The University of Sheffield.	☐	☐
Optional		
I give permission to members of the research team to contact me about being involved in future research activities. I understand that agreeing to be contacted does not oblige me to participate in any future activities.		

Appendix 4: Search strategy (Systematic review)

Scopus 2008- February 2021		
No.	**Query**	***Results***
1	(TITLE-ABS-KEY ("Dietary Approach* to Stop Hypertension") OR TITLE-ABS-KEY ("DASH diet"))	*1712*
2	(TITLE-ABS-KEY ("mobile application") OR TITLE-ABS-KEY ("smartphone app*") OR TITLE-ABS-KEY ("smartphone") OR TITLE-ABS-KEY ("Cell phone") OR TITLE-ABS-KEY ("digital technology") OR TITLE-ABS-KEY ("mHealth") OR TITLE-ABS-KEY ("mobile health") OR TITLE-ABS-KEY ("mobile phone application") OR TITLE-ABS-KEY ("Mobile adj3 app*") OR TITLE-ABS-KEY ("*medical informatics applications") OR TITLE-ABS-KEY ("Ehealth") OR TITLE-ABS-KEY ("e?health") OR TITLE-ABS-KEY ("m?health") OR TITLE-ABS-KEY ("window adj3 phone") OR TITLE-ABS-KEY ("Apps") OR TITLE-ABS-KEY ("Iphone") OR TITLE-ABS-KEY ("software adj3 app*") OR TITLE-ABS-KEY ("mobile adj3 app*") OR TITLE-ABS-KEY ("mobile adj3 software") OR TITLE-ABS-KEY ("telehealth") OR TITLE-ABS-KEY ("Computer"))	*5,197,012*
#1 AND #2	(_(_TITLE-ABS-KEY_(_"mobile application"_)_OR_TITLE-ABS-KEY_(_"earphone app*"_)_OR_TITLE-ABS-KEY_(_"earphone"_)_OR_TITLE-ABS-KEY_(_"Cell phone"_)_OR_TITLE-ABS-KEY_(_"digital technology"_)_OR_TITLE-ABS-KEY_(_"health"_)_OR_TITLE-ABS-KEY_(_"mobile health"_)_OR_TITLE-ABS-KEY_(_"mobile phone application"_)_OR_TITLE-ABS-KEY_(_"mobile adj app*"_)_OR_TITLE-ABS-KEY_(_"*medical informatics applications"_)_OR_TITLE-ABS-KEY_(_"health"_)_OR_TITLE-ABS-KEY_(_"e?health"_)_OR_TITLE-ABS-KEY_(_"m?health"_)_OR_TITLE-ABS-KEY_(_"window adj phone"_)_OR_TITLE-ABS-KEY_(_"Apps"_)_OR_TITLE-ABS-KEY_(_"phone"_)_OR_TITLE-ABS-KEY_(_"software adj app*"_)_OR_TITLE-ABS-KEY_(_"mobile adj app*"_)_OR_TITLE-ABS-KEY_(_"mobile adj software"_)_OR_TITLE-ABS-KEY_(_"telhealth"_)_OR_TITLE-ABS-KEY_(_"Computer"_)_)_)_AND_(_(_TITLE-ABS-KEY_(_"Dietary Approach* to Stop Hypertension"_)_OR_TITLE-ABS-KEY_(_"DASH diet"_)_)_)_	*35*

Cochrane Library 2008- February 2021		
No.	**Query**	***Results***
#1	MeSH descriptor: [Dietary Approach* to Stop Hypertension] explode all trees	511
#2	MeSH descriptor: [DASH diet] explode all trees	623
#3	#1 OR #2	723
#4	mobile application	4147
#5	smartphone app*	4225
#6	smartphone	5213
#7	Cell phone	2061
#8	digital technology	1641
#9	mHealth	2076
#10	mobile health	7738
#11	mobile phone application	1194
#12	Mobile adj3 app*	241
#13	*medical informatics applications	178
#14	Ehealth	1645
#15	e?health	1648
#16	m?health	2104
#17	window adj3 phone 6	24
#18	Apps	3385
#19	Iphone	304
#20	software adj3 app*	1976
#21	mobile adj3 app*	241
#22	mobile adj3 software	181
#23	telehealth	2692
#24	Computer	49656
#25	#4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20 OR #21 OR #22 OR #23 OR #24	67591
#26	#3 AND #25	84

Embase *2008-February 2021*			
No.	**Query**	***Results***	**Type**
1	Dietary Approach* to Stop Hypertension.mp.	1440	Advanced
2	DASH diet.mp.	1565	Advanced
3	1 OR 2	2037	Advanced
4	mobile application.mp.	18814	Advanced
5	smartphone app*.mp.	6881	Advanced
6	smartphone.mp.	27114	Advanced
7	Cell phone.mp.or mobile phone	22121	Advanced
8	digital technology.mp.	3928	Advanced
9	mHealth.mp.	6976	Advanced
10	mobile health.mp.	8576	Advanced
11	mobile phone application.mp.	495	Advanced
12	(Mobile adj3 app*).mp.	26001	Advanced
13	*medical informatics applications/	10915	Advanced
14	Ehealth.mp.or telehealth/	17316	Advanced
15	e?health.mp.	6012	Advanced
16	m?health.mp.	7028	Advanced
17	(window adj3 phone).mp.	7	Advanced
18	Apps.mp.	11249	Advanced
19	Iphone.mp.	2213	Advanced
20	(software adj3 app*).mp.	10456	Advanced
21	(mobile adj3 app*).mp.	26001	Advanced
22	(mobile adj3 software).mp.	384	Advanced
23	Computer.mp.	1444116	Advanced
24	4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24	1532211	Advanced
25	#3 AND #25	30	

CINAHL 2008- February2021		
No.	**Query**	***Results***
S1	Dietary Approach* to Stop Hypertension OR dash diet	1180
S2	(mobile application or smartphone app* or Cell phone or digital technology or mobile health or mobile phone application or mHealth) OR (Mobile adj3 app* or *medical informatics applications or Ehealth or e?health or m?health or Apps or Iphone or mobile adj3 app* or telehealth) OR (Computer or software adj3 app* or window adj3 phone)	204,968
S3	((mobile application or smartphone app* or Cell phone or digital technology or mobile health or mobile phone application or mHealth) OR (Mobile adj3 app* or *medical informatics applications or Ehealth or e?health or m?health or Apps or Iphone or mobile adj3 app* or telehealth) OR (Computer or software adj3 app* or window adj3 phone)) AND (S1 AND S2)	15

Web of Science 2008- February 2021		
No.	**Query**	***Results***
1	Dietary Approach* to Stop Hypertension OR DASH diet	5,647
2	mobile application or smartphone app* or Cell phone or digital technology or mobile health or mobile phone application or mHealth or Mobile adj3 app* or *medical informatics applications or Ehealth or e?health or m?health or Apps or Iphone or mobile adj3 app* or telehealth or Computer or software adj3 app* or window adj3 phone	284,060
3	#1 AND #2	19

Appendix 5: PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist.

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title, page 68
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Appendix 5 p:258
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Page 71-73
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Page 73
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Page 73-74
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Page 73
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	73 + Appendix 4 p:254-257
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Page 73-74
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Page 74-75
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Page 75
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Page 74-75
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Page 76
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results	N/A- no mete-analysis conducted
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Page 76
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	N/A
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	N/A

Section and Topic	Item #	Checklist item	Location where item is reported
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Page 74
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	N/A- no mete-analysis conducted
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N/A
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	N/A
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N/A
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Page 77-78 Fig:2-1
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Page 77
Study characteristics	17	Cite each included study and present its characteristics.	Page 78-80
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Page 85-86 Appendix 7 P:264
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	P:81-85
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	P:81-85
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	N/A
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	N/A
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	N/A
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N/A
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	N/A
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Page 87
	23b	Discuss any limitations of the evidence included in the review.	Page 87-88
	23c	Discuss any limitations of the review processes used.	Page 87-88
	23d	Discuss implications of the results for practice, policy, and future research.	Page 89
OTHER INFORMATION			

Section and Topic	Item #	Checklist item	Location where item is reported
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	the review was not registered.
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	the review was not registered.
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	the review was not registered.
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	is funded by Princess Nourah bint Abdulrahman University, Saudi Cultural Bureau.
Competing interests	26	Declare any competing interests of review authors.	None declared
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	N/A

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71For more information, visit: http://www.prisma-statement.org/

PRISMA 2020 for Abstracts Checklist

Yes Section and Topic	Item #	Checklist item	Reported (Yes/No)
TITLE			
Title	1	Identify the report as a systematic review.	Yes
BACKGROUND			
Objectives	2	Provide an explicit statement of the main objective(s) or question(s) the review addresses.	Yes
METHODS			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for the review.	Yes
Information sources	4	Specify the information sources (e.g. databases, registers) used to identify studies and the date when each was last searched.	Yes
Risk of bias	5	Specify the methods used to assess risk of bias in the included studies.	Yes
Synthesis of results	6	Specify the methods used to present and synthesise results.	Yes
RESULTS			
Included studies	7	Give the total number of included studies and participants and summarise relevant characteristics of studies.	Yes
Synthesis of results	8	Present results for main outcomes, preferably indicating the number of included studies and participants for each. If meta-analysis was done, report the summary estimate and confidence/credible interval. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).	Yes
DISCUSSION			
Limitations of evidence	9	Provide a brief summary of the limitations of the evidence included in the review (e.g. study risk of bias, inconsistency and imprecision).	Yes
Interpretation	10	Provide a general interpretation of the results and important implications.	Yes
OTHER			
Funding	11	Specify the primary source of funding for the review.	is funded by Princess Nourah bint Abdulrahman University, Saudi Cultural Bureau.
Registration	12	Provide the register name and registration number.	NO

Appendix 6: Summary of study Characteristics (Systematic review)

First Author, Year and Country	Study Tittle	Study Characteristics		Input		Intervention			outcome	
		Participants (Sample Size, Mean Age)	Study Method, Duration	[e]mode	[g] content	mode	content	Theory	mode	content
Weerahandi et al (2020) USA	A Mobile Health Coaching Intervention for Controlling Hypertension: Single-Arm Pilot Pre-Post Study	N=17 age=18-65 prehypertension and stage 1 hypertension	Pilot study Pre-post evaluation 120 days	Text	Daily diet, BP, weight Step, goal, chat	In-App log, In-App chat with coach, Feedback by phone call, SMS, email	Personalized feedback about diet, number of steps, goal educational information	[f] NR	Self- reported	[c] **HS**: BP, weight, BMI, heart rate, [b] **BC**: PA **Engagement and Acceptability**
Darabi et al (2020) Iran	The effectiveness of a mobile phone education- based on self-efficacy and DASH diet among patient with high blood pressure: a randomized controlled trial	N=88 age= 30-69 hypertension	RCT 12 weeks	--	--	App + patient's compliance monitored by phone call, weekly text message	DASH diet recommendation based on self-efficacy	self- efficacy	Self- reported Questionnaire and clinical outcome measured by research team	**HS:** BP, weight and height **BC:** self-efficacy +PA
Toro-Ramos et al (2017) USA	Efficacy of a mobile hypertension prevention delivery platform with human coaching	N=50 age =18-75 prehypertension, hypertension	Pilot study per-post evaluation 24 weeks	Text	Daily diet, BP, weight, and PA,	In -App log, In – App communication by application message, biweekly phone call	Individual plan and goal with coach, educational information	Cognitive behavioural therapy, motivational interviewing	Self- reported	**HS:** BP**,** weight **Engagement**

First Author, Year and Country	Study Tittle	Study Characteristics		Input		Intervention			outcome	
		Participants (Sample Size, Mean Age)	**Study Method, Duration**	**mode**	**content**	**mode**	**content**	**Theory**	**mode**	**content**
Bozorgi et al (2021) Iran	The Effect of the Mobile 'Blood Pressure Management Application' on Hypertension Self-Management Enhancement: A Randomized Controlled Trial	N=120, age= 30-60 primary hypertension	RCT 24 weeks	Text	Daily BP	In -App log	Received feedback, reminder time for drug, visit date and BP measurement, DASH diet plan, send notification to the family, individual motivation messages	NR	The adherence to treatment measured by the Hill-Bone Scale, the clinical outcome measured by physician. The questionnaire was completed by trained researcher.	**HS**: BP, weight, **BC:** adherence to treatment, and PA [a]**DBC:** adherence to healthy diet [d] DASH **Satisfaction, Knowledge, attitudes**
Steinberg et al (2020) USA	Feasibility of a Digital Health Intervention to Improve Diet Quality Among Women with High Blood Pressure: Randomized Controlled Feasibility Trial	N=59, age= 21-70 hypertension	RCT 3month	Text	Daily diet	In- app log, SMS daily or weekly feedback with motivational message	Tailored feedback with DASH score, motivational message, educational video, tips for certain dietary change	NR	Self- reported questionnaires clinical outcome measured by research team	**HS:** BP **DBC:** adherence to healthy diet (DASH) **Engagement, Satisfaction**

[a] DBC: Dietary behaviour change, [b] BC: Behaviour change, [c] HS: Health status, [d] Dietary Approach to Stop Hypertension

[e] Mode: How to enter data in the app or how to deliver the intervention. [f] NR: Not reported [g] Content: the information that intervention gives or requires from user

Appendix 7: Quality criteria checklist of the articles included in a systematic review assessing the effectiveness of DASH mobile applications.

Author(s) (year	Quality rating	Validity Questions [a]												Comments /study limitations
		1	2	3	4	5	6	7	8	9	10	11	12	
Weerahandi et al (2020)	Poor quality	Y	Y	Y	Y	N	Y	N	NR	Y	Y	CD	NA	Despite having a good attrition rate. Bias was generated due to the study's design (pilot study, small sample size, lack of power analysis). Some missing information that affected study validity, it was not well-reported.
Toro-Ramos et al (2017)	Fair quality	Y	Y	Y	Y	Y	Y	Y	NR	N	Y	N	NA	Some have potential for titration bias, but it has a good sample size, a clear method was used and procedures well-reported.

N = no; Y = yes; CD = cannot determine; NA = not applicable; NR = not reported

Validity Questions [a]

1. Was the study question or objective clearly stated?

2.Were eligibility/selection criteria for the study population prespecified and clearly described?

3.Were the participants in the study representative of those who would be eligible for the test/service/intervention in the general or clinical population of interest?

4.Were all eligible participants that met the prespecified entry criteria enrolled?

5. Was the sample size sufficiently large to provide confidence in the findings?

6.Was the test/service/intervention clearly described and delivered consistently across the study population?

7.Were the outcome measures prespecified, clearly defined, valid, reliable, and assessed consistently across all study participants?

8. Were the people assessing the outcomes blinded to the participants' exposures/interventions?

9. Was the loss to follow-up after baseline 20% or less? Were those lost to follow-up accounted for in the analysis?

10. Did the statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests done that provided p values for the pre-to-post changes?

11. Were outcome measures of interest taken multiple times before the intervention and multiple times after the intervention (i.e., did they use an interrupted time-series design)?

12. If the intervention was conducted at a group level (e.g., a whole hospital, a community, etc.) did the statistical analysis take into account the use of individual-level data to determine effects at the group level?

Appendix 8: DASH diet Apps

	App name	App store	The developer	Version date	Cost	Number of downloaded	functions		comments
							Self - monitoring	DASH diet information	
1	My Dash Diet : Food tracker and low sodium Recipes	Android Apple	Prestige Worldwide Apps	19/04/2022	£8.48	+10,000	✓	✓	
2	Noom	Android Apple	Noom,Inc	8 Dec 2022	£0.62-£121.82	10M+	✓	✓	
3	Track – calorie Counter Nutritionnix	Android Apple	Nutritionnix	25 Oct 2021	£4.77-£23.6	---	✓	x	
4	DASH diet: weight loss plan	Android	Alebg	22/04/2022	£1.69	+10,000	✓	✓	
5	DASH Diet: Doctor Recommendation	Apple	Realized	2021	£ 10.84	--	✓	✓	
6	DASH to ten	Apple	Elencee, Inc	2020	£8.18	--	✓	✓	
7	DASH Diet Tracker	Apple	Rick Hutchinson	2021	£0.81	---	✓	x	
8	DASH Diet Recipes	Android	Riafy Technologies	2021	£1.29-52.99	+5,000	✓	✓	This app offers a variety of diets.
9	DASH diet plan and food tracker	Apple	Nikita Gnedin	2020	£7.66	---	✓	x	Nutrition information related to other diets
10	DASH daily tracker	Android	Rom Oded	18/05/2021	free	No reviews yet	✓	x	Technical issue
11	WHEELS for DASH VA	Apple	The University of Michigan	2022	--	---	✓	✓	The app is part of a research project and requires an access code.
12	WHEELS for DASH	Apple	The University of Michigan	2022	--	---	✓	✓	The app is part of a research project and requires an access code.

Appendix 9: Frequency of behaviour change techniques (BCTs) (n = 19) utilised in the apps reviewed

	BCTs	Explanation	Number of Apps
1	Self-monitoring of behaviour	Ask the person to monitor and record their behaviour(s), including recording their daily food consumption, blood pressure measurements, how many cups of water they drink, and their daily number of steps.	7
2	Self-monitoring of outcome(s) of behaviour	Require the user to weigh themselves at the end of each day / week or monitor their BP reading for some weeks and record their daily weight on a graph to encourage them to eat healthily.	7
3	Problem solving	Allow the user to analyse the factors that influence [a] DASH diet adherence and create strategies (e.g. diet self-mentoring) that include overcoming barriers that prevent DASH diet adherence.	7
4	Action planning	Set a plan to cook specific recipes suitable for hypertensive patients or send notifications to complete a task(s) (record food, drink water, measure blood pressure, exercise, read articles) at a particular time.	7
5	Feedback on outcomes of behaviour	Offer feedback on the behaviour outcome, such as informing the user of how much weight they lost and/or their blood pressure reduce	7
6	Review behaviour goal(s)	Enable the user to examine their performance of agreed-upon objectives, then modify based on their achievement.	7
7	Goal setting (behaviour)	Allow the user to define goals for the behaviour to be achieved, such as setting a daily aim of eating five pieces of fruit as specified in [a] DASH diet guideline.	7
8	Review outcome goal(s)	Enable the user to assess how successfully they have adhered to DASH diet recommendations, such as how much how much weight have you lost, or how much does BP decrease, and adjust their goals accordingly.	7
9	Feedback on behaviour	Provide feedback on performance of the behaviour by displaying data in a graph (e.g., how many calories the user ate each day) or traffic lights colours to demonstrated how healthy the food was and how many calories are consumed every day.	6

	BCTs	Explanation	Number of Apps
10	Information about health consequence	Provide educational information about the benefits of adherence to the DASH diet and consequences of non-adherence to the DASH diet to control hypertension.	5
11	Prompts/cues	Send notifications when it is time to do task(s), such as eating meals at a particular time, recording food or reading articles to remind and encourage the user.	5
12	Habit formation	Repeatedly prompt the user to perform a behaviour at the same time in order to elicit a behaviour, such as eating their food at a specific time.	5
13	Instruction on how to perform a behaviour	Provide information or tips on how to follow the DASH diet and general information on how to control hypertension.	4
14	Credible source	Present information based on evidence.	4
15	Social support	Offer social support, such as providing a place to chat with a coach or their friends.	4
16	Goal setting (outcome)	Allow the user to set a goal defined by a positive outcome, such as weight loss (e.g., 0.5 kg in a week).	3
17	Reduce negative emotions	Provide suggestions for activities, such as meditation, for reducing negative feelings.	2
18	Biofeedback	Inform the user of their blood pressure reading to encourage adoption of the DASH diet.	2
19	Social incentive	Add points for the user when they answer the quiz questions or achieve their goal.	1

[a] DASH: Dietary Approaches to Stop Hypertension

Appendix 10: Mapping functionalities to BCTs and TDF

Functionalities	BCTs	TDF
Self-monitoring	Self-monitoring of behaviour	Behaviour regulation
	Self-monitoring of outcome(s) of behaviour	
Communication with other	Social support	beliefs about capabilities
Goal setting	Goal setting (outcome)	Goals
	Goal setting (behaviour)	
	Review outcome goal(s)	
	Review behaviour goal(s)	
Food plan	Action planning	Skills beliefs about capabilities Goals Behaviour regulation
	Problem solving	
Educational information	Information about health consequences	Knowledge
	Instruction on how to perform a behaviour	
	Credible source	knowledge reinforcement
Feedback	Feedback on behaviour	Knowledge beliefs about consequences
	Feedback on outcomes of behaviour	
	Biofeedback	Skills Behaviour regulation
Reminder and Notification to log food	Prompts / cues	Memory attention and decision process
	Habit formation	Memory attention and decision process Behaviour regulation
	Action plan	goal
Stress management	Reduce negative emotion	Emotion

Appendix 11: Data privacy and security evaluation of apps (data gathering, sharing, and security) as stated in the privacy policy.

Note: One app did not have a privacy policy available.

	Privacy and security questions	iPhone (N = 2) n	Android (N =4) n	Total (N =6) n
Availability	Is the privacy policy available without the need to download the app?			
	No	0	0	0
	Yes	2	4	6
	Is the privacy policy available within the app?			
	No	0	2	2
	Yes	2	2	4
Accessibility	Is there a short form notice (in plain English) highlighting key data practices?			
	No	0	0	0
	Yes	0	0	0
	Not applicable	2	4	6
	Is the privacy policy available in any other languages?			
	No	2	3	5
	Yes	0	1	1
Data gathering	Does the app collect personally identifiable information?			
	No	0	0	0
	Yes	2	4	6
Data sharing	Does the app share users' data with a 3rd party?			
	No	0	1	1
	Yes	2	3	5
Data security	Does the app say how the users' data security is ensured? For example, encryption, authentication, and firewall			
	No	0	2	2
	Yes	2	2	4

Appendix 12: The Consolidated Criteria for Reporting Qualitative Research Checklist

Domain 1: Research team and reflexivity *Personal Characteristics*	
1. Interviewer/facilitator	GA conducted all interviews.
2. Credentials	Master of Public Health
3. Occupation	PhD student in the Division of Population Health at the University of Sheffield.
4. Gender	Female
5. Experience and training	I have undergone training in collecting and analysing data using qualitative research methods.
Relationship with Participants	
6. Relationship established	Before the study began, the primary researcher had no relationship with the participants.
7. Participant knowledge of the interviewer	Participants had no knowledge of the interviewer except that she was a PhD student promoting dietary self-management using smartphone apps.
8. Interviewer characteristics	It was difficult to avoid personal bias since the primary researcher was fully involved in the research process.
Domain 2: Study design Theoretical framework	
9. Methodological orientation and theory	The thematic framework analysis was used to analyse the semi-structured interviews and focus groups. Framework analysis involves five steps: (i) Familiarisation, (ii) identification of a theoretical framework, (iii) indexing, (iv) charting, and (v) mapping [1]. This study opted for the thematic framework analysis as it provides a distinct structure and analysis steps [2]. Its systematic approach renders it an ideal method for researchers, and it is effective for extensive and intricate qualitative data sets [2]. Framework analysis was also selected due to its suitability for addressing research questions pertinent to this study [3]. Furthermore, framework analysis enables the incorporation of pre-existing ideas, such as a priori themes, and allows unexpected aspects of the participant experience to be considered[1, 4]. As a result, the framework analysis employed in this study remained impartial towards both inductive and deductive analysis.
Participant selection	
10. Sampling	A purposive sampling strategy was employed to capture as wide a variety of patients with specific qualities as possible. To be eligible to participate, patients must be (1) individuals must be 18 years old or older and have a systolic blood pressure reading between 130 mmHg and 159 mmHg and a diastolic blood pressure reading between 85 mmHg and 99 mmHg, (2) were willing to read in the English language (second language in Saudi Arabia), (3) own an iPhone, and (4) have the desire to discuss and reflect on their DASH diet app experiences. A convenience sample was used to recruit healthcare professionals at KAAUH.
11. Method of approach	Patients and healthcare professionals were recruited from outpatient clinics in Riyadh, Saudi Arabia, at King Abdullah bin Abdulaziz University Hospital (KAAUH). The researcher identified eligible participants using clinical teams – the eligible

	subjects were recruited at the hospital's family clinics. The researcher shared her contact information, brief details of the project, and the inclusion criteria by asking the patients interested in participating to scan a QR code. Due to Coronavirus Disease 2019 (Covid-19) protocols, the researcher could not provide her contact information on paper leaflets.
12. Sample size	This study included fifteen patients and ten professionals (5 family physicians and five dietitians).
13. Non-participation	This study recruited 20 patients. However, three withdrew because their ages ranged from 67 to 72 and had difficulties dealing with technology, and two were excluded because they were underweighted, which meant that the two apps did not accept them.
Setting	
14. Setting of data collection	The data was collected from the family clinic at KAAUH, where patients visit regularly to monitor their hypertension and receive routine check-ups.
15. Presence of non-participants	No non-participants other than the interviewer (GA) were present during data collection.
16. Description of sample	As shown in Tables 1 and 2, participants characteristics are summarized.
Data collection	
17. Interview guide	The focus groups and interview guides were composed by reviewing the systematic review of the effectiveness of the DASH diet smartphone apps [5]and an app review and content analysis of a commercial DASH diet smartphone app[6]. The guides also drew from qualitative research conducted on other dietary smartphone apps. The interview schedule was intentionally broad, we discussed the apps' interactive functions separately to gain qualitative insights from patients and healthcare professionals on each function in both apps.
18. Repeat interviews	No repeat interviews were conducted
19. Audio/visual recording	Interviews were audio recorded
20. Field notes	Field notes were made during and after the interviews
21. Duration	The duration of the interviews and focus groups ranged from 30 to 45 min and from 75 to 90 min, respectively.
22. Data saturation	Data saturation was used to determine the sample size.
23. Transcripts returned	Participants did not receive transcripts for comment or correction.
Domain 3: Analysis and findings Data analysis	
24. Number of data coders	
25. Description of the coding tree	These recurring ideas were then grouped into similar themes to create a framework (7). The first part of the framework was developed using the topic guide of the interviews and focus groups as well as familiarisation with the data. Participants' attitudes toward hypertension self-management strategies and dietary self-management apps were examined in the first part of the framework. The second part of the framework explored the interactive functions in the apps and participants' attitudes toward both apps. Indexed transcripts were examined whenever a new theme or sub-theme was added to identify any

	potentially relevant information. Upon completion of the indexing, the framework was reviewed to ensure that only relevant information had been incorporated into its themes and sub-themes.
26. Derivation of themes	Themes were identified from the data using an inductive and deductive approach
27. Software	the MAXQDA (version 12, VERBI GmbH, Berlin, Germany) software program was used for the analysis.
28. Participant checking	Participants did not provide feedback on the study's findings.
Reporting	
29. Quotations presented	The findings have been illustrated and supported by quotations. Quotations are accompanied by participants' specialization and gender information
30. Data and findings consistent	The findings and the data presented are consistent. In this study, the unit of analysis was the theme rather than the statements' frequency.
31. Clarity of major themes	The research team discussed the codes identified in the initial coding process. All major recurring themes were carefully described in the findings to ensure a comprehensive and accurate representation of the data.
32. Clarity of minor themes	Subthemes are also described under each major theme.

References

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Appendix 13: Focus Group Interview Guide

Experiences and perceptions of healthcare professionals and patients with prehypertension or hypertension accessing publicly available DASH diet apps for dietary self-management in Saudi Arabia

I appreciate that you have agreed to take part in this study. The purpose of the study is to obtain insights into the perspectives and experiences of individuals who use a commercial DASH diet self-management app to control their blood pressure. We hope that the information you provide will help the researcher to select the most helpful DASH diet self-management app, that is appropriate for the Saudi context. I am going to be asking you questions about your experiences with, and perceptions of, using DASH diet self-management apps in general, after which I will ask you which app you prefer. There are no right or wrong responses in this conversation. The focus groups should take up to one hour. Do I have your permission to record the focus group on audio?
I want to emphasise once more that anything you say here is confidential. Please let me know if you feel uncomfortable answering any of the questions so we can skip them. Similarly, if at any time you decide that you do not want to proceed with the interview, please let me know so that we can end it. Do you have any questions before we begin? Do you consent to taking part in the interview and to it being audio recorded?

- Do you have prehypertension or hypertension?
- How long have you suffered from hypertension?
- How do you manage your prehypertension or hypertension?
- Has your doctor discussed self-management strategies or skills with you to control your BP, such as trying to follow the DASH diet?
- If yes, which strategies or skills have you adopted?
- What problems are you facing in adopting a dietary self-management strategy? Please provide details.

We are going to switch topics to focus more intently on how the features of DASH diet self-management applications increase user satisfaction and ongoing engagement.

- How long did it take for you to learn how to use the Noom and DASH to Ten apps? What kinds of skills are needed to use the apps well?
- What are their most useful functions/characteristics? Let's discuss the apps' functions/ characteristics in detail.
- First, could you tell me a bit about the sign-up process for both apps? Are you happy with the **registration process? Why? Which app do you prefer?**
- Second, could you tell me a bit about the homepage for both apps? Which homepage do you prefer and why?
- Third, what are your feelings about the dietary **self-monitoring/tracking and feedback features? Which method is more convenient: calorie counting or serving counting? Which is the best method for monitoring food intake?**
- **Fourth, what do you think about the reminder feature? Which app has the best reminder?**
- Fifth: Could you tell me a bit about the apps' **educational features? Which app provides the best information about the DASH diet?**
- **Finally, could you tell me a bit about the graphic and visual design of the apps, such as** colours**, fonts, icons and language?**

- What benefits do you experience when using the DASH diet self-management applications?
- Are there any drawbacks to using the apps? If so, please describe them.
- Do you think that some training is required to use the dietary smartphone apps?
- If you were designing a smartphone app, what other features would you consider adding to make it more attractive to you? And how would they help you?
- Finally, which app would you use in your everyday life: Noom or DASH to Ten? And why?

Interview closing.

Is there anything else about the apps that you would like to add?

Thank you for participating in this interview!

Appendix 14: Healthcare Professionals Interview Guide

Demographic Data

1	Age	
2	Gender	○ Male ○ Female
3	Profession	○ Family physician ○ Dietitian
4	Work experience in years	○ 1-5 years ○ 5-10 years ○ 10-15 years ○ 15-20 years

In your general experience…

1. How do your patients manage their hypertension?

2. Do you encourage them to change their dietary habits?

3. What are the main barriers that your patients face when they adopt the DASH diet?

4. Have you ever used a dietary smartphone app?

5. If yes, have you ever recommended that your patients use a dietary smartphone app? Which application, and why?

6. Do you think that using a dietary smartphone app would help them to adopt the DASH diet?

We are going to switch topics to focus more intently on the characteristics of both DASH diet self-management applications.

1. What are their most useful features? Let's discuss the apps' features in detail.
2. What do you think about users' information and health history in sign-up process?
3. What do you think about the dietary **self-monitoring/tracking and feedback features? Which method is more convenient, calorie counting or serving counting? Which is the best way to monitor one's food intake?**
4. **What do you think about the educational information provided by the apps?**

General experience using DASH diet self-management applications.

1. What benefits do you experience when using the DASH diet self-management applications?
2. Are there any drawbacks to using the apps? If so, please describe them.
3. Do you think that some training is required to use dietary smartphone apps?
4. **Finally which app would you recommend your patients use it in their everyday life: Noom or DASH to Ten? And why?**

Interview closing.

Is there anything else about the apps that you would like to add?

Thank you for participating in this interview!

Appendix 15: Ethical Approval (Qualitative Study)

The University Of Sheffield.

Downloaded: 13/12/2022
Approved: 07/12/2022

Ghadah Alnooh
Registration number: 200222035
School of Health and Related Research
Programme: PhD/ Health and Related Research

Dear Ghadah

PROJECT TITLE: Experiences and perceptions of healthcare professionals and patients with prehypertension or hypertension accessing publicly available DASH diet apps for dietary self-management in Saudi Arabia
APPLICATION: Reference Number 049904

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 07/12/2022 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 049904 (form submission date: 07/12/2022); (expected project end date: 25/10/2023).
- Participant information sheet 1112430 version 5 (07/12/2022).
- Participant information sheet 1112431 version 6 (07/12/2022).
- Participant information sheet 1112432 version 5 (06/12/2022).
- Participant information sheet 1112433 version 4 (06/12/2022).
- Participant consent form 1112436 version 4 (06/12/2022).
- Participant consent form 1112434 version 4 (06/12/2022).
- Participant consent form 1112435 version 4 (06/12/2022).
- Participant consent form 1112437 version 4 (06/12/2022).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Your responsibilities in delivering this research project are set out at the end of this letter.

Yours sincerely

Devianee Keetharuth
Ethics Administrator
School of Health and Related Research

Please note the following responsibilities of the researcher in delivering the research project:

- The project must abide by the University's Research Ethics Policy:https://www.sheffield.ac.uk/research-services/ethics-integrity/policy
- The project must abide by the University's Good Research & Innovation Practices Policy: https://www.sheffield.ac.uk/polopoly_fs/1.671066!/file/GRIPPolicy.pdf
- The researcher must inform their supervisor (in the case of a student) or Ethics Administrator (in the case of a member of staff) of any significant changes to the project or the approved documentation.
- The researcher must comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
- The researcher is responsible for effectively managing the data collected both during and after the end of the project in line with best practice, and any relevant legislative, regulatory or contractual requirements.

Kingdom of Saudi Arabia
Ministry of Education
Princess Nourah bint Abdulrahman University
(048)
Graduate Studies and Scientific Research Vice- Rectorate

المملكة العربية السعودية
وزارة التعليم
جامعة الأميرة نورة بنت عبدالرحمن
(٠٤٨)
وكالة الجامعة للدراسات العليا والبحث العلمي

IRB Registration Number with KACST, KSA: HAP-01-R-059

October 18, 2022

IRB Log Number: 22-0490
Project Title: 'Experiences and perceptions of healthcare professionals and patients with prehypertension or hypertension accessing publicly available DASH diet apps for dietary self-management in Saudi Arabia
Category of Approval: EXEMPT

Dear Ghadah Saud Alnooh, Dr Mark Hawley, Dr. Elizabeth Williams

Thank you for submitting your proposal to the PNU Institutional Review Board. Your proposal was evaluated considering the national regulations that govern the protection of human subjects. The IRB has determined that your proposed project poses no more than minimal risk to the participants. Therefore, your proposal has been deemed ***EXEMPT*** from IRB review. Please note that this approval is from the research ethics perspective only. You will still need to get permission from the head of the department in PNU to commence data collection.

Please note that the research must be conducted according to the proposal submitted to the PNU IRB. If changes to the approved protocol occur, a revised protocol must be reviewed and approved by the IRB before implementation. For ***any*** proposed changes in your research protocol, please submit a Request for Modification form to the PNU IRB. Please be aware that changes to the research protocol may prevent the research from qualifying for exempt review and require submission of a new IRB application or other materials to the PNU IRB. In addition, if an unexpected situation or adverse event happens during your investigation, please notify the PNU IRB as soon as possible. If notified, we will ask for a complete explanation of the event and your response.

Please be advised that regulations require that you submit a progress report on your research every 6 months. Please refer to the protocol number denoted above in all communication or correspondence related to your application and this approval. You are also required to submit any manuscript resulting from this research for approval by IRB before submission to journals for publication.

The researcher is personally liable for plagiarism and any violations of intellectual property rights.

IRB is not responsible for accuracy of statements on religious and cultural affairs so researchers must consult competent authorities.

For statistical services you are advised to contact the Data Clinic at the Health Sciences Research Center (hsrc-DC@pnu.edu.sa) or the Scientific Research Center at the Deanship of Scientific Research (dsr-rsc@pnu.edu.sa) extension 30711.

We wish you well as you proceed with the study. Should you have additional questions or require clarification of the contents of this letter, please contact me.

You can apply for research funding at (DSR-RS@pnu.edu.sa).

Sincerely Yours,

جامعة الأميرة نورة بنت عبدالرحمن
مجلس المراجعة المؤسسي
Institutional Review Board (IRB)
16 Oct 2022

[redacted]

Dr. Amel Fayed
Chairperson, Institutional Review Board (IRB)
Professor of Public Health. Chair of Research Methodology and Biostatistics Course.
Clinical Department, College of Medicine.
Princess Nourah bin Abdulrahman University, Riyadh, KSA
Mobile: (+966) 594395059 Email: aafayed@pnu.edu.sa; irb@pnu.edu.sa

الرقم: .... التاريخ: ..../..../....١٤هـ المشفوعات: ....

Appendix A

APP# 1-70004-024(1): Research Projects Proposal

جامعة الأميرة نورة بنت عبد الرحمن
Princess Nourah bint Abdulrahman University
مستشفى الملك عبد الله بن عبد العزيز الجامعي
King Abdullah bin Abdulaziz University Hospital

Academic Affairs/Research

Research Approval Form at KAAUH

1. Please complete electronically with signatories and submit to ATA-Research@kaauh.edu.sa
2. Attach a copy of the Research Proposal
3. Attach a copy of the IRB Approval
4. Attach a copy of the Institute/College approval letter *(for PNU and external researchers)*

Application Number *(Filled by the Research Office)*	RO-2022-P-035	Date	Enter Date

Personal information

Name	Ghadah Alnooh	Email	Gsaalnooh1@sheffield.ac.uk
Contact Number(s)	+966555490332	Affiliation *(Institute/Department)*	Internal - PNU
KAAUH ID *(for KAAUH researchers & PNU researchers with KAAUH ID)*	Enter Text		Department of Health Sciences, College of Health and Rehabilitation Sciences.
National ID *(for PNU & external researchers)*	1031778770		

Project Information

Level of Research	Doctoral Degree	Other: Enter Text	
Title of Research Project	**Experiences and perceptions of healthcare professionals and patients with prehypertension or hypertension accessing publicly available DASH diet apps for dietary self-management in Saudi Arabia**		
IRB Log Number	22-0490		
Type of Research	☐Clinical Trials ☐Meta-analysis	☐Human Studies ☐Lab Studies	☐Systemic Reviews
	☐Observational Studies	☐Case Control Study ☐Prospective Study	☐Retrospective Study ☐Case Reports
	Others: This study will use an exploratory, qualitative approach		
Study Start Date	19th December	Study Completion Date	3/19/2022
Principal Investigator (PI)	Ghadah Saud Alnooh	Co-Investigator (Co-PI)	Prof Mark Hawley, Dr. Elizabeth Williams
Department(s) to be conducted in at KAAUH	Family medicine clinic and Nutrition clinic		

Department Approval at KAAUH	Enter Text		
Funding/Grant Source	No funding		
The Project Involves the following *(please select all that applies)*	☒Humans ☐Animals	☐Clinical Study Drug ☐Biohazardous Materials	☐Clinical Study Device ☐Radioactive Materials
	☐Other: Enter Text		
Research Requirement	Enter Text		
KAAUH Facilities to be used in this Research	I need room to conduct the interview and focus group		
Services needed from the Research Office	☒Yes ☐No	If Yes, please specify: Please email family physicians and dietitians to encourage them to participate in this study.	

Investigator's Statement

By signing below, **I confirm** that I will use no research instruments and/or instructional materials including standardized tests, surveys, questionnaires, interview questions, observation protocols, etc. in the implementation of my research study other than those I have submitted to the Research & Academic Accreditation Compliance Office of ATA/KAAUH. I confirm that in the event I want to modify any aspect of this study, I will submit the modification(s) to the office for review and approval before implementation begins. Confidentiality, dignity and ethical rights for all participants should be strictly guaranteed.

By signing below, I confirm that **King Abdullah Bin Abdulaziz University Hospital** **will be identified** in any **reports, publications, or/and presentations about this study.**

I agree to provide a copy of the completed study to the Research & Academic Accreditation Compliance Office at KAAUH.

Ghadah Saud Alnooh	Ghadah Alnooh	27 November 2022
Name	Signature	Date

Investigator's Statement

By signing below, **I acknowledge** to:

- Keep all patients/ research/ hospital information shared with me **confidential and secure** by not discussing or sharing in any form or format (e.g. verbally, disks, tapes, transcripts, etc.) with anyone other than the participating researcher(s).
- **Return** all patients/ research/ hospital information in any form or format to the Researcher(s) when I have completed the research tasks.

Ghadah Saud Alnooh	Ghadah Alnooh	27 November 2022
Name	Signature	Date

Approvals

Department Research Committee / Officer	☒Approved	☐Not approved	Dr. Fahad AlMazyad Chairman / Consultant Family Medicine & CHO 15. 12. 22
Health Information Management Department *(for studies that requires patients' data collection)*	☐Approved	☐Not approved	
Research & Academic Accreditation Compliance Office Review	☒Approved	☐Not approved	[redacted] 15 December 2022

Appendix 16: Addirional quotations

Theme	Sub-theme	Initial codes	Patients	Healthcare professional
Managing hypertension [a]	***Hypertension self-management strategies***	Walking, salt reduction, a healthy diet and taking medicines, weight reduction, drinking water, sleeping well, following a low-cholesterol diet, and reducing stress.	• I try to **walk** every day for at least 1/2 hour I try to **reduce salts** and fats in food and of course with treatment (Focus group 1/female). • The doctor was focusing on reducing salt and fat in food, and also advising me to **reduce weight**, but with my busyness and lack of time to exercise and **cook healthy food**, I had to take **medication.** (Focus group 2/male) • The doctor advice me to drink water and sleep well (Focus group 1/female) • I Try to control **stress** as much as I can (Focus group 2/male) • The doctor advised me to follow a **low- cholesterol diet** because I had a high- -cholesterol level, and it was the leading cause of my high blood pressure (Focus group 1/male)	• The first axis is the axis of **medication** and nutrition, and this is essential, as I always advise patients, in general, to reduce salt and then raise the **level of vegetables and fruits**, especially fruits high in potassium, to improve blood pressure. This is in regard to nutrition and the fact that I advise my patients to follow the **DASH diet**, which is present, I mean, in the sources, there are references in Arabic, in reliable sources, I always tell the patient to write it on an external paper or let him write it in his mobile phone and start on it..... The subject of practising sports activity on a regular basis because of its impact has proven on pressure; therefore, **physical activity** should always be an integral part of behavioural therapy (Family physician/male) • For example, they are obese or overweight. At this stage, they need to be referred to a dietitian to give them a specific diet to **reduce their weight** (family physician/female).
	Barriers to dietary self-management	Busy life, irregular meals, lack of commitment and motivation, a weak will, the high cost of healthier foods, lack of awareness and skills, dietary habits, and patients' needs.	• Healthy meals are more **expensive** than unhealthy meals, and this is one of the obstacles that makes one not commit to a certain beginning: the prices are very high (Focus group 1/male). • A healthy diet needs an **arrangement** and needs someone to prepare it for you. No one will	• Most patients need **motivation**, do you think they don't know the benefits of fruits and vegetables? No, Let's go back to the point before: the lack of motivation to eat them (Dietician/ female). • I noticed that some **patients don't know** that the diet has something to do with high BP, unlike for example sugar and cholesterol, they know, I mean, especially

			cook for you separately unless you take care and cook for yourself and this is difficult as the working hours are very long (Focus group 1/male). • We need **behaviour change therapy**. Our problem is not knowledge itself. Our problem is changing nutritional behaviour, and this is the hardest thing. Evidence for that is that we stick to diets and things that they give for a month or months up to six months, and then we go back and relapse (Focus group 1/female). • **Lifestyle, in general, is fast-paced.** When one goes out in the morning to work at 7:00 or 8:00, they find themselves having to have anything in the office, a fast meal, snack, or chocolate, and they have an impact (Focus group 1/male)	when they come with high sugar or cholesterol, and I'm telling them about the diet, they know it, but with blood pressure, many don't know the relation (Family physician/male).
Dietary apps' potential and current reach	**Potential users**	Simple smartphone application. Educated, young adults.		• We use **simple** applications, such as blood sugar measurements. However, dietary applications are too complicated because they involve behaviour modification (Family physician/male). • According to the age, if he is aged, that means a person who is 60/70 years old, it is impossible to advise him to use it because it is difficult for him. But if he was young, from **30 to 40 years old, and educated,** I would feel the contrary because they like dealing with technology, but in all honesty, I have never used it with my patients(dietitian /female)

	Awareness of the dietary app benefits	Help users to achieve their goal, provide dietary assessments, commitment, increasing motivation, accessibility.	• Help to organise meals; for example, the application sends notifications to help you organize and adhere to your diet (focus group 1/male). • It gives you more time to understand what you have never understood from the specialist who has limited time, while applications help you calculate your calories, and you can know the alternatives and obtain clear information (focus group 2/male). • [By using the app] I can gain motivation (focus group 2/ male)	• The benefit is that aiming to help and facilitating registration of your daily habits, then after a period you can know whether you made right or not (Family physician/male). • The benefit is to review patient's diet during the previous days, especially some patients forget some meals he has taken. If the application register readings of blood pressure, this will help me in patient's review (Family physician/male)
	Awareness of the dietary app challenges	Lack of commitment, cost, language, lack of time, accuracy of information.	• The only defect is that the patient **entered the wrong information,** and the application makes the plan according to the entered information, which may not be in accordance with the patient, so the dietician must exist (focus group/female).	• **Compliance** is important because it always is as a result of pain, while blood pressure without pain is a painful thing for me that I try to decrease it, I mean high blood pressure without causing pain which a silent disease (family physician/male). • **I don't have enough time.** You know, within 10 to 14 minutes, I have to review medication with the patient and understand his health condition and other things. Therefore, I have no time to explain to him how to use technology. • **The cost**: I think the patient came to the clinic to obtain free treatment, so it is difficult for me to advise my patients to use a mobile application that requires money (family physician/male).

				• **Education level**: I was afraid advising them to use a somewhat complicated application and this may influence on stability. Therefore it couldn't be used properly, because it was used for one week, then got bored or they didn't know how to use it. Also, most nutrition apps support the **English** language (family physician/male)
Comparison of Apps	***Interactive apps functions***	Sign-up process	• Dash to Ten was very easy and fast and I immediately understood it, it took 10 minutes .... It didn't ask me for any information about myself, only there was a problem in asking for weight and height in imperial units and we in the Kingdom use metric units!! OK, how should I do the conversion process? I mean, maybe this is one of the obstacles in the Dash to Ten program, but the rest of the things are nice and fast (Focus group 1/female) • The NOOM App. had many questions, and it took me about one hour, but it was better on the one hand, as it was asking me questions that made me trust the App more and more. Yes, it was asking me about the types of food and what I like, what my habits about exercise are, about my weight and height, and if I'm sick of pressure and sugar or not (Focus group 1/ female).	• NOOM is based on changing people's thoughts about healthy eating, while DASH To TEN only takes basic information about height and weight and is very brief (Dietitian, female). • NOOM took more details, but honestly, registering could have been boring and challenging. Users might say, 'If this is [only] the beginning, I will withdraw.' It requires many details as if it wants to know your personality. I noticed that it is focused on reducing weight. It didn't focus on the DASH diet, for example, or patients with high blood pressure. It asks many personal questions, and it focuses on emotional aspects (if you like to travel, etc.). Some patients will say that these are useless details and will not continue. (Family physician, male)

		Dietary self-monitoring, tracking and feedback.	• NOOM App. has easier options for me to choose. I mean the meal is calculated, so when I wrote Shawarma, it showed me all kinds of Shawarma that I can eat, and also eggs, all kinds of eggs that might come to my mind, so I can choose the meal ((Focus group 1/ male). • It tells me that this food has these calories, and the damage can be this. I mean, it gives me feedback from the food that I eat, I mean I can avoid it, not just take it in and that's it (Focus group 2/ female). • I thought calculating serving size felt easier than counting calories, honestly, because calculating calories is more complicated I mean calculating quotas, for example, I can if I have a scale, I can calculate them, but the calories I have to read each product which is difficult (Focus group 1/ female).	• Dash to Ten is easier and NOOM is longer ... I noticed, and correct me, NOOM gives you open options, Dash to Ten is limited ... Dash to Ten has a problem for our society that the Dash itself doesn't include the options that we have, and are considered vegetables, and are considered part of the Dash, but they are not included!! I mean some types of broth and vegetables that are not among the options that are in the Dash I mean it becomes hard for me to calculate it. Yes, I mean for example I ate Saleeq!! Come on, for example, Saleeq …, how do I do? the names of the different foods can cause confusion, and even the names of vegetables we have sometimes can go by the name. Sometimes I eat only when I add it to a specific thing such as dressing, or I fry it or add anything on!! I mean we don't eat vegetables alone (Family physician/male) • NOOM's advantage is when it is distributed in groups of green, yellow, and orange colors with high density and low density I mean the advantage of NOOM is the feedback on the questions you have. In NOOM, it gives you feedback on the information and the skills you gain but in Dash to Ten, it only gives you information. Second, NOOM covers the psychological (how you feel and how do I motivate you). It covers mindfulness. (Family physician).
		Blood pressure self-monitoring	• It is a useful feature, but I did not use it (Focus group 2/ female).	• NOOM is better because it has this feature that alerts the patient. You are talking about a chronic disease, the complications of which are serious—heart disease (Dietitian, female)

				• To be honest, I did not see this feature (Dietitian, female)
		Reminder	• NOOM sends many times. I liked that when it sends the articles that are friends of NOOM. Do you understand me? In addition to reminding me of entries and other things, it gives you things that encourage you to continue, while Dash to Ten gives you a reminder about the entry. As I told you articles, it gives you an motivation, I mean, whatever it is, reading always renews determination, you understand me. I mean, when you hold something, you are lurking for a while, and when an article about this thing and its • importance comes back, your determination comes back, and you refill it again.... NOOM is more interactive than Dash to Ten (Focus group 2/ female). • I like Noom; send me notifications like this because it always makes me aware of what I ate (focus group 1/ male) • I liked DASH To TEN because it alerts me only once, which is enough. I downloaded the application when I was convinced to use it and continue with it. I would not download it and pay for it without being willing to	• NOOM is number one. I think that one of the things and the idea that NOOM is based on is motivating, and is working on motivating and this undoubtedly motivate patients to change (Family physician/male).

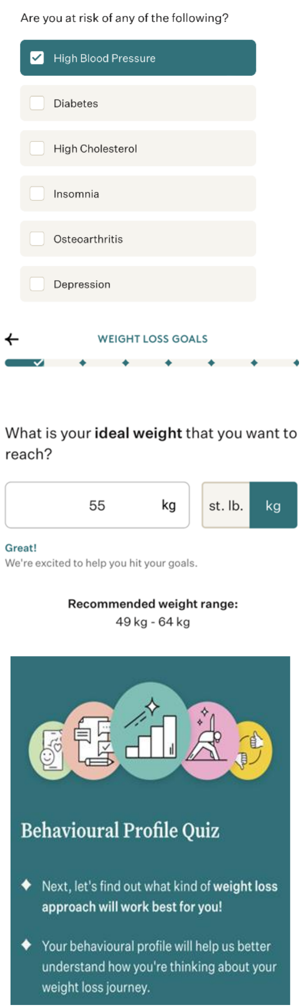
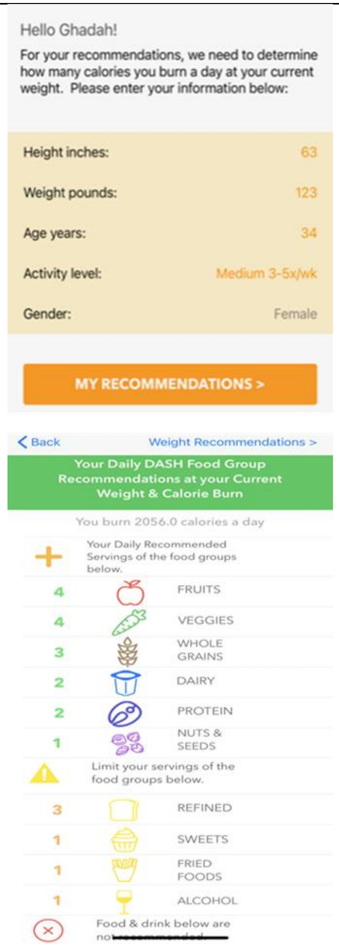
			follow the instructions. I felt that just one reminder was enough. If I don't have the desire in the first place, I will not continue, regardless of whether it reminds me many times or once. (Focus group 1, female)	
		Goal setting	• NOOM because from the beginning it makes me a plan and gave me a specific date to reach the goal (Focus group 2/ female).	• NOOM is better because it deals with dates and the plan is clearly stating on such a date we reach such and such weight, and also a beautiful thing in the application is that it added the Arabic dates (Dietitian, female)
		Educational features	• NOOM of course has a wide culture, there is no doubt about this, which means a flood of questions and a flood of clarifications and will bring you things in many ways. For example, if you answer a question, and move on to another group of questions, I feel that it is asking about the same thing, but in another way to fix the information (Focus group2/ female).	• NOOM mainly focuses on weight loss, saying that you should eat fruit and vegetables and a healthy diet, while DASH To TEN is more about the DASH diet. I felt that NOOM is suitable for weight reduction (Dietitian, female)
		social communication	• "I see that it is useful, especially when I use it for a long time and I want to know the food exchange list (Focus group 1, male). • I feel it is limited because if we depend on a single person, this person may not always be available, even if there are people available in the places at all	• Exchanging experience between users is essential as it builds trust among the app's users (Family physician, male)

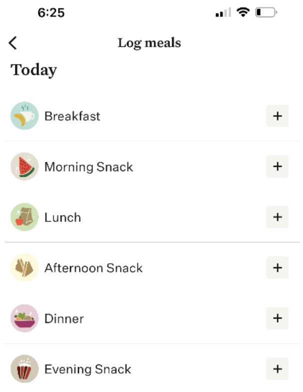
			times. […] Some applications offer 24-hour availability, but I like to deal with a specific person, which is better than dealing with a different person every time (Focus group 1, male).	
Comparison of Apps [a]	***Visual design***	Home screen, colour, font, and language	• I prefer Dash to Ten, NOOM uses hard words I need to explain. Not easy, they are scientific words you need to have a medical background to understand. I had to translate a lot, unlike Dash to Ten (Focus group 1/ male). • Dash to Ten had better colors and language and clearer font (focus group2/ male) • The pictures helped me and motivated me in Dash to Ten (focus group 2/ male) •	
Overall app assessment	***App preference***	Reasons for selecting the app.	• Because when I lost weight, I was able to control my pressure, and this application helps me to lose weight and do sports. (Focus group 1/female). • NOOM because it is more accurate in terms of entering food and calculating, as it tries to have an integrated picture of the patient so that the system in the end remains completely effective (Focus group 2/ female) • NOOM is better because it has an **extensive database** with many Arabic options. I found shawarma	• From my point of view eating with **mindfulness** is the basis for the success of any nutritional plan. I mean an essential element in any diet success, so I chose NOOM (Family physician, male) • I recommend NOOM because it is **comprehensive and I can cover more than one problem** ...... It may solve more than one problem for me, sometimes pressure may be the result of a previous problem, for example, overweight or having heart problems, so it can solve the problem for me by providing me with cause and effect (Dietician, female).

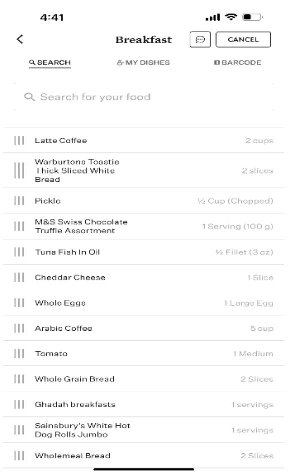
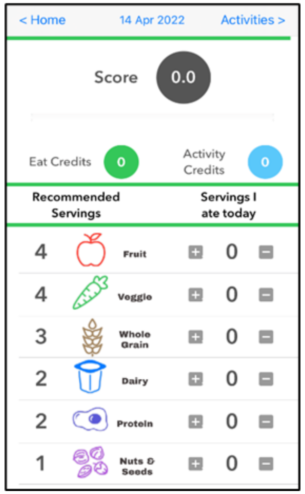
			and Kabsa. I found many good options and you can add the meals you are used to. It's not that Friendly, but in the end, it is a simple list where you can choose the one you want, so I think it is better (Focus group 1/ male). • For me, **Dash to Ten is easier** and simple, and everything in it is clear. You don't need to go deep. No registration and no information, I liked it more, everything in it is clear, and this encourages one to try the App. (Focus group 1/female)	• NOOM, because it is **easier to calculate the serving size**, as Dash to Ten deals with ounces, and patients do not know its meaning (Dietician, female). • This suits one group of people and that suits another. If I receive an old person, I would look for something easy for him. Something that he can fill in easily even if it is not accurate. While if I receive someone who can't write down to me the type of food and can search on the food menu, then I would recommend NOOM for them. So, anyone over 55/60 years old, I will probably recommend **Dash to Ten** for them and anyone younger can go for **NOOM.** I will be comfortable doing so because that means they will fill in the information I need. I wouldn't want them to come back in two weeks or a month and have done nothing because it is difficult (Family physician/male)
	Recommendation	Translation, Training, reducing the cost, and calculating sodium and potassium intake automatically.	• In the beginning, and to some extent, the new generation has knowledge on how to **use an application**, but for certain things, you must have someone to explain to you how and when to use it (Focus group 1/ male). • We recommend to translate it to **Arabic** (Focus group 2/ female). • The **price**, for example, is high, you download an application to save the value of going to the specialist, what is the benefit if you will pay, you are dealing with an application that reaches thousands of people, and the price	• I have to explain to the patient this application and its goal in a **brief session** in which we explain the functions of the application because it is possible if they don't know how to use it, they may discontinue (Dietician/female). • it needs to be in **Arabic**. The idea of the two applications is successful, but it needs to be in Arabic to be easy for people (Family physicians /male). • From the beginning, if he has high pressure, the focus should be on **providing articles** about pressure, as we said, for example, add articles about pressure (Family physician/female).

			is supposed to be better in order to gain a larger number of participants, I can browse the web and find all the information (Focus group2 /male). • [DASH to Ten] For example, adding a pressure monitoring function and saving readings so that we can compare the pressure readings (Focus group2 /female).	• NOOM, should address the issue of complexity in registration. Very important for patients is to be simple to ensure continuity (Family physician/male). • Both apps should calculate sodium and potassium intake automatically (Family physician/male).

Appendix 17: The description of each feature

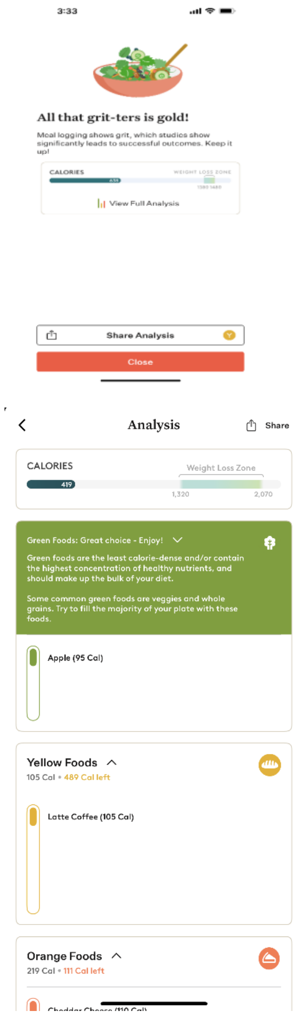
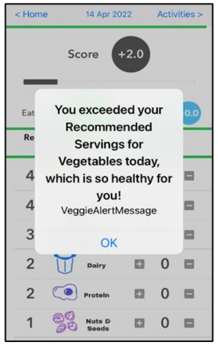
Functions	Noom	DASH To Ten	Description	Results
Sign-up			**Noom:** there are six registration steps with Noom , each of which includes a number of questions on the following aspects: 1) demographic profile (gender, age, weight and health history), 2) weight-loss goal (questions regarding a significant upcoming event the user might be preparing for or their focus for the plan), 3) behavioural profile and quiz (10 questions), 4) eating habits and nutrition, 5) health and fitness (questions regarding medical diagnoses [e.g., diabetes] or physical impairments) and 6) behavioural change (questions about the user's motivation). **DASH To Ten**: DASH To TEN asks for preliminary information, including name, email address, password, gender, height (inches), weight (pounds), age, and activity level, to determine how many calories users need to burn per day.	**Noom** • 13 out of 15 patients were not happy with the registration process due to it taking a long time (one hour on average). However, they believed that the amount of information required by Noom was needed to understand users and that the app asked them logical questions to build a good plan. • In the first session, during the observation phase, four patients (two females and two males) faced a technical issue with Noom 's registration and payment processes, which was resolved by deleting it and downloading it again. One participant also asked the other patients in his group to explain some questions in the app. • Most of the dietitians reported that they liked the Noom app because it uses the same type of assessment they employ in their clinics. One dietitian stated the following: Noom *is based on changing people's thoughts about healthy eating, while DASH To TEN only takes basic information about height and weight and is very brief* **[Dietitian, female].** • However, some family physicians criticised Noom because it focuses on weight reduction and collects information about mental health that is unimportant to them. **DASH To Ten** • All the **participants** said that signing up was easy, but some patients faced difficulties in converting inches and pounds into centimetres and kilograms.

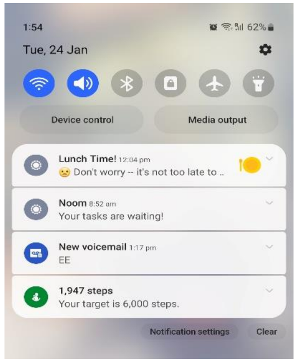
<table>
<tr><th>Functions</th><th>NOOM</th><th>DASH To Ten</th><th>Description</th><th>Results</th></tr>
<tr>
<td>Dietary self-monitoring</td>
<td>

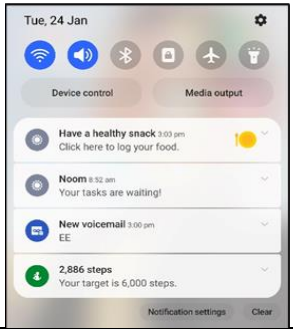
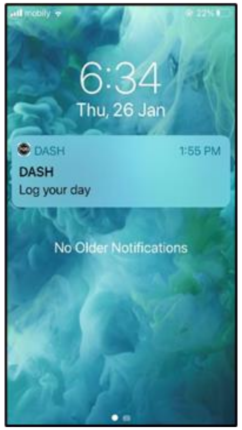

</td>
<td>

MUNE</td>
<td>Noom: users can self-monitor their dietary intake by searching for foods and drinks in the application's database, which is comprehensive and includes a variety of different foods. Users can also scan the food barcode to add their meals and log their dishes (create their meals).

DASH To Ten: Users self-monitor their dietary intake by calculating the serving size.</td>
<td>Noom
• 13 out of 15 patients reported that they preferred selecting their food from the app's database because it is more accurate and accessible. One patient said: The Noom app is easier for me because it has a list of meals. I can choose my meal and do not need to calculate the serving. I mean, the meal is calculated, so when I wrote "shawarma," it showed me all kinds of Shawarma I could eat.[Focus group 1, female]
• Most healthcare professionals reported that they liked Noom because it focuses on the type, not the quantity, of food and how patients cook. One Doctor said: DASH To TEN is easier, while Noom takes longer. [But] Noom gives you open options, while DASH To TEN is limited and problematic in our society. It is complicated to calculate the serving size for some Saudi dishes. For example, I ate Saleeg [it consists of white rice cooked with broth, chicken, and milk]. How do I calculate the serving size? Sometimes, I eat vegetables when I add them to a specific sauce or fry them or add something on! We don't eat vegetables on their own. [Family physician, male]
DASH To Ten
• Several patients reported struggling to calculate the serving size because they did not know how to do this. The app provides a brief guide for this purpose, but the patients mentioned that they did not understand the guide and that it did not include Arab food</td>
</tr>
</table>

Functions	Noom	DASH To Ten	Description	Results
Feedback			Both apps use the line chart to track weight-loss progress. **Noom:** uses a colour system (orange, yellow and green) to categorise all foods based on their calorie density and help users determine which ones are nutritious and which are not. In addition, NOOM offers quizzes to its users and gives them feedback on their results. **DASH To Ten:** Uses credits (points) to illustrate users' dietary intake and activity.	Noom : • All the patients said that Noom 's feedback was better than that of DASH To Ten because Noom provides users with information about their diets, instructions for improving healthy dietary behaviours and reflections on their behaviours. Some patients noted that feedback could motivate them to change their behaviour. • Most healthcare professionals liked Noom because it shows patients' behavioural performance and instructs them on how to improve their dietary habits. **According to a doctor's statement**: Noom*'s advantage is that it classifies food into green, yellow and orange groups according to calorie density. [Another] advantage is the feedback you get on the questions. The app gives you feedback on the information and the skills you gain, while DASH To Ten only gives you information. Also,* Noom *covers the psychological aspect—how you feel and how to motivate you. It uses mindfulness training.* ***[Family physician, male]***

<table>
<tr><th>Functions</th><th>Noom</th><th>DASH To Ten</th><th>Description</th><th>Results</th></tr>
<tr>
<td>Reminder</td>
<td>


</td>
<td>
</td>
<td>Both apps offer a reminder feature. Noom: push four daily notifications (breakfast, lunch, dinner, and reading articles).

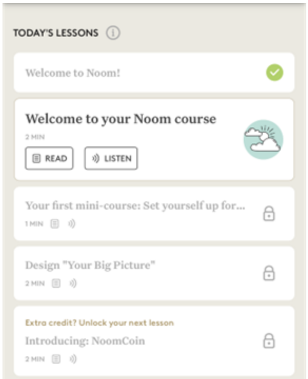
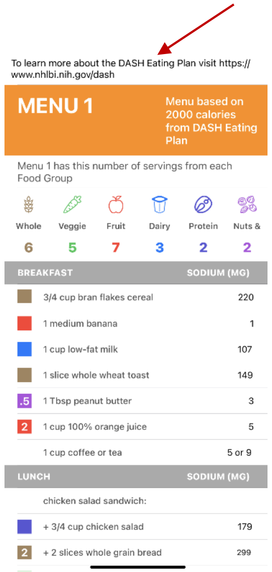
DASH To Ten: push one daily notifications</td>
<td>Noom

Most patients liked Noom 's reminder feature as it motivated them to continue to use the app.
Most healthcare professionals preferred Noom because it motivates patients to manage their diet. One male family physician said Noom is number one. I think that the idea Noom is based on is motivation. The app works on motivating, and this undoubtedly encourages patients to change. [Family physician, male]

DASH To Ten

One patient preferred DASH To TEN because it has only one daily reminder, which asks users to log their day. This person argued that the fact that she downloaded the app showed she was willing to change her behaviour, so she did not need many reminders.
</td>
</tr>
</table>

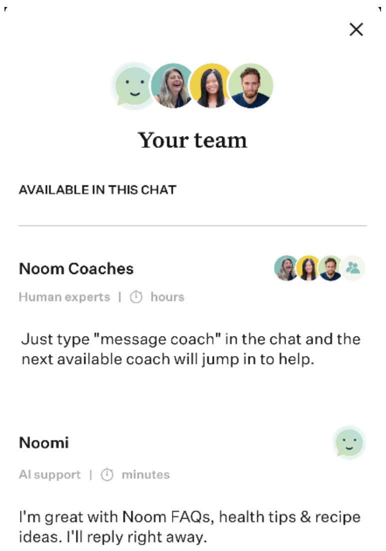
<table>
<tr><th>Functions</th><th>Noom</th><th>DASH To Ten</th><th>Description</th><th>Results</th></tr>
<tr>
<td>Educational features</td>
<td>

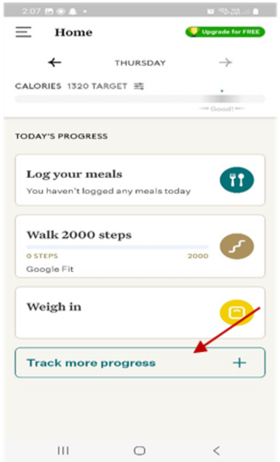

</td>
<td>

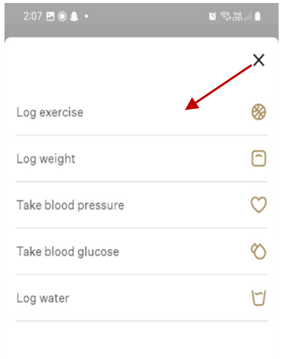
Once the link above is clicked, it will redirect the user to the website of the National Heart, Lung, and Blood Institute.</td>
<td>There are differences between the two apps in terms of the kind of information and the level of detail they provide.
Noom: The application provides users with a comprehensive range of content created by leading nutrition, medicine, and psychology experts to assist them in adopting and maintaining a healthy lifestyle. During the course of the program, participants are encouraged to develop healthy eating habits, increase their physical activity, and develop skills for overcoming obstacles and challenges. The courses cover various topics, including calorie balance, staying active, overcoming unhealthy behaviours, and seeking support from family and friends. Additionally, the app provides:
• Valuable guidance on reducing fat and calorie intake.
• Making healthy food choices.
• Replacing unhealthy snacks with healthier alternatives.
Further, the app emphasizes the importance of eating regularly, getting enough sleep, and managing stress. All of this content is delivered in short, easy-to-understand segments daily, making it easy for users to achieve their goals.

DASH To Ten:
Focus only on the DASH diet, its benefits, and how to adopt it.</td>
<td>Noom: The patients had different opinions on whether the apps offer helpful, clear and appropriate information. Most of them preferred Noom because it provides basic information on stress management, healthy eating, exercise and sleep as well as quizzes to help users remember what they have learnt. The app also offers guidance on altering behaviour and reminds users to read the articles. It even offers audio rentals for those who lack time to read. One patient said:
Noom has a broad knowledge base; there is no doubt about this, which means many questions and explanations. For instance, when you answer a question and move on to another set of questions, I feel that it is asking about the same thing but in a different way, thereby reinforcing the information. [Focus group 2, female]
While the healthcare professionals liked Noom, they criticised it for focusing more on weight loss than the DASH diet or high blood pressure. They chose Noom for two reasons: its interactive nature and its breadth, which addresses a variety of elements, including social and mental factors.

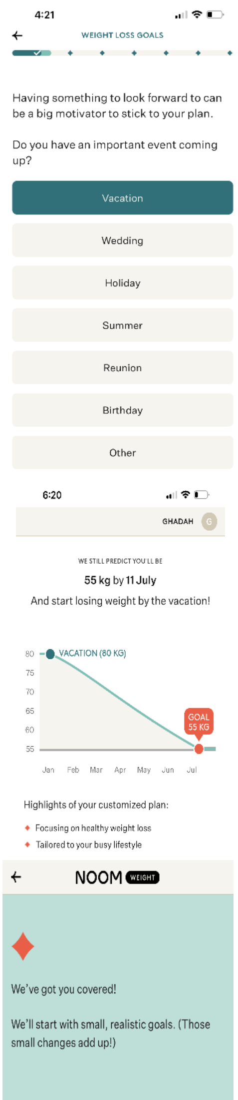
DASH To Ten: Some patients criticised the information feature in DASH To TEN, saying it was not clear. Many of them did not see it. One patient said, Noom has articles and a listening feature and displays them daily, while the educational information in DASH To Ten was not clear. However, based on the pictures, I understood that we should eat fruit and vegetables.[Focus group 1, male]</td>
</tr>
</table>

Functions	Noom	DASH To Ten	Description	Results
Social communication		NA	**Noom:** Only Noom enables users to share their weight-loss progress with their friends via social media platforms. Noom also allows users to chat with coaches in the app.	Many of the patients **liked this feature** because it helped them to contact coaches when they had questions about their diet or wanted to receive food exchange lists or advice on reducing sodium. One patient said, *I see that it is useful, especially when I use it for a long time and I want to know the food exchange list*. **[Focus group 1, male].**

<table>
<tr><th>Functions</th><th>Noom</th><th>DASH To Ten</th><th>Description</th><th>Results</th></tr>
<tr>
<td>Blood pressure self-monitoring</td>
<td>

The drop list appears when users press the button.

</td>
<td>NA</td>
<td>Only Noom has this feature.</td>
<td>Noom
Although healthcare professionals and patients consider blood pressure self-monitoring necessary, many patients did not use it due to the unclear interface.

During the interview, The researcher helped the healthcare professionals explore this feature.</td>
</tr>
</table>

Functions	Noom	DASH To Ten	Description	Results
Goal setting			Both apps provide goal-setting features. **In Noom**, a realistic goal is used. The app creates a practical action plan to avoid the underestimation/overestimation of abilities and determines the date for reaching the goal on this basis.	Both the patients and the healthcare professionals **liked Noom** because it provides a realistic action plan and motivates users by reminding them of special events such as travel or social events. From the beginning, Noom made me a plan and gave me a specific date to reach the target. **[Focus group 2, female]** *NOOM is better because it deals with a date and the plan is clearly based on that date. We reach such and such a weight. Another good thing about the application is that it has the Islamic calendar.* **[Dietitian, female]**

Appendix 18: CONSORT 2010 checklist of information to include when reporting a pilot or feasibility trial*

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a pilot or feasibility randomised trial in the title	164
	1b	Structured summary of pilot trial design, methods, results, and conclusions (for specific guidance see CONSORT abstract extension for pilot trials)	165-166
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale for future definitive trial, and reasons for randomised pilot trial	167-169
	2b	Specific objectives or research questions for pilot trial	167-169
Methods			
Trial design	3a	Description of pilot trial design (such as parallel, factorial) including allocation ratio	170
	3b	Important changes to methods after pilot trial commencement (such as eligibility criteria), with reasons	202-206
Participants	4a	Eligibility criteria for participants	
	4b	Settings and locations where the data were collected	170-171
	4c	How participants were identified and consented	170-171
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	170-172
Outcomes	6a	Completely defined prespecified assessments or measurements to address each pilot trial objective specified in 2b, including how and when they were assessed	173-175
	6b	Any changes to pilot trial assessments or measurements after the pilot trial commenced, with reasons	202-206
	6c	If applicable, prespecified criteria used to judge whether, or how, to proceed with future definitive trial	170-171
Sample size	7a	Rationale for numbers in the pilot trial	170
	7b	When applicable, explanation of any interim analyses and stopping guidelines	NA

Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	NA
	8b	Type of randomisation(s); details of any restriction (such as blocking and block size)	NA
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	NA
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	NA
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	NA
	11b	If relevant, description of the similarity of interventions	NA
Statistical methods	12	Methods used to address each pilot trial objective whether qualitative or quantitative	175
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were approached and/or assessed for eligibility, randomly assigned, received intended treatment, and were assessed for each objective	177 and 202
	13b	For each group, losses and exclusions after randomisation, together with reasons	177
Recruitment	14a	Dates defining the periods of recruitment and follow-up	177
	14b	Why the pilot trial ended or was stopped	NA
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	175
Numbers analysed	16	For each objective, number of participants (denominator) included in each analysis. If relevant, these numbers should be by randomised group	175-189
Outcomes and estimation	17	For each objective, results including expressions of uncertainty (such as 95% confidence interval) for any estimates. If relevant, these results should be by randomised group	--
Ancillary analyses	18	Results of any other analyses performed that could be used to inform the future definitive trial	175-189
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	NA
	19a	If relevant, other important unintended consequences	NA

Discussion			
Limitations	20	Pilot trial limitations, addressing sources of potential bias and remaining uncertainty about feasibility	195
Generalisability	21	Generalisability (applicability) of pilot trial methods and findings to future definitive trial and other studies	190
Interpretation	22	Interpretation consistent with pilot trial objectives and findings, balancing potential benefits and harms, and considering other relevant evidence	190-194
	22a	Implications for progression from pilot to future definitive trial, including any proposed amendments	193
Other information			
Registration	23	Registration number for pilot trial and name of trial registry	NA
Protocol	24	Where the pilot trial protocol can be accessed, if available	NA
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	NA
	26	Ethical approval or approval by research review committee, confirmed with reference number	176

*We strongly recommend reading this statement in conjunction with the CONSORT 2010, extension to randomised pilot and feasibility trials, Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomised trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up-to-date references relevant to this checklist, see www.consort-statement.org.

Appendix 19: 3-day dietary record form

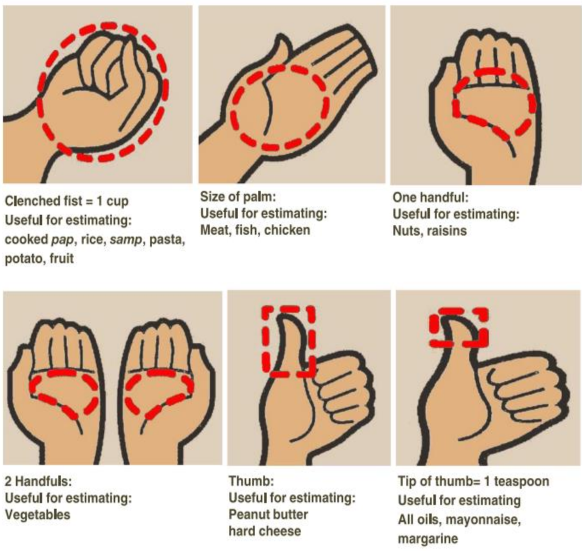
Please answer the following questions:

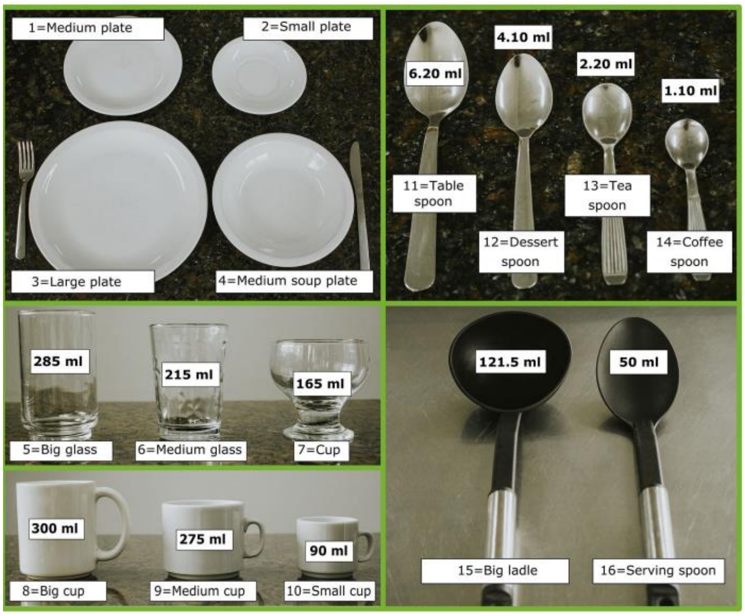
1: Please enter today's date / / 2023

This record enables the research team to find out what you have eaten the previous day; all you have eaten, including drinks, snacks, sauces, spices, pickles, and dressings, must be recalled. In this record, there is no right or wrong answer. Could you tell us what you have eaten? If you have any questions, please do not hesitate to contact the principal researcher: gsaalnooh1@sheffield.ac.uk

❖ **The questionnaire instruction:**

1. Kindly complete this form thrice, twice on weekdays and once on weekends. For instance, you may choose Sunday, Wednesday, and Friday.
2. In **Column 2,** Could you please provide some information about the ingredients in your dish and the cooking process? For instance, I had a tuna sandwich with mayonnaise and three cucumber slices. The tuna was the type packed in sunflower oil. As another example, I eat five spoons of rice with fried chicken breasts.
3. In **Column 3,** How much did you eat? **Please use the picture below to describe your eating.**





Individual 3-day food record form

1. which day of the week does this record?

☐ Sunday ☐ Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☐ Saturday

Column 1	Column 2	Column 3	Column 4
Occasion	**Description of food/ drink and ingredients**	**How much of this food did you consume (eat/drink)?**	**Where did you obtain this food [a]?**
Breakfast			
snacks			
Lunch			
snacks			
Dinner			
Last night meal			

a Source of food: 1. Homemade 2. Restaurant/cafeteria/fast food shop

Individual 3-day food record form

1. which day of the week does this record?

☐ Sunday ☐ Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☐ Saturday

Column 1	**Column 2**	**Column 3**	**Column 4**
Occasion	**Description of food/ drink and ingredients**	**How much of this food did you consume (eat/drink)?**	**Where did you obtain this food [a]?**
Breakfast			
snacks			
Lunch			
snacks			
Dinner			
Last night meal			

a Source of food: 1. Homemade 2. Restaurant/cafeteria/fast food shop

Individual 3-day food record form

1. which day of the week does this record?

☐ Sunday ☐ Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☐ Saturday

Column 1	Column 2	Column 3	Column 4
Occasion	**Description of food/ drink and ingredients**	**How much of this food did you consume (eat/drink)?**	**Where did you obtain this food?**
Breakfast			
snacks			
Lunch			
snacks			
Dinner			
Last night meal			

a Source of food: 1. Homemade 2. Restaurant/cafeteria/fast food shop

Pictures reference

1. Contreras-Guillén IA, Leeson S, Gili RV, Carlino B, Xutuc D, Martins MC, Zapata ME, Segovia-Siapco G, Sabaté J, Pacheco FJ, Pacheco SO. Development and Usability Study of an Open-Access Interviewer-Administered Automated 24-h Dietary Recall Tool in Argentina: MAR24. Frontiers in Nutrition. 2021 Aug 5;8:642387.
2. Ameh OI, Cilliers L, Okpechi IG. A practical approach to the nutritional management of chronic kidney disease patients in Cape Town, South Africa. BMC nephrology. 2016 Dec;17(1):1-8.

Appendix 20: The interview guide (Feasibility study)

NOOM has been available to you for eight weeks, and you have had access to its various features. You have received notifications to log your food, had the opportunity to set goals, view your dietary habits, and receive feedback. Could you share your experience with these features with us? Due to this, I will ask questions about it in today's interview. Do you have any questions before we begin? Can you consent to participating in the interview and recording it (audio)?

1. Can you tell me about your experience using NOOM?
2. Can you tell me about any aspects of NOOM you liked?
3. PROMPTS:
   - Ease of use and convenience
   - Design (color, information, and language)
4. Can you tell me about any aspects of NOOM you disliked?
   - Technical issue.
   - Record your food every day.
   - Reminder to log your food or to read articles.
5. How did using NOOM app for tracking your food/drink impact you? Why / why not?
   PROMPTS:
   - **Improve your dietary habits.**
6. How do you think it changed how you thought about your food choices, if at all?
7. Did using the app change your time thinking about your food choices?
8. Would you have wanted to use the app more than you did? If yes, what would have had to have been different for you to have used the app more?
9. What has your involvement in the overall project been like?
10. Did you need to contact the researcher during the project? If yes, about what? Was it helpful or not?
11. Did you need to use Google Translation or research to understand any topic?
12. Did anything happen in your life that made using the app challenging? For example, travel, holiday, or Eid?
13. In your opinion, were any tests or questionnaires that are particularly relevant to the project?
    PROMPTS:
    - **It was long.**
    - **Difficult to understand.**
    - **Time-consuming.**
14. Do you have any questions?

Thank you for participating in this interview!

Appendix 21: Integration matrix

Research questions	**Engagement with Diet Tracking *(QUAN)***	**DASH Diet Adherence *(QUAN)***	**DASH Diet Self-Efficacy *(QUAN)***	**system usability scale *(QUAN)***	**Interviews *(QUAL)***	**Comments to integration *(QUAN+QUAL)***
Is it feasible to use the Noom app to change dietary behaviour in hypertension patients and their self-efficacy? Is the Noom app acceptable to people with raised blood pressure?	Most participants (61%) logged their food 3-5 days a week and spent an average of 15 minutes using the app.	Participants had a small increase in DASH score over 8 weeks	Participants self-efficacy had slightly increased over 8 weeks	The overall mean SUS score was 73.7 (8.07); it indicates that the Noom app is acceptable. In response to question 10, half of the users indicated that they would need to learn a lot before using the Noom app.	Theme: acceptance Most users found the app very user-friendly and had no trouble making it a part of their daily routine. Moreover, the app is an excellent motivator for users to maintain healthy dietary habits. The app also offers various features that enable users to interact with it effectively and provide helpful feedback, motivational messages, and reminders to keep them on track with their dietary goals. However, all participants were not satisfied with some of the app suggestions, which did not impact their engagement with the app. Using the app during the holiday received mixed reviews from participants. While some found it helpful in controlling their dietary behaviour, others found it challenging. **Theme: app usability** Despite the easy app, some participants faced challenges logging complex food and traditional cuisine—also	The questionnaires and interviews are very **similar**, but the interviews provide more details about the reasons why users are satisfied with this application and why not. In addition, the difference in opinions among participants regarding using the app during holidays and usability issues could account for their varying levels of engagement with the app. **In the interview**, the participants shared that they needed to acquire a lot of knowledge before using the app, as they encountered difficulties while trying to log complex meals.

					some concerns about the food database accuracy.	
Are there any technical problems with the Noom app?				Three participants who responded to the question believed they would require technical assistance to use the Noom app.	**Theme: technical issue.** During the interview, we explored that the Noom app frequently freezes twice weekly or responds slowly; this happened to four participants. They solved this issue by uninstalling and reinstalling the app. Also, they contacted the Noom team support.	The questionnaires and interviews are very **similar**, but participants provided more details about the technical issues they faced and how they solved them during the interview.
Should any changes be made to increase the feasibility of using the Noom app?					**Theme: Suggested Improvements** There were some suggestions to increase the feasibility of using the Noom app, including translating it into Arabic, reviewing its content, and deleting any recommendations unsuitable for the Arab and Muslim populations.	Nothing to integrate

Appendix 22: Ethical Approval (Feasibility study).

The University Of Sheffield.

Downloaded: 02/06/2023
Approved: 02/06/2023

Ghadah Alnooh
Registration number: 200222035
School of Health and Related Research
Programme: PhD Health and Related Research

Dear Ghadah

PROJECT TITLE: Feasibility of Commercial DASH Diet Smartphone App to Improve Dietary Self-Management Among People with Raised Blood Pressure in Saudi Arabia: Single-Arm Feasibility Study
APPLICATION: Reference Number 053461

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 02/06/2023 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 053461 (form submission date: 02/06/2023); (expected project end date: 26/10/2023).
- Participant information sheet 1122051 version 3 (02/06/2023).
- Participant consent form 1122052 version 2 (01/06/2023).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Your responsibilities in delivering this research project are set out at the end of this letter.

Yours sincerely

Devianee Keetharuth
Ethics Administrator
School of Health and Related Research

Please note the following responsibilities of the researcher in delivering the research project:

- The project must abide by the University's Research Ethics Policy: https://www.sheffield.ac.uk/research-services/ethics-integrity/policy
- The project must abide by the University's Good Research & Innovation Practices Policy: https://www.sheffield.ac.uk/polopoly_fs/1.671066!/file/GRIPPolicy.pdf
- The researcher must inform their supervisor (in the case of a student) or Ethics Administrator (in the case of a member of staff) of any significant changes to the project or the approved documentation.
- The researcher must comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
- The researcher is responsible for effectively managing the data collected both during and after the end of the project in line with best practice, and any relevant legislative, regulatory or contractual requirements.

Kingdom of Saudi Arabia
Ministry of Education
Princess Nourah bint Abdulrahman University
(048)

Graduate Studies and Scientific Research Vice- Rectorate

المملكة العربية السعودية
وزارة التعليم
جامعة الأميرة نورة بنت عبدالرحمن
(٠٤٨)

وكالة الجامعة للدراسات العليا والبحث العلمي

IRB Registration Number with KACST, KSA: HAP-01-R-059

May 07, 2023

IRB Log Number: 23-0453
Project Title: Feasibility of Commercial DASH Diet Smartphone App to Improve Dietary Self-Management Among Prehypertensive Patients in Saudi Arabia: Single-Arm Feasibility Study
Category of Approval: EXEMPT

Dear Ghadah Saud Alnooh, Prof Mark Hawley , Dr. Elizabeth Williams
Thank you for submitting your proposal to the PNU Institutional Review Board. Your proposal was evaluated considering the national regulations that govern the protection of human subjects. The IRB has determined that your proposed project poses no more than minimal risk to the participants. Therefore, your proposal has been deemed ***EXEMPT*** from IRB review. Please note that this approval is from the research ethics perspective only. You will still need to get permission from the head of the department in PNU or an external institution to commence data collection.
Please note that the research must be conducted according to the proposal submitted to the PNU IRB. If changes to the approved protocol occur, a revised protocol must be reviewed and approved by the IRB before implementation. For ***any*** proposed changes in your research protocol, please submit a Request for Modification form to the PNU IRB. Please be aware that changes to the research protocol may prevent the research from qualifying for exempt review and require submission of a new IRB application or other materials to the PNU IRB. In addition, if an unexpected situation or adverse event happens during your investigation, please notify the PNU IRB as soon as possible. If notified, we will ask for a complete explanation of the event and your response.

Please be advised that regulations require that you submit a progress report on your research every 6 months. Please refer to the protocol number denoted above in all communication or correspondence related to your application and this approval. You are also required to submit any manuscript resulting from this research for approval by IRB before submission to journals for publication.

The researcher is personally liable for plagiarism and any violations of intellectual property rights.

IRB is not responsible for accuracy of statements on religious and cultural affairs so researchers must consult competent authorities.

For statistical services you are advised to contact the Data Clinic at the Health Sciences Research Center (hsrc-DC@pnu.edu.sa) or the Scientific Research Center at the Deanship of Scientific Research (dsr-rsc@pnu.edu.sa) extension 30711.

We wish you well as you proceed with the study. Should you have additional questions or require clarification of the contents of this letter, please contact me.

You can apply for research funding at (DSR-RS@pnu.edu.sa).

Sincerely Yours,

Dr. Najla AlMasoud

جامعة الأميرة نورة بنت عبدالرحمن
مجلس المراجعة المؤسسي
Institutional Review Board (IRB)

07 MAY 2023

[redacted]

Chairperson, Institutional Review Board (IRB)
Associate Professor of Chemistry Science, Chemistry Department, College of Science
Princess Nourah bin Abdulrahman University, Riyadh, KSA

الرقم: .... التاريخ: ....../....../١٤ هـ المشفوعات: ....

Appendix 23: The thematic framework analysis (Feasibility study)

Theme	Sub-theme	Initial codes
Acceptance [a]	Using the app and monitoring	Modify dietary behaviour, break old habits, integrate the app into daily routines, self-monitoring and feedback,
	Encouraging a culture of healthy eating	Recommend the app to friends, increase vegetable and fruit serving sizes for their children, eat healthy snacks, having dinner earlier.
	App functions	1) Push notifications, helpful, inconvenient times, annoying. 2)Daily goals such as calorie limits. 3)motivational messages 4)educational components, selecting healthier food, monitoring their dietary intake 5) Dietary self-monitoring and feedback: regulating food intake, increasing awareness, and gaining knowledge.
	App disengagement	busy or holiday
	dissatisfaction	suggestions and language, including limiting alcohol consumption, pork and incorporating American slang
app usability	How easy to use	The food database is convenient and valuable.
	Challenges	missing local options, mixed dishes, adding foods to the database, accuracy of food information, and integrating the app into their daily routine quickly.
technical issues	freezes or responds slowly	uninstalling and reinstalling the app, slow internet connections, and Noom app support team
suggestions for improvement	List of suggestions	Translating it into Arabic, reviewing its content, adding traditional Saudi and Arab cuisine, using it offline, decreasing the cost, and simplifying the method of logging food.

a A priori themes are indicated in italics