Use of Behaviour Change Techniques Delivered in Short Text Messages to Promote Cycling

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There are people that I am glad that they exist. Not only because they contribute to my functionality or wellbeing, but also because they give me courage, inspiration, and strength to go forward just by existing, in addition to their endless support. I would like to count a few of them for me.

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General Abstract

Cycling as a form of active travel can help tackle a range of environmental, economic, and health related problems experienced by society. Despite the known benefits and ubiquitous efforts to promote it, cycling is not commonly adopted in many countries and the best ways to promote cycling are not fully understood. In three empirical studies, the current thesis aims to (i) better understand the most effective intervention components to promote cycling, (ii) test if intervention components can be delivered via short text messages, and (iii) test if intervention components are effective in promoting cycling when delivered via short text messages. For identifying the active components of interventions, the Behaviour Change Techniques (BCTs) Taxonomy v1 was utilized. In the first empirical chapter, a meta-analysis of interventions to promote cycling was conducted and BCTs used in those interventions were coded to identify the most effective methods to promote cycling. The results indicated that interventions that used the BCTs of self-monitoring of behaviour and adding objects to the environment to promote cycling were more effective, whereas interventions that used restructuring the physical environment were less effective than others. In the second empirical chapter, a list of short text messages to deliver BCTs was developed and then assessed by experts through the Delphi Method. Sixty-six of the 93 messages were judged to deleiver their intended BCT with fidelity. In the third empirical chapter, an intervention was developed to promote active travel drawing on the results of the first and second studies. BCTs specific to the Control Theory delivered via short text messages had a small and non-significant effect ($g_+ = 0.24$) on behaviour. The findings are discussed in relation to future interventions for cycling and behaviour change in general, and implications for the next version of the BCT taxonomy.

Chapter One

Overview of Cycling and Interventions to Promote Cycling

Abstract

In the first chapter of this thesis an overall view of cycling is provided. A brief history of cycling, prevalence rates of cycling in the UK and other countries are provided. Demographic, infrastructural, and psychosocial correlates of cycling are explained. Furthermore, interventions, programmes, and governmental projects to promote cycling are mentioned. Gaps in understanding the best ways to promote cycling is discussed and ways to answer these questions are also suggested.

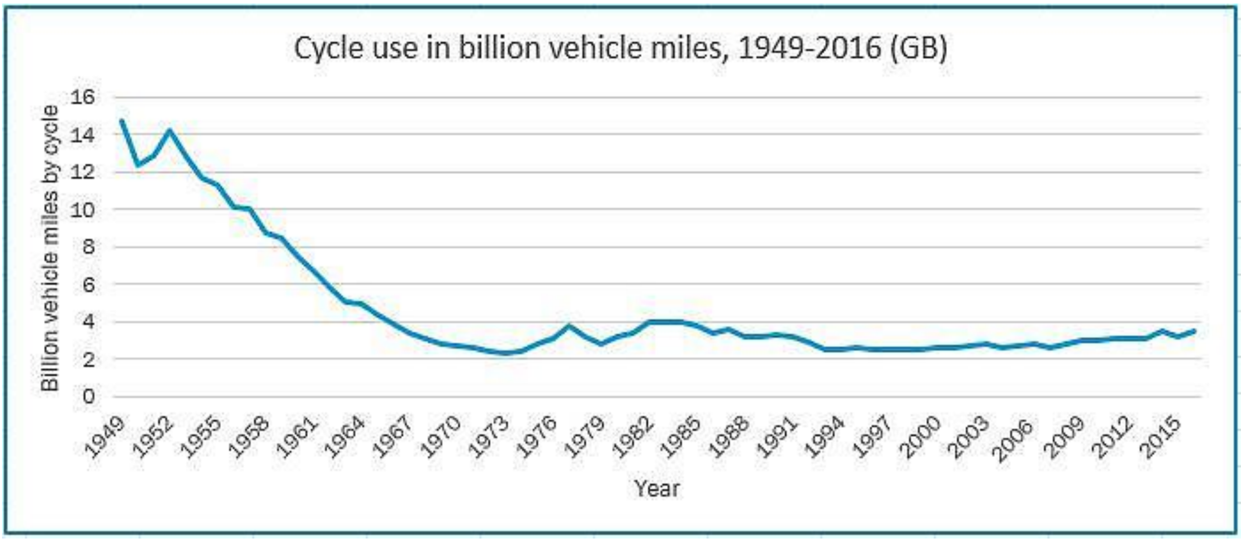
1. Introduction

1.1. A Brief History of Cycling

"Bicycular velocipedes", or "bicycles" as we call them now, were not invented but were upgraded with mechanical improvements over two centuries from 17th to 19th century (Apperson, 1898). Bicycles started to be mass produced in the late 19th century and became widely used through Europe, including the UK. The first cycling clubs were also founded in 1870s in the UK ("Cycling UK", 2018). As bicycles were easier to produce than cars, cheaper, and more convenient to use at that time, they were a more common form of transport than cars in the 19th century. Bicycle use experienced its golden age in the early 1950s. This period falls just before the rapid increase in car manufacturing and road infrastructure, especially for motorized traffic (Beroud & Anaya, 2015). However, after this period, cycling rates dropped rapidly (see Figure 1.1). For instance, the total distance cycled by people in the UK in 1949 was more than 14 billion miles whereas this dropped to 3.5 billion miles in 2016 ("Cycling UK", 2018). Currently, around the world, the main mode of transport is by car, despite the fact that bicycles are still more numerous than cars (the number of bicycles produced per year is more than twice of number of cars produced) (Worldometer, 2018), and more bicycles are owned per capita than cars in Europe (200 million bicycles vs 160 million cars) (European Cycling Lexicon, 2018).

Figure 1.1

Distance travelled by bicycle. Note that figures before 1993 are not directly comparable to 1992 or earlier, according to the DfT



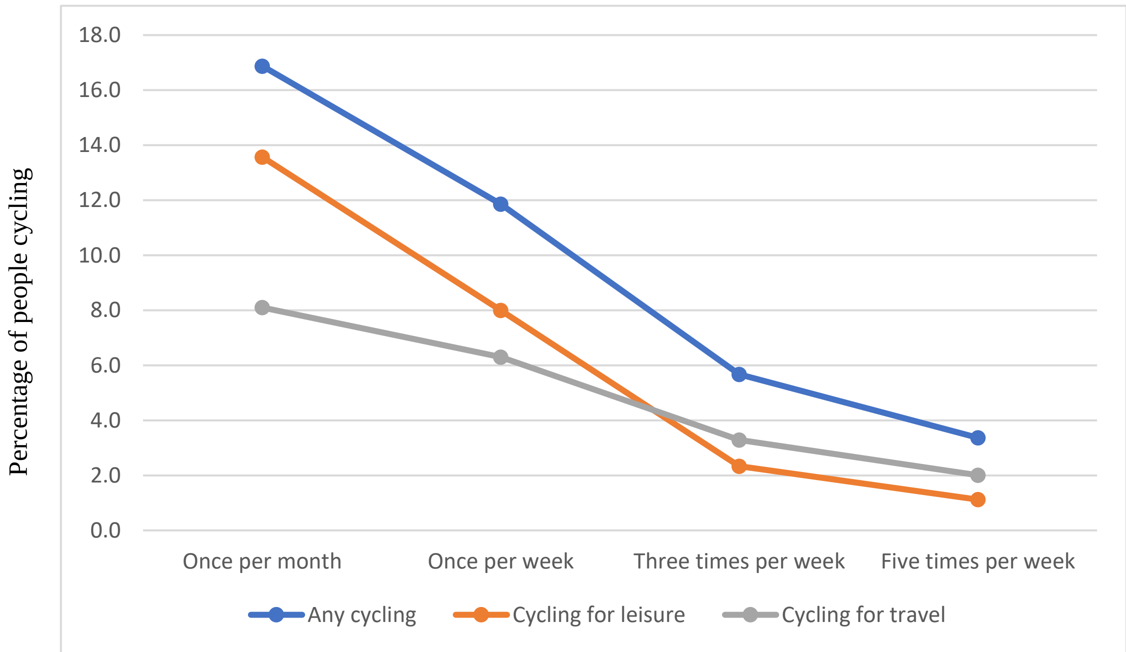
1.2. Cycling Rates across Countries

In the UK, 42% of the population own a bicycle but only 2.1% of all trips are made by bicycle and only 17 cycling trips were made per person in the UK in 2017 (Department for Transport [DfT], 2018a). The percentage of people that commute by bicycle is 3%. On the other hand, the percentage of trips that are made by car in the UK was 68% in 2017 f (DfT, 2018b). Cycling rates are similar in many other countries with only a few exceptions. In countries such as USA, Canada, Ireland, Switzerland, or France, less than 2% of all trips are made by bike (Diniz et al., 2015; Ministere de la Transition Ecologique et Solidaire, 2018; Nehme et al., 2016). In the United States, cycling is the main mode of transport only for 0.51% of the population (0.95% in principal cities) (Schoner et al., 2015). However, there are also countries where cycling rates are higher and cycling culture is more established. For instance, 80% of households in Germany have at least one bicycle and 10% of all trips are made by bikes (Bundesministerium fur Verkehr und digitale Infrastruktur, 2018; Lanzendorf, & Busch-Geertsema, 2014), 90% of population in Denmark owns at least one bicycle and 16% of all trips are made by bicycles (Cycling Embassy of Denmark, 2018), and 85% of the population in The Netherlands owns at least one bike and 27% of all trips are made by bicycles in The Netherlands (European Cycling Lexicon, 2018). On average, Dutch people make more than 250 trips per year by bicycles ("Dutch Cycling Figures", 2018).

Bike use has been increasing recently in the UK, albeit slowly. According to a National Travel Survey (with 194,622 respondents), the percentage of people who cycle at least once a month in the UK increased from 15.2% in 2010 to 16.1% in 2019 (DfT, 2016; DfT, 2020). Rate of cycling at least once a month is 9.7% in Germany ("Using a bicycle in Germany", 2018), and 19% in France (Statista, 2018). Naturally, cycling rates are even lower for higher frequencies such as once per week (11.2%) or three times per week (5.3%) (see Figure 1.2) and 69% of all adults in the UK do not cycle at all.

Figure 1.2

Cycling Modes and Frequency in UK (2017)



There are many opportunities to cycle in daily life. For instance, in 2017, 24% of all trips were under 1 mile and 68% of all trips were under 5 miles in the UK and only 0.87% and 2% of these trips were made by cycling, respectively (DfT, 2019). Of all car trips made in the USA, 59.4% are shorter than six miles, and 76.7% are shorter than 10 miles (Office of Energy Efficiency and Renewable Energy, 2018). Even when only the trips that are under a mile are considered, motored vehicles account for 60% of trips in USA (Bikeleague, 2018). In Belgium, only 25% of all trips under three kilometres and 14% of all trips under five kilometres are made by active modes of transport such as walking and cycling. In a study that collected data from a range of European cities including Barcelona, Helsinki, and Milan, Woods and Masthoff (2017) reported that 29.9% of all trips were under five kilometres, and 55.9% of all trips were under 10 kilometres and cycling had the smallest share in these trips. Hence, there is a gap of active travel even for very short distances, which can be filled with cycling. Filling these gaps with cycling, and active travel in general, is associated with health-related, environmental, and economical positive outcomes.

1.3. Why Do We Need to Promote Cycling?

1.3.1. Health-Related Reasons for Promoting Cycling

There are numerous economic, health, and environmental reasons for promoting cycling, both as a mode of transport and as a leisure pursuit. First of all, lack of regular physical activity increases risk of obesity, cardiovascular diseases, cerebrovascular diseases, diabetes, colorectal and breast cancer, hypertension, dementia, osteoporosis, and depression (Jarrett et al., 2012; Urhonen et al., 2016; Warburton et al., 2006), while also decreasing life quality, and brain plasticity (Bos et al., 2011; Brummer et al., 2011). As a consequence, lack of regular physical activity is the fourth highest cause of mortality (Petrunoff, Rissel, & Wen, 2016). Sedentary life causes approximately 3,200,000 deaths every year, and another 1,500,000 are caused by pollution, traffic accidents, and alike (Fernandez-Heredia et al., 2014). Longitudinal studies have shown that people who commute via cycling have 30 to 39% less all-cause mortality rates than those who do not (Andersen et al., 2000; Diniz et al., 2015; Department of Health, 2016). Furthermore, adults who cycle regularly have fitness levels of 10 year younger counterparts who do not cycle at all (Tuxworth et al., 1986).

Obesity, as a condition which could be prevented with regular exercise, is a major risk factor and it is associated with breast and colorectal cancer (Torre et al., 2015), diabetes (Wild et al., 2004), heart disease, hypertension, osteoarthritis, disability for work, and premature death (Brujin et al., 2005). It is also associated with negative psychosocial consequences in earlier ages such as poor self-esteem, teasing, distress, and emotional problems (Falkner et al., 2001). Even though most interventions targeting obesity fail to yield long-term results, cycling can be directed at both prevention and treatment of obesity (Brujin et al., 2005; Hemmingsson et al., 2009) as well as diabetes (Piwek et al., 2015). Without any intervention, it is estimated that by 2050, 60% of men, 50% of women, and 25% of children in the UK might be obese ("Cycling UK's Cycling Statistics", 2018).

Active travel has the potential to increase physical activity and also has positive and linear effects, i.e., the more physical activity, the better health outcomes (Humphreys et al., 2013; Warburton et al., 2006; Yang et al., 2010). As after 7 years of age, people in the UK (and in the majority of the world) are required to go to school or work and stay there for extended hours, generally sedentarily, commuting is a great opportunity for physical activity. As mentioned, 24% of all trips were under 1 mile and 68% of all trips were under 5 miles in the UK (DfT, 2018e). For these trips, cycling could be the best option as an active transport method (over walking and running) because of efficiency (distance covered per time and per calories burnt) (de Geus et al., 2009).

In terms of the safety of cycling in traffic (i.e., accidents in traffic while cycling), established cycling networks could be more important in promoting safe cycling than individual efforts (Rissel et al., 2010). For instance, Finland has 50 fatal accidents per 1,000,000,000 kilometres cycled but Netherlands has fewer than 20 fatal accidents for the same distance cycled, while only 0.1% of cyclists use a helmet (European Cycling Lexicon, 2018). In the UK, more than 130,000 traffic accidents happened for motorized vehicles, while only 101 accidents happened for bicycles in 2017 (DfT, 2018f). When the ratio between car use rates (68%) to cycling rates (2.1%) is considered, it can be suggested that cycling is a safer travel mode than car use (DfT, 2018f). However, these numbers of accidents should be taken with caution because, while the number of car accidents are reported and recorded in hospital and police documents, many minor bicycle accidents might not be reported in those documents.

1.3.2. Environmental Reasons for Promoting Cycling

There are also environmental benefits to increasing active travel. For example, active travel decreases air and noise pollution (Brand et al., 2014). Motorized transport causes approximately one sixth of all global anthropogenic carbon emissions, while also emitting additional pollutants such as carbon monoxide, and nitrogen oxides (Woods, & Masthoff, 2017). In addition to the effects of the motorized versus non-motorized transport on carbon emissions, maintaining the infrastructure for motorized transport also negatively affect the environment more than maintaining the infrastructure for non-motorized infrastructure (Jain & Tiwari, 2016). It is suggested that the maximum decrease in carbon emissions are achieved by building and maintaining infrastructure for both public transportation and cycling (Jain & Tiwari, 2016). Contrary to motorized transport, active travel (e.g., walking, or cycling) produces almost no noise or air pollution. Noise from means of motorized traffic is a problem for nearly 30% of the population in The Netherlands (Ministry of Infrastructure and Water Management [MIWM], 2018).

1.3.3. Economic Reasons for Promoting Cycling

Cycling is also a cheaper mode of transport than using personal cars and/or public transport. The estimated cost of cycling (owning and maintaining a bike, having protective equipment such as helmets, gloves, appropriate clothes, etc.) ranges from €175 to €300 per year for a regular cyclist, while (owning, maintaining and) using a car ranges between €2500 and €8500 in the EU (MIWM, 2018). Infrastructure maintenance annual costs are also lower for bicycles (€0.03 per kilometre) than cars (€0.1 per kilometre) and trains (€0.18 per kilometre), indicating less expenditure for governments, as well as individuals (MIWM, 2018).

1.4. Factors Associated with Cycling

While it is well established that cycling has many positive benefits for individuals and societies, cycling rates are still low and yet, there are large variations in cycling rates. In order to better understand why and how cycling rates differ between individuals, groups, or countries, factors associated with cycling should be examined. Understanding these factors might also help to inform interventions designed to promote cycling. The factors that are systematically associated with likelihood of cycling can be examined in three main categories; namely, demographic, environmental, and psychosocial factors. According to Ma and Dill (2015), demographic (e.g., age, gender, income) and objective environmental factors (e.g., existence of traffic-free bike lanes, low volume of traffic, and number of possible destinations) explain 8.3% of the variance in cycling frequency (i.e. how many times the participants cycle in a given period). Demographic and perceived environmental factors (e.g. perceptions/beliefs about cycling environment such as the belief that there are many bikeable destinations or quiet streets easy for biking) explain 16.4% of variance in cycling frequency.

When psychosocial factors (e.g. attitudes towards pro-environment, anti-car, supportive social environment for bicycling) are added to those variables, the variance explained in cycling frequency increases to 28.8% (Ma & Dill, 2015).

1.4.1. Demographic Factors Associated with Cycling

Demographic factors associated with cycling include gender, age, income, education, and the number of children in the household. Age is negatively associated with cycling status and frequency (Brujin et al., 2005; Liao, 2016; Ma et al., 2014; Ma & Dill, 2015; Nehme et al., 2016; Nkurunziza et al., 2012; Sener, & Lee, 2017) consistently across countries and cultures. Rates of cycling decrease with age, especially after 25 years of age (Braun et al., 2016; Munoz et al., 2016; Nehme et al., 2016). There is also evidence suggesting that young adults favour cycling more than older adults (Woods & Masthoff, 2017). Only 2% of children aged between 5-10 years of age (DfT, 2018c), and 3% of children between 11-16 years, of age cycle to school in the UK (DfT, 2018d). In contrast, 49% of all children aged 11-15 in Denmark (Cycling Embassy of Denmark, 2018) and 75% of all secondary school children (84% for those living within 5 kilometres of schools) in The Netherlands cycle to school (Bicycledutch, 2018).

Globally, men are more likely to be physically active than women (Hallal et al., 2012). This is the same for cycling. In the UK, the percentage of men who cycle at least once a month is 21.6, whereas the percentage of women who cycle at least once a month is 10.9 (DfT, 2018e). Indeed, in most areas of the world, males cycle more than females (Brown et al., 2016; DfT, 2018e; Dickinson et al., 2003; Dill et al., 2014; Ministere de la Transition Ecologique et Solidaire, 2018; Singleton & Goddard, 2016), although there are some exceptions such as Denmark where 53% of cyclists are female (Cycling Embassy of Denmark, 2018). Aldren et al. (2016) and Haustein et al. (2020) have also reported that in countries with established cycling cultures (i.e., countries where cycling is incorporated into motorized traffic with infrastructure and laws, traffic rules are regulated in accordance with motorized vehicles, pedestrians, and also with cyclists, etc.) and high cycling rates, gender differences do not exist or even in the opposite direction. Gender also moderates the effect of SES on cycling. According to Singleton and Goddard (2016), men in zero-car and/or low income households are the most likely to cycle while women in zero-car and/or low income households are the least likely to cycle. Additionally, single women are reported to be less likely to cycle than women living in households with more than one adult (Singleton & Goddard, 2016).

Relationships between other demographic factors and cycling also varies between countries. For instance, a study conducted in El Paso, Texas (Sener, & Lee, 2017) and a study conducted in Montreal, Quebec (Belanger-Gravel et al., 2016) reported that income is positively associated with likelihood of cycling and cycling frequency, which can be construed as participants adopted cycling by choice. On the other hand, studies conducted in Dar-Es-Salaam, Tanzania (Nkurunziza et al., 2012), and Barcelona, Spain (Braun et al., 2016), identified income as negatively associated with cycling. Additionally, education is also positively associated with cycling in the U.S. (Belanger-Gravel et al., 2016; Sener, & Lee, 2017) and Spain (Braun et al., 2016), but negatively associated in Tanzania (Nkurunziza et al., 2012). Furthermore, Braun et al. (2016) reported that number of children in the household was not significantly associated with cycling in their sample from Barcelona but was negatively associated with cycling in a sample from Oregon, Portland (Ma, & Dill, 2015). Hence, the relationship between demographic factors and cycling may be different in different countries.

1.4.2. Environmental/Infrastructural Factors Associated with Cycling

The environment that people cycle in (i.e., infrastructural qualities/attributes of the road) can also be related to cycling rates. Objective environmental characteristics such as traffic-free paths, traffic volume, living close to traffic free bicycle paths, population density, weather, speed limits in the streets to be cycled, evenness of the cycle path surface, appeal of the cycle paths (e.g., painting the cycle path with a different colour than vehicle roads, decoration of surroundings, greenness of the street, vegetation, etc.), and lighting of the paths have consistently been found to be associated with cycling status and frequency (Goeverden, & Godefrooij, 2011; Hoelscher et al., 2016; Jones, 2012; Mertens et al., 2016; Nehme et al., 2016; Schmiedeskamp, & Zhao, 2016).

Infrastructural attributes of cycling environment are frequently reported to be a barrier for potential cyclists. In their intervention, Fyhri et al. (2017) asked participants to report barriers for them to cycle for daily travels. The most frequently reported barrier was infrastructure on their path not being good enough (46%), followed by not feeling safe while cycling (40%), bad weather (34%), cycling being a demanding travel mode (22%), and that there are steep hills (18%). Mertens et al. (2016) also suggested that the streets' appeal (traffic density, vegetation of the surroundings, general upkeep and evenness of the roads, etc.) is an important factor for cyclists. While new paths are being built, usually, the focus is on segregating the paths from motorized traffic (Tapp et al., 2016; Woods & Masthoff, 2017). It is reported that the width of the bicycle paths are also an important factor for the cyclists (van Goeverden et al., 2015). Furthermore, continuity of the bicycle paths between destination points (e.g., from home to work) are also positively associated with cycling rates, as they decrease the traffic volume for streets and decrease exposure to motorized traffic for cyclists (van Goeverden et al., 2015).

1.4.3. Psychosocial Factors Associated with Cycling

Psychosocial factors that have been found to be related to cycling include perceived social norms within the community (e.g., behaviours that are considered normal and appropriate), attitudes (i.e., belief that cycling will be beneficial and enjoyable for oneself), preferences, physical capacity, past experiences (e.g., habits), intention, self-confidence to cycle (Bruijn et al., 2005; Fyhri et al., 2017; Handy & Xing, 2011; Jones, 2012; Ma & Dill, 2015; Ma et al., 2014; Nkurunziza et al., 2012). Generally, these factors are positively associated with cycling. For instance, people who believe that cycling is enjoyable, and it is beneficial for them or for the environment (Woods & Masthoff, 2017), those who prefer cycling over other transportation methods (Munoz et al., 2016), those who intend to cycle (Bruijn et al., 2005; Forward, 2014), those who think that important others also cycle or approve of cycling (Fyhri et al., 2017) are more likely to cycle. However, these relationships are not always straightforward or linked to cycling directly. For example, in a UK sample, 65% of participants agreed that "cycling to work is normal", while only 10% of participants disagreed with that statement (Tapp et al., 2016). In the same study, Tapp et al. (2016) reported that almost half of the participants agreed that "cycling is cool nowadays" (46%) whereas only 13% of participants disagreed with that statement. Yet, cycling rates are still low in the UK, as mentioned above.

Perceptions about the environment in which one cycles are also important and the objective qualities of the environment are not always directly associated with intentions to cycle or actual cycling behaviour. In other words, perceived environmental quality is associated with cycling even when the objective qualities of the environment are controlled for. Furthermore, studies suggest that people do not always perceive their environment as it is, but instead, perceptions can be influenced by a mix of personal and social factors such as culture, norms, physical capacity, gender, social class, etc. (Ma, & Dill, 2015). For instance, the main barrier for people to start cycling is reported to be safety (Thigpen et al., 2015; Woods & Masthoff, 2017), and people's perceptions about safety of cycling in cities do not change depending on the actual safety measures and statistics (Goeverden & Godefrooij, 2011; Woods & Masthoff, 2017). In the 2016 National Travel Survey in UK, 62% of all respondents, 48% of cyclists, 68% of non-cyclists, 61% of drivers, and 65% of non-drivers perceive cycling as “dangerous” (DfT, 2017). It has also been suggested that women perceive cycling as more of a social activity than a mode of transportation (Akar et al., 2012; Winters et al., 2011). Furthermore, women feel less safe while cycling than men (Singleton & Goddard, 2016).

Psychosocial factors can also mediate the relationship between objective environmental factors and cycling. In Tilburg and The Hague, building new, continuous, segregated cycle paths significantly improved the public’s perception of the safety of cycling while actual numbers showed little or no change in number of accidents (Goeverden & Godefrooij, 2011). Ma et al. (2014) suggested that the objective environment is associated with cycling behaviour only through the mediation of perceptions about the environment. In other words, cycling is related to environmental quality only through perceptions about the environment. Attitudes towards the objective environment are as important the environmental attributes themselves for people to adopt cycling (Thigpen et al., 2015). In fact, psychosocial factors such as attitudes and perceptions are associated with cycling behaviour more strongly than built environmental factors such as infrastructure and traffic (Braun et al., 2016; Ma & Dill, 2015; Ma et al., 2014; Nkurunziza et al., 2012).

Motivators, barriers, attitudes and perceptions about cycling are different for those who regularly cycle and those who do not (Sener & Lee, 2017; Thigpen et al., 2015). Cyclists and non-cyclists have different attitudes towards cycling with non-cyclists highlighting more negative aspects. For instance, cyclists tend to mention positive aspects of cycling such as positive effects on health, environmental impact, productivity, efficiency, convenience, flexibility, fun, and lower stress levels of cycling than commuting by car, whereas non-cyclists mention their concerns about safety and the time consumed while commuting by cycling (Fernandez-Heredia et al., 2014; Sener, & Lee, 2017; Woods, & Masthoff, 2017).

Even though safety is a main concern for both cyclists and non-cyclists, it is less of a concern for cyclists (40.9%) than car drivers (64.2%) and public transport users (82.4%) (Woods & Masthoff, 2017). In different samples from Canada, participants who frequently cycle reported cycling as a more satisfying mode of transport than car drivers did (Willis et al., 2013; Woods & Masthoff, 2017). In another study where self-monitoring solutions (e.g., cycling computers, accelerometers, smartphone apps, etc.) were used, regular cyclists reported using these devices mainly for measuring their average speed, and distance covered, whereas non-regular cyclists reported using these devices mainly for locating themselves on the map, and adding destinations to the map (Piwek et al., 2015). However, it is not yet known whether people who have more positive attitudes and perceptions tend to cycle more, or people who frequently cycle develop more positive attitudes and perceptions.

1.5. Theories Used to Explain Cycling Behaviour

The different factors discussed above are helpful in identifying the correlates of cycling but they are not enough to fully explain the behaviour by themselves (Davidoff et al., 2015). Theories of behaviour can be used to combine these factors in a more meaningful way, both in order to understand and explain the behaviour, and in order to inform interventions to change the behaviour (Webb, Sniehotta, & Michie, 2010). Yet, theories of behaviour which originate from the discipline of psychology are not frequently used to explore and explain cycling behaviour as cycling is studied by many different disciplines including architecture (Uttley & Lovelace, 2016), geography (Lanzendorf & Busch-Geertsema, 2014), computer science (Lathia et al., 2012), city and regional planning (McDonald et al., 2013; Pucher et al., 2010), public health (Lo et al., 2016; Petrunoff, Wen, & Rissel, 2016), medicine (Martin et al., 2014), sports sciences (Ducheyne et al., 2014), and psychology (Gatersleben & Appleton, 2007; Quine et al., 1998). Hence, psychological theories and models are not frequently used to explain cycling behaviour. Among the ones that have been used, the Theory of Planned

Behaviour (TPB) is most frequently applied to cycling behaviour (Brujin et al., 2005; Jones, 2012). Additionally, the Transtheoretical Model (TTM), Health Belief Model, and Stage Model of Behavioural Change have also been applied in a few studies (Forward, 2014; Quine et al., 1998).

1.5.1. The Theory of Planned Behaviour

The Theory of Planned Behaviour suggests that behaviour is determined by intentions, which are in turn are determined by attitudes towards the behaviour, subjective norms, and perceived behavioural control (Ajzen, 1991; Ajzen & Madden, 1986). Perceived behavioural control also has a direct effect on behaviour according to the theory. Constructs specified by the Theory of Planned Behaviour have been used to examine cycling behaviour as well as the effects of new cycling infrastructure on cycling behaviour (Brujin et al., 2005; Jones, 2012).

Attitude is defined as the negative or positive evaluation of performance of the behaviour (Ajzen, 1991). Attitudes towards cycling are generally positive across cultures and different travel mode users (Burke, 2011; Munoz et al., 2013; Sener & Lee, 2017). In a recent study from the UK, 54% of participants reported that they believe “Britain would be a better place if more people cycled”; only 13% who disagreed with that statement (Tapp et al., 2016). Attitudes towards cycling are mostly consistent among different age and ethnic groups, and genders (Sener & Lee, 2017). Positive attitudes towards cycling (e.g., believing that cycling may improve physical health, decrease carbon emissions caused by motorized traffic, help one to save money, cycling is a more convenient and flexible mode of transport than other modes of transport, etc.) increase both intentions to cycle and frequency of cycling (Brujin et al., 2005; Burke, 2011; Gatersleben, & Appleton, 2007; Ma, & Dill, 2015; Schoner et al., 2015; Sener, & Lee, 2017). The opposite is also true, as people with negative attitudes towards cycling (e.g., believing that cycling is time consuming, tiring, not safe, etc.) or more positive attitudes towards other travel modes than cycling such as driving or public transport, are less likely to cycle (Sener & Lee, 2017). Forward (2014) has reported that attitudes towards cycling is the most strongly associated factor among the Theory of Planned Behaviour constructs with intention to cycle.

Subjective norm refers to the perception of whether important others also cycle (descriptive) or would approve (injunctive) of cycling (Ajzen, 1991; Smith et al., 2012). In measuring subjective norm, injunctive (whether one perceives that cycling is approved by others) and descriptive (whether cycling is observed in others) norms have been examined separately. Descriptive norms have been found to be consistently associated with travel mode choice and cycling behaviour in particular (Brujin et al., 2005). In an intervention study about a new traffic free cycling path in Bristol, UK, participants who had family members that cycled on the new path were more likely to cycle on the new path themselves as well (Jones, 2012). Norms may also influence the way that people perceive the built environment (i.e. according to their perceptions about the social norms, people might have different perceptions about the cycling environment) in a way that people who perceive the built environment as being used by important others for walking and cycling are more likely to think that the available built environment is suitable for walking and cycling (Ma & Dill, 2015).

Perceived behavioural control is defined as the degree of volitional control that people feel over the behaviour (Ajzen, 1991). Studies using Theory of Planned Behaviour have found significant associations for perceived behavioural control in line with the theory. For example, in a study with Dutch adolescents, Brujin et al. (2005) reported that students with stronger perceived behavioural control had stronger intentions to cycle, and were more likely to cycle as a commuting method. Furthermore, perceived behavioural control has also been found to differentiate between people who do not think about cycling in the future from those who plan to start cycling regularly and those who cycle regularly (Forward, 2014).

In short, attitude, subjective norms, and perceived behavioural control usually have positive relations with intentions to cycle and cycling frequency, although there are some exceptions (Jones, 2012; Quine, Rutter, & Arnold, 1998). Demographic (distal) variables are less effective in explaining variance in intention to cycle (5%) than proximal variables and when attitude, subjective norm, and perceived behavioural control are included, explained variance increases substantially (to 49%, Bruijn et al., 2005). In another study, Eriksson and Forward (2011) reported that attitudes, subjective norms, and perceived behavioural control for cycling explained 44% of variance in intention to cycle. Brujin et al. (2005) reported that attitude towards cycling has the strongest relationship with intention to cycle, while Eriksson and Forward (2011) reported perceived behavioural control has the strongest relationship with intention to cycle.

As proposed by the Theory of Planned Behaviour, intention to cycle has also found been to be related with cycling frequency. However there are also differences between intention to cycle and cycling frequency (Bruijn et al., 2005; Ma & Dill, 2015). For intention to cycle Bruijn et al. (2005) reported that demographic (distal) factors explain 5% of variance explained, and when attitudes, subjective norm, and perceived behavioural control are also considered, explained variance increases to 49% the intention to cycle. For actual cycling behaviour (rather than intention for it), demographic factors explained 19% of variance and including attitudes, social norms, and perceived behavioural control increased this number to 28%, while adding intention on top of those increased the variance explained to 29%. These differences between the amounts of variances explained in intentions and behaviour might be reflect the intention-behaviour gap, i.e., people do not always do what they intend to do (for a review see Sheeran, & Webb, 2016). For instance, Fernandez-Heredia et al. (2014) reported that only 54% of participants with strong intentions to cycle in the future actually cycled. Ma and Dill (2015) also reported that objective environmental measures were not associated with intention to cycle but they were associated with cycling frequency.

The Theory of Planned Behaviour (TPB) has been criticized for not covering all psychosocial factors (Munoz et al., 2016). Perceived behavioural control was originally assumed to account for the effect of past experience about the behaviour when predicting intentions and future behaviour (Ajzen, 1991). However, the inclusion of habit as a factor in addition to attitudes, subjective norms, perceived behavioural control, and intentions increases the explained variance significantly in both cycling status and cycling frequency, as well as other transport mode use (Donald, Cooper, & Conchie, 2014; Jones, 2012; Panter, 2010; Willis, Manaugh, & El-Geneidy, 2015). Similar findings have been found for other behaviours. For example, Abraham and Sheeran (2003) reported that adding a measure of habit' on top of other TPB constructs increased the amount of variance explained in physical activity from 36% to 53%. Ajzen (2011) has argued that the effect of past behaviour on future behaviour should be mediated by the TPB and that if past behaviour is found to have a direct effect on future behaviour, this indicates that the TPB is not sufficient. In contrast, Ouellette and Wood (1998) have argued that when behaviour is repeated frequently in a stable context, it is likely to lead to strong habitual responses which will then guide behaviour (i.e., through automatic rather than reflective processes). There is increasing evidence that habit is a strong predictor of behaviour, accounting for the influence of automatic processes not included in the TPB (Gardner, 2015). A further limitation of the TPB is that it does not focus on volitional processes that might explain how intentions are translated into behaviour (Sniehotta et al., 2014) – i.e., the TPB does not explain the "intention-behaviour gap" (Orbell & Sheeran, 1998). Other models such as the Health Action Processes Approach (Schwarzer & Luszczynska, 2015) outline a number of volitional variables, such as action planning and coping planning, that help people overcome the gap between their intentions and their behaviour. Finally, the TPB has also been criticized for its limitations for informing interventions to change behaviour (Webb et al., 2010). Webb et al. (2010) suggested that TPB is mainly useful in measuring intervention effectiveness, rather than informing the design of more effective interventions.

1.5.2. Transtheoretical Model

According to Prochaska and DiClemente (1982)'s Transtheoretical Model, behaviour change involves five ordinal stages: precontemplation, contemplation, preparation, action, and maintenance. Precontemplation is the stage where people do not even think about or feel the need to change their behaviour in near future. In the contemplation stage, people start thinking about changing their behaviour but do not commit to it yet. The preparation stage is defined as the stage in which people plan to take action to change their behaviour in near future (Prochaska, DiClemente, & Norcross, 1992). In the action stage, people start adopting a new behaviour for, at most, the next six months. Finally, people are classified to be in the maintenance stage six months after continuous adoption of a new behaviour.

As mentioned above, cycling is not usually adopted as a mode of transport. So it is possible to suggest that majority of the population are in the pre-contemplation stage and only a few people are in the maintenance stage (Gatersleben, & Appleton, 2007). Stages of Transtheoretical Model are generally used to cluster people according to a target behaviour which can help interventionists to tailor their material according to the needs of participants from different stages. Studies using the Transtheoretical Model and measuring cycling behaviour tend to associate group membership with demographic and psychosocial variables. Most of the findings are compatible with what is reported so far. For instance, Thigpen et al. (2015) reported that gender is associated with stage membership with males represented more in the later stages. Similarly, endorsement of barriers such as the distance to be cycled, safety concerns, and inclement weather are associated with people being in the earlier stages of transtheoretical model for cycling behaviour while having a positive attitude towards cycling and living close to destinations are associated with being in the later stages (Thigpen et al., 2015). A study comparing the Theory of Planned Behaviour and the Transtheoretical Model as explanations of cycling behaviour found that attitudes only distinguished participants between preparation and action stages, perceived behavioural control distinguished participants between precontemplation and contemplation, and between preparation and action stages, descriptive norms distinguished participants between precontemplation and contemplation stages, and intention to cycle distinguished participants between precontemplation and contemplation, and between preparation and action stages of TTM (Forward, 2014). In the same study, it was also found that habit (the construct that TPB was also criticized to not include) only distinguished the participants between the precontemplation and maintenance stages. Finally, participants from all stages of TTM reported higher injunctive norm than descriptive norm (Forward, 2014). This finding can be construed as that attitudes, subjective norms, and perceived behavioural control is effective in can be cycling is perceived as an acceptable travel mode even though it is not commonly observed in the social environment, which also affects intentions to cycle (Ajzen, 1991). Furthermore, different factors were found to be important for moving between stages. For instance, attitudes and self-efficacy were more important in differentiating people in earlier stages (i.e., between precontemplation and action), but demographic variables and habit were more important for differentiating between the action and maintenance stages (Forward, 2014; Gatersleben, & Appleton, 2007).

The factors outlined in theories of behaviour that are related to cycling can be used to understand and explain determinants of cycling which, in turn, can help future interventions to target participants according to the individual needs in order to promote cycling. For instance, Gatersleben and Appleton (2007) suggested that in order to promote cycling (even further) among people in the later stages of TTM, interventions should focus on positive consequences like flexibility (as they have more immediate effect) rather than health and environmental benefits (as they have more distal effects). As discussed below, even though psychological theories are not frequently used in interventions to promote cycling, they can still be useful in developing interventions.

In a recent scoping review, Davis et al. (2017) reported that the Transtheoretical Model is the most frequently used theory for behaviour change (33%), followed by Theory of Planned Behaviour (13%), and Social Cognitive Theory (11%). However, being used the most frequently does not make TTM the most successful theory in terms of explaining variance or designing effective interventions (Davis et al., 2017). For instance, Cahill et al. (2010) reported in their systematic review of stage-based interventions for smoking cessation that interventions based on the stage models are not more effective than other interventions. Furthermore, even though labelling participants with a stage membership provides ease in terms of categorizing participants, stage membership is not always a clear-cut distinction. Hypothetically, for example, someone with a positive attitude towards a given behaviour, e.g. cycling, can be a member of the precontemplation stage because s/he has no opportunity to cycle, whereas someone in the maintenance stage can have no strong opinion about the behaviour but still cycles because s/he has no other travel option (Forward, 2014; Thigpen et al., 2015). As a model, TTM, and stage theories in general, are also criticized for creating artificial or pseudo stages where continuous variables are only turned into orthogonal variables (Nigg et al., 2011).

1.6. Current Approaches to Promoting Cycling

There are many intervention studies that have tried to promote cycling, given that cycling has many benefits, is accepted and approved by majority of the society, and as there is a gap of active travel even for short journeys, as explained above. These studies come from different fields including medicine, economics, urban studies and planning, civil engineering, and psychology (Caulfield, 2014; Dill et al., 2014; Fitzhugh et al., 2010; Hemmingston et al., 2009; Kerr et al., 2010) as cycling is beneficial for mental and physical health, as well as for the environment and economy. Due to the different nature of the interventions in these different areas, interventions will be examined here under three subheadings; namely, infrastructural changes, psychosocial interventions, and governmental policies. This categorization is made mainly because the interventions that targeted the cycling infrastructure are from fields that are unrelated to psychology and they do not control for such variables (other than few demographics such as age, gender, ethnicity, etc.; Pucher et al., 2010). The studies that come from fields related to psychology, on the other hand, do not have the means to change the cycling infrastructure (Bird et al., 2013; Yang et al., 2010). Then there are larger projects that have enough funding and include researchers from different fields and manipulate both infrastructural and psychosocial factors.

1.6.1. Infrastructure Changes

Most of the interventions targeting cycling behaviour have sought to change environmental conditions such as building or improving cycling paths, segregating motorized and non-motorized traffic, building traffic free paths and/or providing end of trip facilities such as bike parking decks, showers, establishing bike share schemes, painting cycling lanes in different colours (Bird et al., 2013; Pucher et al., 2010). When building new bicycle paths, generally the focus is on relaying the asphalt and/or repainting the lanes with visible colours. Building new cycling paths has generally been found to increase cycling rates in surrounding areas (Brand et al., 2014; Brown et al., 2016; Jones, 2012; Pucher, & Buehler, 2008) even though there are few studies with non-significant effects (Dill et al., 2014). Building segregated or traffic-free cycling paths allows inexperienced cyclists to practice, increases the sense of safety and accessibility, and connects multiple destinations (Jones, 2012). This connectivity across and within cities has been identified as an important factor that influences cycling and has been prioritized in major European cities. For instance, over the past few decades Barcelona has built 159 kilometres of bicycle lanes (where cycling rates are around 3%), while Helsinki has built about 750 kilometres of bicycle lanes (where cycling rates are around 8%) (Woods & Masthoff, 2017). Improvements in city wide cycling infrastructures have also been made and increases in cycling rates have been achieved in major German cities such as Berlin (10% to 15%), Frankfurt (6% to 15%), Munich (10% to 17%), and Hamburg (9% to 18%) since 2000 (Lanzendorf & Busch-Geertsema, 2014). The most established cycling culture and highest cycling rates are observed in The Netherlands (27%) and Denmark (16%), as they have invested in cycling infrastructure since the 1970s (Goeverden et al., 2015). New York City has also tripled its total length of bicycle lanes between 2000 and 2010, and observed a 50% increase in cycling rates during the same time period (Thigpen et al., 2015). Furthermore, end of trip facilities such as safer bike parking decks, showers, lockers etc. removes some of the other barriers that regular cyclists face such as keeping bicycles safe, refreshing etc. (Burke, 2011; Nkurunziza et al., 2012).

On the other hand, infrastructure changes may only improve active travel around intervention sites, such as among people living up to half or one-mile radius of the intervention areas (Brown et al., 2016; Crane et al., 2017; Heesch, & Langdon, 2016; Howden-Chapman et al., 2015; Jones, 2012). Furthermore, in a recent study, Schoner et al. (2015) stated that built environment is mainly a 'magnet' attracting people who already cycle, instead of being a 'catalyst' which prompts change among non-cyclists. Having a cycling path nearby is not enough to convince people to start cycling probably because starting cycling requires an investment, i.e., to buy a bicycle and cycling equipment. Establishing bike share schemes partially solves these barriers and enables people who want to cycle but do not have resources to maintain (e.g., safe keeping, repairing) a bike. Consistent with this idea, implementing bike share schemes has been found to increase cycling rates (Belanger-Gravel et al., 2016; Fuller et al., 2013), although there are also some exceptions (Stewart et al, 2011).

1.6.2. Psychosocial Interventions

Research has shown that people can cycle regardless of whether the environment supports cycling (Schmiedeskamp & Zhao, 2016) and that attitudes toward cycling and perceptions of environmental quality matter more than objective environmental features (Heinen et al., 2011; Thigpen et al., 2015). As a result, targeting cycling with psychosocial interventions has potential. Even though this field has relatively neglected to date, there is evidence to guide future psychosocial interventions.

One of the main psychosocial interventions involves offering cycling training in schools and public centres. Cycling training is given to teach and/or improve people's ability to cycle, and to boost feelings of safety and competency. There is evidence of both significant (Chillon et al., 2011; Ooms et al., 2017; Pucher et al., 2011) and non-significant (Ducheyne et al., 2014; Goodman et al., 2016) effects of training interventions. Even in those studies with significant effects, the improvements in cycling rates are small. Other studies have combined cycle training with other methods such as influencing the attitudes of students' parents, providing further support for cycling, organizing cycling days or social events, etc. Such interventions typically yield larger effects for increasing cycling rates (Wen et al., 2008). Hemmingsson et al. (2009) investigated the effects of physicians in Sweden recommending active commuting (including cycling) to obese women. They focused on raising awareness, identification of barriers, and tailoring recommendations to individual needs and found significant improvements in intervention group participants. There are also studies that have tried to promote cycling (and/or active travel) via recommendations for and increasing exposure to cycling through local media such as televisions and radio stations, albeit with inconsistent findings (Clark et al., 2014; Rissel et al., 2010).

It can be suggested that interventions targeting perceptions about cycling can complement interventions targeting cycling environment (Ma et al., 2014). As mentioned previously, participants in different stages of action as specified by the transtheoretical model may require different approaches to proceed to the next stage. For example, Andersson et al. (2018) conducted a systematic review and meta-analysis in order to identify and summarize interventions to promote sustainable travel via smartphone applications. They suggested that tailored, user-centred campaigns that deliver relevant and contextualized feedback and information might be more effective for interventions.

1.6.3. Eclectic Projects and Governmental Policies

Other than individual researchers looking for ways to promote cycling, there are also larger projects that combine the methods mentioned above and look for ways to promote active travel in entire cities, or even across countries. One of the biggest organizations is SUSTRANS charity, which aims to promote active transport throughout the UK. Founded in 1977, SUSTRANS has instigated many interventions throughout the country including building new cycle paths and/or restoring existing ones, influencing local and nationwide governmental policies, arranging cycling days, working with companies and other organizations to look for ways to promote cycling among employees, and arranging volunteering actions to give cycle trainings or cycle with children, etc. (“SUSTRANS”, 2018). The biggest campaign that SUSTRANS led is the “National Cycle Network” that has built, restored, or decorated 16,575 miles of cycle and walking paths throughout England, Northern Ireland, Scotland, and Wales over the last 20 years (“National Cycle Network impact”, 2018). More than half of the population of the UK is within one mile of this network. The estimated effect of the National Cycle Network on the economy is substantial, with estimates suggesting that more than £7 billion has been saved in health costs in the last 20 years, which is almost £1 million per day (“National Cycle Network impact”, 2018). By reducing sick days among employees, the network is estimated to save local businesses about £33 million per year (“National Cycle Network impact”, 2018).

In addition to the National Cycle Network, the Department of Transport in the UK has funded investment in cycling infrastructure programmes in six different cities in the UK, in cooperation with SUSTRANS (Sloman et al., 2009). The Department for Transport allocated approximately £500,000 per year for each city not only to build new infrastructure, but also for demonstration and education programmes in primary and high schools, town-wide media campaigns, personalised travel planning, etc. Data about cycling and general physical activity were collected before (March, 2006) and after (March, 2009) the implementation of these investments and results suggested that regular cycling rates among school aged children increased from 11.6% to 26.2% and among adults cycling rates increased from 2.6% to 3.5% in the target areas (Sloman et al., 2009). Furthermore, the percentage of inactive adults (those who do not meet the criteria for physical activity requirements, taking cycling, other physical exercise, and activity at work together) in targeted cities decreased from 26.2% in 2006 to 23.6% in 2009.

In Dublin, Ireland, governmental policies to increase cycling rates have been implemented from 2006 to 2011, including establishing a bike share scheme, bicycle purchasing schemes, reducing speed limits in central locations (around main destination points), and building new segregated bicycle lanes. These efforts have led to increasing cycling rates from ~2.4% in 2006 to ~6% in 2016 (“Commute into Dublin city”, 2018; Caulfield, 2014). In The Netherlands and Denmark, promotion of cycling as a governmental policy started in the 1970s. Elaborative efforts were made in The Netherlands between 1979 and 1991 to improve cycling infrastructure, increase continuity of the bicycle lanes and highlighting continuity of cycle paths with different colours, building new two-directional colourized cycling routes, as well as restricting motorized traffic in central areas in a number of cities and towns (Goeverden & Godefrooij, 2011). Large increases were observed in cycling rates as a result of these efforts which supports the notion that large scale investments in cycling infrastructure can increase cycling rates. Another project including promotional campaigns and infrastructure changes was conducted in Odense, Denmark, between 1999 and 2002, and an increase from 22.5% to 24.6% was observed in cycling rates (Troelsen, 2005 as cited in Yang et al., 2010). These efforts have resulted in significant improvements in The Netherlands (27%) and Denmark (16%) such that they are now the countries with highest two rates of cycling in the world ("Dutch cycling figures", 2018; Pucher, & Buehler, 2008).

In Germany, serious efforts have also been made to promote cycling in the last 20 years (Lanzendorf & Busch-Geertsema, 2014). In the early 2000s, Berlin, Frankfurt, Hamburg, and Munich senates/governments decided to work to increase the modal share of cycling up to 15%. For that purpose, they developed a strategy that included many different measures such as extending the cycling network, building more and safer bike parks, sign-posting, establishing a bike share scheme, etc. Even though they also included communication efforts in their strategy, these efforts were not intensive or clearly visible (Lanzendorf & Busch-Geertsema, 2014). From 2002 to 2008, national mode share for cycling increased from 8.7% to 9.6% in Germany and for the same period, the improvements were from 7% to 9.4% in Berlin, from 8.8% to 10.4% in Frankfurt, from 11.2% to 11.6% in Hamburg, and from 11.1% to 14% in Munich. Note that at least 1.5 million Euros were spent per year in each of these cities to promote cycling.

In the USA, "Safe Routes to School" is the biggest project aiming to promote active travel. This project mainly aims to promote walking and cycling among students and their parents as in the USA, 10% to 14% of all car trips during morning rush hours are to schools

(U.S. Department of Transportation, 2018). The methods that this program uses to improve active travel to school includes redesigning the school surroundings such as sidewalks, traffic lights and signs, lowering speed limits, building new cycle paths or improving existing ones, teaching cycling to students and parents, arranging promotional activities such as cycle to school days, or educational campaigns for parents, etc. (U.S. Department of Transportation, 2018). Evidence suggests that Safe Routes to School programme has been inconsistently effective in increasing cycling and walking rates among intervention schools, and there are also instances where the programmes were negatively affected the cycling and active travel rates (Boarnet et al., 2005; Chillon et al., 2011; Kerr et al., 2006).

1.7. Measuring Cycling Behaviour

Cycling has been studied by a number of research areas including medicine, civil engineering, and psychology. As a consequence, various methodologies have been used to measure cycling behaviour and which has also resulted in .different measures of cycling behaviour being employed (e.g., cycling frequency – number of times cycled in a week/month/year, cycling status – whether one has ever cycled at all or not in the past year, cycling distance/time – in kilometres or minutes, cycling propensity – intentions or plans to cycle in the future).

For instance, studies that measure the effects of building new bicycle lanes usually do not measure the cycling behaviour of individuals, rather they measure the usage of the new lanes (e.g., number of cyclists in a given day; Pucher, Dill, & Handy, 2010). As a result, it is hard to detect who uses the new bicycle infrastructure in a given neighbourhood; collecting data on individual level is not the focus of studies from certain research areas. Hence, studies that improve cycling infrastructure usually measure their effects by counting the number of cyclists using these paths (Crane et al., 2016; Fitzhugh et al., 2010; Pucher, Dill, & Handy, 2010) or using national travel surveys or census data (Caulfield, 2014; Hosford et al., 2019).

This type of data makes it hard to detect the true effect of the interventions on individuals' cycling behaviour, or to utlisise experimental designs.

A few studies have recruited participants residing near the intervention area and surveyed them about their travel behaviour before and after infrastructural interventions (Panter et al., 2016). However, individual level data is more commonly collected in studies with more of a focus on the psychosocial aspects of cycling behaviour such as intentions, attitudes, and social norms (Braun et al., 2016; Forward, 2014). Intervention studies targeting psychosocial aspects of cycling usually use self-report measures of individual level cycling behaviour (Bird et al., 2013; Yang et al., 2010), or intentions or propensity to cycle in the future (Ma & Dill, 2015; Mertens et al., 2016). While self-report measures of cycling frequency or distance allows data collection on individual level, they might lack accuracy and/or be biased (Podsakoff et al., 2012), as participants might forget about their past behaviour and give inaccurate responses due to social desirability effects, for example.

One option to obtain accuate measures of cycling behaviour is to use objective measures such as accelerometers, smartphone apps, or smart watches (Piwek et al., 2015). These devices can collect individual level data for cycling frequency, time, distance, and status at the same time (Bourdeaudhuij et al., 2010; Stephens & Allen, 2013). With the increasing usage of smartphones and smart watches, these solutions can become easier to be used for researchers, while also providing accurate and reliable data. For instance, many bike share schemes around the world are now operated through smart phone applications, which allows people to cycle without owning and maintaining one (Belanger-Gravel et al., 2016). These applications provide information about different aspects of cycling behaviour.

1.8. Behaviour Change Techniques Taxonomy v1

Psychosocial methods used to promote cycling are not always systematically implemented, described, or evaluated for us to be able to understand which components make interventions effective or ineffective. As cycling has been researched by many different fields, it would be helpful to have a common language and a systematic methodology to develop and report interventions. Using Behaviour Change Techniques (BCT) Taxonomy v1 (Michie et al., 2013) may be helpful in this respect. BCT taxonomy v1 was prepared in an effort to categorise every unique technique or 'active ingredient' used in interventions to change various behaviours. In a previous version of the taxonomy, Abraham and Michie (2008) identified 28 BCTs and this list was updated by Michie et al. (2013) to include 93 unique BCTs clustered under 16 categories. These BCTs are defined as "observable, replicable, and irreducible component(s) of an intervention designed to alter or redirect causal processes that regulate behavio(u)r; that is, a technique is proposed to be an 'active ingredient'" (Michie et al., 2013, p. 82). To identify BCTs and determine their uniqueness, the Delphi Method was utilized, which requires collecting opinions from experts working in a particular field (Linstone & Turoff, 1975; Pill, 1971). Data were collected from 14 experts to identify BCTs and another 18 experts were used to group BCTs into clusters.

BCT taxonomy v1 can be used as a systematic way of identifying, organizing, and explaining active ingredients of interventions that are designed to change wide range of behaviours. Being able to identify the active ingredients of interventions also eases replication of successful methods in different fields. For instance, meta-analyses have been used to scrutinize interventions designed to change behaviours in specific fields such as smoking (Bartlett et al., 2014; Black et al., 2020), alcohol consumption (Black et al., 2016), medication adherence (Easthall et al., 2013), weight loss (Ashton et al., 2020; Cradock et al., 2017; Lara et al., 2014), etc. and these meta-analyses have sought to identify the most useful

BCTs in their respective fields. Hence, these meta-analyses can inform and guide future interventions to use effective techniques as well as not to use ineffective ones. However, no prior meta-analysis has been used to identify the most effective techniques to promote cycling, or even active travel.

In a recent systematic review, Bird et al. (2013) reported useful techniques for promoting walking and cycling (active travel) behaviours. Even though this study was based on an older version of the behaviour change techniques taxonomy (Abraham & Michie, 2008), the use of conceptually similar techniques was reported across different intervention studies. In the 46 studies included, "Intention formation" (13 times), "self-monitoring" (13 times), "Consequences" (11 times), "general encouragement" (11 times), "instructions" (10 times), and "goal-setting" (10 times) were the techniques that were most frequently used in significant interventions. However, these techniques were also used in several studies with non-significant results. Moreover, of the 46 studies that have been identified, none of them used the same combination of behaviour change techniques. So, the specific techniques which are significantly effective in promoting active travel as well as the combinations of, or conditions under which, these BCTs are useful are not known. None of the studies included in their systematic review targeted promoting cycling specifically. Instead, 30 of the studies targeted promoting only walking, and 16 targeted promoting active travel (walking and cycling). Furthermore, even though they reported that most of the interventions had significant effects on active travel, their overall effect was not quantified. Hence, a meta-analysis specific to interventions to promote cycling is needed and effects of specific BCTs need to be quantified.

1.9. How Can Gaps in Research on Cycling Be Addressed?

The present thesis sought to address three gaps in our current understanding of research designed to promote cycling: (i) What effect do cycling interventions have, on average, and what makes these interventions effective? (ii) Can BCTs be delivered via digital methods and, if so, (iii) what is the effectiveness of BCTs delivered via digital methods? Section 1.9 will explain each of these in turn.

1.9.1. What effect do cycling interventions have, on average, and what makes these interventions effective?

Policies to promote cycling tend to address distal factors (e.g., infrastructure) instead of proximal factors (e.g., attitudes, intentions) for cycling (Nkurunziza et al., 2012; Yang et al., 2010). Furthermore, most interventions are very expensive to implement, ranging from thousands to billions of pounds. In April 2017, UK Department of Transport published their long term plan for promoting active travel, allocating £1.2 billion for this project ("Government publishes £1.2 billion plan", 2018). Similarly, in Hamburg, more than 40 million Euros were spent between 2002 and 2008 to increase cycling rates (Lanzendorf, & Busch-Geertsema, 2014; Sloman et al., 2009). But as explained above, psychosocial factors are at least as important as environmental aspects and targeting those may be considerably cheaper. However, these factors are also not necessarily easy or cheap to target with interventions. For instance, teaching students to cycle and improving their skill levels would require one-to-one interaction and long hours of experts or teachers, which is also costly (Ducheyne et al., 2014). Interventions that are designed to change attitudes about cycling or intentions to cycle of individuals also require long time periods to be implemented; reaching individuals through TV advertisements, leaflets, or billboards is also expensive and not always effective in promoting cycling (Goodman et al., 2016; Tapp et al., 2016; Yang et al., 2010).

1.9.2. Can BCTs be delivered via digital methods and, if so, what is the effectiveness of BCTs delivered via digital methods?

Digital methods are increasingly being used to change behaviour (Orr & King, 2015; Spohr et al., 2015). For instance, Black et al. (2016) identified computer-delivered interventions to reduce alcohol consumption in their meta-analysis and found that computer delivered interventions in general are effective in reducing alcohol consumption. Furthermore, they also reported that providing information on consequences, prompting commitment, and reviewing goals were the most effective BCTs to reduce alcohol consumption. In another meta-analysis, Black et al. (2020) reported that, in general, interventions targeting smoking cessation were significantly effective and Spohr et al. (2015) also reported that interventions delivered specifically via SMS messages targeting smoking cessation were significantly effective. Orr et al. (2015) also identified the interventions that used SMS messages to enhance health related behaviour in general and found that interventions delivered via SMS messages had a small but significant effect across many different health related behaviours.

Using digital technology could be an appropriate way to deliver the interventions in the field of cycling research as well. For promoting healthy behaviours, different methods have been used, such as SMS text messages (Gerber et al., 2009; Militello et al., 2012), social media such as Facebook or Twitter (Turner-McGrievy & Tate, 2011; Wojcicki et al., 2014), smartphone applications (Carter et al., 2013; Stephens & Allen, 2013; Turner-McGrievy & Tate, 2011), or biofeedback devices such as pedometers (Griffin et al., 2018; Newton et al., 2009). These studies show the usefulness of digital technology to increase self-regulation directed at physical activity and other health related behaviours of a larger number of people with convenience, and at little or no cost (Hall et al., 2015; McKay et al., 2018; Webb et al., 2010). However, digital interventions specific to cycling behaviour have been lacking. As most of the bike share schemes already have smartphone applications that keeps track of the behaviour and gives feedback about cycling frequency, time, or distance, using these applications could also be used to deliver intervention components.

Digital interventions (e.g., SMS messages) have the potential to tackle some key problems of previous interventions such as not being able to reach large sections of the population easily, in a short period of time, or in a cheap way. The use of SMS messages could allow researchers to deliver the behaviour change techniques that they know to be significantly effective in changing certain behaviours, such as cycling, to large populations easily. Yet, there are no previous studies that tested the most effective BCTs to promote cycling or effectiveness of BCTs to promote cycling when delivered via SMS messages.

Summary

To summarize, while current literature helps us understand the cycling behaviour in general, it falls short in answering three specific questions: (i) What effect do cycling interventions have, on average, and what makes these interventions effective? (ii) Can BCTs be delivered via digital methods and, if so, (iii) what is the effectiveness of BCTs delivered via digital methods? The current thesis aims to answer these questions in the following consecutive chapters. In order to address these questions: (i) A systematic review and a meta-analysis of the interventions to promote cycling was conducted to measure the effectiveness of these interventions and to identify the most effective BCTs; (ii) a Delphi method study was conducted to test if BCTs can be delivered via short text messages; (iii) a series of interventions were conducted to test if the short text messages conveying specific BCTs are effective in promoting cycling and/or active travel.

Chapter Two

What is the Best Way to Promote Cycling? A Systematic Review and Meta-Analysis

The empirical work presented in this chapter was published as follows:

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Abstract

Cycling has the potential to address a number of personal and societal challenges, not least with respect to health and the need for more sustainable modes of transport. However, the best way(s) to promote cycling is still unclear. In an effort to answer this question, we identified 39 interventions designed to promote cycling, with a total sample of 46,102 participants. Random effects meta-analysis estimated a small but statistically significant effect of interventions on cycling behaviour (g_+ = 0.14, 95% CI [0.05, 0.23]). To identify the most effective intervention strategies, we coded the behaviour change techniques used within each of the interventions. Interventions that prompted people to self-monitor their behaviour or added objects to the environment (e.g., provided shared bikes) were more effective than those that did not use these strategies. Interventions that restructured the physical environment (e.g., built new cycle paths) were less effective than the studies that did not do this. We also identified a number of factors that moderated the effect of the interventions on outcomes; specifically, interventions that targeted a specific group, used objective measures of cycling such as accelerometers, and that were tested using independent groups designs typically yielded stronger effects. The findings should help to guide interventions to promote cycling in the future.

2.1. Introduction

Cycling is widely encouraged as a sustainable mode of transport (McDonald, Yang, Abbott, & Bullock, 2013; Pucher, Dill, & Handy, 2010; Spotswood, Chatterton, Tapp, & Williams, 2015) that also benefits health by increasing levels of physical activity (Warburton, Nicol, & Bredin, 2006). Globally, more than half of all trips are shorter than 5 kilometres, yet only 1 to 2% of all trips are made by bicycle (Pucher, & Buehler, 2008; Pucher, Buehler, & Seinen, 2011; Department for Transport [DfT], 2018). Promoting cycling has attracted attention from different disciplines such as city and regional planning, civil engineering, public health, and psychology. However, the success of efforts to promote cycling varies and likely depends on the specific strategies used. We therefore aimed to review the evidence to date to identify the best way to promote cycling.

Strategies that have been used to promote cycling include improving the physical environment and infrastructure, as well as strategies targeting individuals' beliefs about cycling (e.g., persuasive messages about the health benefits), skills, or opportunities, or combinations of these approaches. For example, interventions have built segregated and connected bicycle paths or traffic free trails, landscaped these paths (e.g., painted trails with visible colours and planted the surroundings), added bicycle parking racks to destination points, or improved traffic signs (Dill, McNeil, Broach, & Ma, 2014; Goeverden, Nielsen, Harder, & Nes, 2015). Interventions have also taught people how to cycle, provided information about new routes and safety requirements, provided incentives to those who cycle, and arranged social activities around cycling (Bourdeaudhuij et al., 2010; Ducheyne, Bourdeaudhuij, Lenoir, & Cardon, 2014; Goodman, van Sluijs, & Ogilvie, 2016; Mantzari et al., 2015; Petrunoff, Rissel, Wen, & Martin, 2015; Petrunoff, Wen, & Rissel, 2016; Teyhan, Cornish, Boyd, Joshi, & Macleod, 2016).

However, interventions vary in how effective they are in promoting cycling and, in some cases, ostensibly similar interventions can yield different results. For instance, Ducheyne et al. (2014) found that participants who received an intervention designed to teach people how to cycle actually cycled less (not more) than participants in a control group. In contrast, Goodman et al. (2016) found no difference between groups who were taught versus not taught how to cycle, and Teyhan et al. (2016) found significantly higher rates of cycling among participants who were taught to cycle than those who were not taught. Similarly, improving the infrastructure for cycling has had mixed results (e.g., Brown et al., 2016; Burbidge & Goulias, 2009; Dill et al., 2014). Therefore, it is necessary to estimate the effect of interventions to promote cycling across different studies and, more importantly, identify what features of the interventions, studies, or samples, account for the heterogeneity in results so that these can be used to improve future interventions.

2.1.1. Previous Reviews

A number of prior reviews have synthesized evidence on promoting active travel (e.g., de Nazelle et al., 2011; Mantzari et al., 2015; Panter, & Jones, 2010; Petrunoff, Rissel, & Wen, 2016; Scheepers et al., 2014), but few of them have focused specifically on cycling. For example, Yang, Shalqvist, McMinn, Griffin, and Ogilvie (2010) systematically reviewed 25 interventions. However, only six of the included studies specifically targeted cycling (16 targeted “environmentally friendly” modes of transport, and three targeted travel behaviour in general). Of the six studies that specifically targeted cycling, two were population level studies, which reported net increases in the prevalence of cycling across a population. The other four also reported significant improvements in cycling rates but on a smaller scale; one distributed free bikes and prescribed physical activity to women with abdominal obesity, one improved cycling infrastructure, and two were multifaceted initiatives (e.g., included promotional campaigns, infrastructure changes, personalized travel planning, bicycle repair services, etc.).

In another review, Pucher et al. (2010) identified 139 interventions that were designed to promote cycling (including interventions targeting active travel in general that measured effects on cycling separately). Pucher et al. divided the interventions into five categories; namely, those providing travel-related infrastructure, end-of-trip facilities (such as sheltered parking, storage, repair, showers, etc.), transit integration programs, bike share schemes, and/or cycling related laws. However, it was not always clear which of the intervention strategies were effective (or not) because some of the interventions incorporated multiple strategies (e.g., a network of bike lanes was extended while also introducing a new bike share scheme and adding extra bicycle parking docks, etc.). As a result, it is difficult to identify the 'active ingredients' of the interventions (Craig et al., 2008) and understand why and how they are (or are not) effective from the previous reviews.

One notable exception is a review by Bird et al. (2013) which identified the Behaviour Change Techniques (or BCTs) that were used by interventions designed to promote active travel (defined as walking and cycling). Bird et al. identified 46 studies targeting walking and/or cycling and found that 21 (46%) reported statistically significant effects of the intervention on these behaviours. The most frequently used BCTs among interventions that had a statistically significant effect were prompting self-monitoring and prompting intention formation (both were used in 13 out of the 21 interventions that had statistically significant effects). Bird et al. also reported that the number of BCTs used in interventions was not associated with how effective they were, which could suggest that multifaceted interventions are not necessarily more effective in promoting cycling than simpler interventions. Again, however, while these findings are useful, from the perspective of identifying how best to promote cycling they are limited because 30 of the 46 studies included in the review focused only on promoting walking, while the remaining 16 studies tried to promote both walking and cycling. This means that none of the studies specifically targeted cycling. Furthermore, Bird et al. used an older taxonomy of 26 BCTs (Abraham & Michie, 2008) to code the content of the interventions, which has now been updated to include 93 techniques (Michie et al., 2013).

It is also important to note that none of the previous reviews have used a meta-analytic approach to estimate the average effect of the interventions and to quantitatively examine which intervention strategies and features are reliably associated with smaller or larger effect sizes. Using such a quantitative approach offers a number of advantages such as being able to compare effect sizes of different interventions, compute precise effects of certain intervention strategies (e.g., infrastructural, psychosocial, or combined), and identify factors that moderate the effect of interventions on outcomes (Johnson & Hennessy, 2019).

2.1.2. The Present Review

The present review aimed to answer the question of how best to promote cycling. This was achieved by addressing three shortcomings of previous reviews. First, we identified and reviewed studies that measured the effect of interventions on cycling (specifically), rather than effects on active travel (e.g., walking and cycling reported together). Even though both walking and cycling can be considered forms of active travel, they are inherently different means of transport. Walking requires (almost) no preparation or equipment and can be easily adopted for short distances, whereas cycling requires a bicycle (along with a safe and free space to keep it at destination points), and equipment such as a helmet or reflective clothing, particularly in countries or states where they are mandatory (de Jong, 2012; Pucher et al., 2011). These differences between cycling and other forms of active travel might decrease the accuracy of implications taken from a review of interventions that target both walking and cycling. Second, we coded the behaviour change techniques used by the interventions using a newer version of the BCT Taxonomy (v1: Michie et al., 2013), which includes a greater number of BCTs. Third, we used meta-analysis to estimate the effectiveness of specific intervention strategies in promoting cycling. This approach also allowed us to identify factors that moderate the effectiveness of interventions.

2.1.3. What Factors Might Moderate the Effectiveness of Interventions to Promote Cycling?

In addition to the nature of the intervention (e.g., the specific strategies used to promote cycling), the effectiveness of interventions is likely to depend, in part, on characteristics of the sample, study design, measured outcomes, and/or other methodological features. The present review therefore aimed to identify potential moderators in an effort to account for variability in the effect of interventions designed to promote cycling on outcomes. Demographic factors such as age, gender, ethnicity, and education have been shown to be associated with cycling. For example, evidence suggests that older people and females cycle less in countries with low rates of cycling (Brujin et al., 2005; Liao, 2016; Ma, & Dill, 2015; Sener, & Lee, 2017), as do those without higher education (Belanger-Gravel et al., 2016; Braun et al., 2016). Methodological characteristics such as the length of the intervention, the way that participants were recruited, and randomization may also be associated with the effectiveness of different interventions. For example, Kang, Marshall, Barreira, and Lee (2009) found that the length of the intervention was positively associated with the effect of pedometers on physical activity. Finally, there are mixed findings with respect to whether using theory when designing and/or implementing interventions influences how effective they are (Garnett et al., 2018; Prestwich et al., 2014). We also aim to address this question in relation to promoting cycling.

2.2. Method

2.2.1. Selection of Studies

We used four inclusion criteria to select studies for the current review. First, studies had to include an intervention designed to promote cycling. Second, studies had to adopt an experimental design either with a pre- and post-intervention measure (i.e., a repeated measures or within-participants design), or include a control group that was exposed to little or no intervention (i.e., an independent groups design). Third, studies had to measure cycling, rather than active travel or physical activity in general. Cycling could be measured in terms of frequency, distance, or time, but not in terms of performance (e.g., speed, force). Finally, studies had to report sufficient detail for us to be able to compute an effect size representing the effect of the intervention on cycling.

Potential studies were identified using Web of Science with the "all databases" option selected using eight search keywords, organised into two filters – one for cycling (cycl* OR bicycl* OR bike*) and one for interventions (intervention OR trial OR experiment OR behavi* change strateg* OR random* control* trial*). The database search was undertaken on 30th January 2020. Combinations of "cycl*" with intervention keywords yielded 475,555 hits. We screened the first 1,000 hits rank ordered by the number of citations, but none of the studies were relevant (the studies were predominantly from biology, chemistry, and medicine). Given the unmanageable number of records returned by this particular combination of search terms, we decided to remove the keyword "cycl*" from the search terms. The remaining combination of keywords yielded 13,384 records (11,162 after duplicates removed).

Figure 2.1 (see in Appendix 1) shows the flow of information through the review. The titles and abstracts were first screened by the author of this thesis to decide whether the studies were likely to meet the inclusion criteria (i.e., described an intervention designed to promote cycling). The full texts of 335 studies that potentially met the inclusion criteria were then examined in detail by the author of this thesis, and 35 studies published in peer reviewed journals were included. In an effort to identify unpublished studies, we sent emails to 46 authors who contributed to the studies identified by the database search. Only one author replied with two possible reports, but neither were included because an effect size could not be computed from the statistics reported. We also searched the ProQuest database with the same combinations of keywords as described above in an effort to identify theses evaluating the effect of interventions designed to promote cycling. Thirty-eight records were identified, and one thesis proved suitable for inclusion (Groesz, 2007). Backward and forward reference searches were also conducted with the studies included and two additional unpublished studies were identified from this search. In total, we included four unpublished studies together with a previous intervention that we conducted, meaning the present review included 39 unique studies. Table 2.1 summarises the characteristics of the studies included in the review.

2.2.2. Data Extraction

In order to extract data from the identified studies, a data coding sheet was prepared together with the supervisors of this thesis, and two studies were independently coded and then compared by the author and the first supervisor of the thesis. We coded the following methodological characteristics of each study: (a) bibliographic information (e.g., author, year of publication, publication status); (b) study design (e.g., independent groups posttest only, single group pretest-posttest, or independent groups pretest-posttest; the number of conditions); (c) the outcomes measured for cycling (i.e., time, distance, and/or frequency), (d) the nature of the measure of cycling (self-report or objective); and (e) aspects of study quality (e.g., randomization, whether the researchers and/or the participants were blind to conditions, representativeness of the relevant population).

We also coded the following sample characteristics: (a) the mean age of the participants (in years); (b) the percentage of females in the sample; (c) the ethnicity of the sample (e.g., percentage white, black, Asian); (d) the modal level of education (no formal education, primary school, high school, undergraduate degree, postgraduate degree); (e) the country in which the study was conducted; and (f) the type of sample (e.g., children and adolescents aged below 17, general public, a specific group of adults such as employees in a specific company, patients of a specific disease, university staff and students).

Finally, we coded the following characteristics of the interventions: (a) the length in days; (b) the behaviour change techniques used; and (c) whether the intervention was guided by theory.

2.2.3. Effect Size Calculation/Meta-Analytic Strategy

Cohen's *d* was used as an index of effect size, which reflects the standardized difference between two means (e.g., mean scores on a measure of cycling for experimental vs. control groups or the mean before vs. after an intervention). Where possible, we calculated this effect size using the means and standard deviations reported in the paper for the measure of cycling. When these statistics were not reported, we converted other statistics (e.g., odds ratios or chi-square) to Cohen's *d* using Psychometrica (www.psychometrica.de). Where relevant data was reported at multiple follow-up points, we used the data reported at the longest follow-up, both to provide a conservative estimate of the effects of the intervention and to focus on long(er) term changes in cycling, rather than immediate effects. Where studies reported the effects of an intervention on multiple relevant outcomes (e.g., how far participants cycled as well as how frequently they did so), we computed effect sizes for each outcome separately and then averaged them before inclusion in the main analysis. Meta-Essentials version 1.4 (Suurmond, van Rhee, & Hak, 2017) was used to compute the sample-weighted average effect (Hedges g_+) of the interventions on cycling, adjusting effect sizes from studies with different methodologies using the procedures described by Morris and DeShon (2002). Three of the studies (Goodman, Panter, Sharp, & Ogilvie, 2013; Hosford et al., 2019; Krizek, Barnes, & Thompson, 2009) had very large samples (i.e., > 3 *SD* from the average sample size), so we "winsorized" these sample sizes to the next largest one within the "normal" range, so as not to bias the overall effect size. Finally, a protocol was not prepared for the current meta-analysis and it was not preregistered. As the meta-analysis was part of the current thesis, no additional financial support was obtained. The journal this meta-analysis was submitted to did not ask for (hence did not make available) the full data set used (see PRISMA Checklist in Appendix 11).

2.3. Results

Meta-analysis of 48 effect sizes from 39 unique studies and a total sample of 46,102 participants indicated that, on average, interventions designed to promote cycling have a small, but statistically significant (positive) effect on cycling ($g_+ = 0.14$, 95% CI: 0.05 to 0.23). Cochrane's Q was statistically significant ($Q = 501.15$, $p < .001$) suggesting that the effect sizes were heterogeneous and the I^2 statistic indicated that a large proportion of the variance in the effect sizes was explained by this heterogeneity ($I^2 = 90.62\%$), which indicates a need to identify variables that account for the variability. The effect sizes obtained from the studies were also tested for the publication bias and Egger's regression (Egger et al., 1997) did not indicate a significant publication bias ($p = .86$). Fail-safe N (Rosenthal, 1979) also indicated that 2555 studies with zero effect sizes would have been needed to show a publication bias. Table 2.3 reports the effect of intervention, sample, and methodological moderators on the effectiveness of the interventions.

2.3.1. Does the Nature of the Intervention Influence Effect Sizes?

The 48 interventions described by the primary studies included 24 unique behaviour change techniques (BCTs; see Table 2.2). The most frequently used techniques were restructuring the physical environment (BCT 12.1; e.g., building segregated bicycle lanes; used in 38% of interventions), instruction on how to perform the behaviour (BCT 4.1; e.g., instruction on how to change gears in a cycling course[1]; used in 33% of interventions), demonstration of the behaviour (BCT 6.1; e.g., demonstration of hand-signals; used in 27% of interventions), and behavioural practice/rehearsal (BCT 8.1; e.g., practicing steering; used in 27% of interventions). Three BCTs were associated with significant differences in the effect of the interventions that used (vs. did not use) them on cycling. First, interventions that prompted self-monitoring of behaviour (BCT 2.3; e.g., asked participants to use a smartphone app to track the distance or frequency with which they cycled) were significantly more effective (Hedges' $g_+ = 0.48$, $k = 4$) than those that did not prompt participants to self-monitor their behaviour (Hedges' $g_+ = 0.12$, $k = 44$), $Q = 8.50$, $p = .004$. Second, interventions that added objects to the environment (BCT 12.5; e.g., placed bike parking racks near university buildings) were more effective (Hedges' $g_+ = 0.45$, $k = 7$) than those that did not use this technique (Hedges' $g_+ = 0.08$, $k = 41$), $Q = 14.72$, $p < .001$. Third, interventions that restructured the physical environment (BCT 12.1; e.g., built segregated bicycle lanes) were significantly less effective (Hedges' $g_+ = -0.01$, $k = 18$) than those that did not (Hedges' $g_+ = 0.24$, $k = 30$), $Q = 18.16$, $p < .001$). The number of BCTs used in the interventions was not significantly associated with the effect of the interventions on cycling ($\beta = 0.005$, $p = .682$). Finally, there was no evidence that interventions that used theory to guide their intervention (Hedges' $g_+ = 0.17$, $k = 9$) yielded significantly larger effects than interventions that did not use a theory (Hedges' $g_+ = 0.13$, $k = 40$), $Q = 0.42$, $p = .517$ (see Table 2.3).

2.3.2. Methodological Moderators

With respect to methodological moderators, the nature of the measure of cycling and the design of the study significantly moderated the effect of the interventions on outcomes (see Table 2.3). Specifically, interventions typically had a larger effect on objective measures of cycling (e.g., accelerometers; Hedges' $g_+ = 0.37$, $k = 11$) than on self-report measures (e.g., online surveys; Hedges' $g_+ = 0.09$, $k = 37$), $Q = 6.72$, $p = .010$. Furthermore, studies that used an independent groups posttest only design typically reported larger effect sizes (Hedges' $g_+ = 0.27$, $k = 9$) than those that used an independent groups pretest-posttest design (Hedges' $g_+ = 0.12$, $k = 33$) or a single group pretest-posttest design (Hedges' $g_+ = 0.01$, $k = 6$), $Q = 7.93$, $p = .019$.

2.3.3. Sample Moderators

We also tested whether characteristics of the sample moderated the effect of the interventions on cycling (see Table 2.3). Only the type of sample had a significant impact on the effectiveness of the interventions. Specifically, interventions targeting a specific group of adults (e.g., employees in a company, patients of a specific disease, university staff and students) were more effective (Hedges' $g_+ = 0.33$, $k = 10$) than interventions targeting children (Hedges' $g_+ = 0.16$, $k = 13$) or members of the general public (Hedges' $g_+ = 0.07$, $k = 25$), $Q = 6.99$, $p = .030$. Age ($B = -0.002$, $p = 0.577$), gender ($B = -0.380$, $p = 0.188$), modal level of education ($Q = 0.15$, $p = 0.985$), ethnicity ($B = -0.248$, $p = 0.244$) did not moderate the effectiveness of the interventions[2].

2.4. Discussion

The present review sought to identify the best way to promote cycling by quantitatively synthesizing evidence on the effectiveness of interventions designed to promote cycling. A systematic search identified 39 interventions that targeted cycling, providing 48 unique effect sizes. On average, the interventions had a small, but positive effect on cycling ($g_+ = 0.14$) confirming that it is possible to change people's cycling behaviour. Although the effects of interventions designed to promote cycling are typically small, it is important to recognise that interventions that produce small effects can have a large impact on public health if they can be scaled up and delivered at a population level

(West, 2007). As expected, however, there was large variation in effect sizes from the primary studies. Part of this variability was accounted for by the nature of the intervention, with evidence that three BCTs influenced the effectiveness of interventions designed to promote cycling. Specifically, interventions that prompted participants to self-monitor their cycling behaviour and added objects to their environment such as bike parking racks or shared bikes were more effective than interventions that did not include these strategies, while interventions that restructured the physical environment were typically less effective than those that did not.

The effectiveness of self-monitoring in promoting physical activity is well supported (Bird et al., 2013; Conn et al., 2002; Davies et al., 2012; Michie et al., 2009; O'Brian et al., 2015), as is the effect of prompting people to monitor their goal progress more generally (Harkin et al., 2016). Self-monitoring is also effective in promoting other health related outcomes such as weight loss (Burke et al., 2011) and reducing alcohol consumption (Crane et al., 2018). That the current review found that prompting self-monitoring helped to promote cycling is therefore consistent with evidence in other domains. The central role of self-monitoring in promoting goal attainment is highlighted by Control Theory (Carver & Scheier, 1982; 2002) in which self-monitoring is viewed as the process by which people compare their current state (or rate of progress) to their desired state and direct their next steps accordingly (e.g., try to cycle more). It is also worth noting that combining self-monitoring with other BCTs targeting self-regulatory processes specified by Control Theory, (e.g., goal-setting and action planning), should yield even larger intervention effects, as reported in a meta-analysis of healthy eating and physical activity interventions (Michie et al., 2009). However, there are no prior studies that applied these BCTs or the Control Theory in an intervention to promote cycling (Bird et al., 2013; Yang et al., 2010). Applying techniques specific to the Control Theory is aimed for in the current thesis.

Relatively few reviews to date have considered the impact of adding objects to the environment on behaviour. In relation to cycling, this BCT includes increasing access to bikes via bike share schemes or adding bike parking racks at destination points such as work places or public transport stations. Such interventions might serve as cues to cycle, especially for those who do not own a bicycle or those who are unsure where they might park their bicycle. Evidence suggests that cues can help to develop habits (Lally & Gardner, 2013), which reflect automatic responses to situational cues (e.g., the availability of a bike share scheme) and have been found to be strong determinants of travel behaviour in general, and cycling specifically (de Bruijn et al., 2009; Willis et al., 2015). In short, interventions that add objects to the environment might be effective because they increase cues to cycle.

The finding that interventions that restructured the physical environment were less effective than those that did not restructure the environment was surprising. In relation to cycling, this BCT included changes to infrastructure (e.g., building new bicycle paths, landscaping lanes) and several previous reviews have reported positive effects of such interventions (Fraser & Lock, 2010; Pucher et al., 2010; Pucher et al., 2011). One possible reason for this difference between the findings of previous reviews and the current meta-analysis might be the challenges associated with quantifying the effects of studies that change infrastructure as they do not typically recruit participants and measure outcomes. As a consequence, it is difficult to control who is exposed to the intervention and obtain direct measures of outcomes. Alternatively, the present findings might suggest that psychosocial interventions (e.g., those prompting participants to keep track of how much they cycle) are more effective in promoting cycling than interventions that modify the infrastructure. While an infrastructure that supports cycling makes it easier to cycle, many people cycle despite the lack of, for instance, segregated bicycle lanes or traffic-free bicycle paths and, in turn, therae are people who do not cycle despite the best infrastructure (Diniz et al., 2015; Nehme et al., 2016). Hence, projects aiming to improve the infrastructure might incorporate psychosocial components in their interventions alongside the changes to infrastructure.

It was interesting to note that only 24 of the 93 BCTs described by the BCT v1 taxonomy (Michie et al., 2013) have been used in interventions designed to promote cycling to date. This suggests that there is considerable scope for considering new ways to promote cycling that may not have been tried (or at least evaluated) previously. For instance, only one study in the present review prompted participants to set behavioural goals; however, goal setting has a small, but robust effect on behaviour (for a review, see Webb & Sheeran, 2006) and so might help to promote cycling together with BCTs targeting other processes from Control Theory (e.g., self-monitoring and goal operating) as suggested by Michie et al. (2009). It is also possible that other combinations of BCTs may be effective. For example, Pucher et al. (2010) suggested that comprehensive programs with multiple active ingredients typically have larger effects on cycling. However, it may not be a case of simply using as many techniques as possible (indeed, we found that the number of BCTs used by interventions was not associated with efficacy) but rather using the right combination of techniques to promote cycling, where the 'right' combination is informed by relevant theory (Prestwich, Webb, & Conner, 2015).

2.4.1. Methodological Moderators

Two methodological variables moderated the effect of the interventions on cycling – the way that cycling was measured and the design of the study. Firstly, interventions that used objective measures of outcomes typically reported larger effects than interventions that used self-reports. One interpretation is that objective measures provide a more accurate assessment of the effects of an intervention, since self-report measures can be biased and/or inaccurate (Podsakoff, MacKenzie, Lee, & Podsakoff, 2012; Podsakoff & Organ, 1986). Finding that objective measures yield possibly more accurate results is also encouraging for future interventions, especially with the increased prevalence of smartphones and applications that can easily be used to (objectively) measure cycling. Secondly, we found that interventions evaluated in independent groups posttest only designs typically yielded larger effects than interventions evaluated in independent groups pretest-posttest designs and single group pretest-posttest designs. One interpretation is that not taking baseline scores into account may artificially inflate the differences observed between experimental groups. Therefore, independent groups pretest-posttest designs should be seen as the gold standard and used to test interventions where possible (Morris & DeShon, 2002).

2.4.2. Sample Moderators

None of the sample related factors moderated the outcomes of interventions in the present review except the nature of the target sample. Interventions targeting specific groups (e.g., university staff and students, employees of a specific company) were typically more effective than interventions targeting members of the general population. One explanation is that interventions targeting a specific target group are better tailored to the needs of their samples and / or the challenges that they face and previous reviews have found that tailored interventions tend to be more effective in changing behaviour (Bird et al., 2013; Zimmerman, Olsen, & Bosworth, 2000). The finding that age, gender and ethnicity did not moderate the effectiveness of interventions in the present review is encouraging as it suggests that interventions designed to promote cycling can be effective regardless of participants' age, gender, or ethnicity.

2.4.3. Limitations and Future Directions

One limitation of the existing review is that BCTs were coded simply as present or absent, which does not capture intensity or variability within BCTs. For instance, restructuring the physical environment (BCT 12.1) can be used to describe an intervention that simply repaints existing bike paths as well as an intervention that provides an entirely new traffic free bicycle path. Furthermore, many of the studies did not fully report sample characteristics, intervention components, or analyses – therefore some of the moderator analyses were based on a reduced number of studies. These differences might be due to the studies coming from various disciplines such as city and regional planning, public health, or civil engineering that differ in their approach to data collection (e.g., using aggregate level vs. individual level data), the language used to explain their interventions, and statistical methods used as well as reported in their analysis. As suggested by Colquhoun et al. (2014), developing a common methodology and terminology would help to overcome these issues. This may also help bring multiple disciplines, such as social science, public health, and engineering, together to promote cycling.

These limitations also highlight a need to create a common methodology to deliver intervention components to promote cycling, as well as to change other behaviours (Michie et al., 2009). For example, self-monitoring was found to be a significant technique to promote cycling, but not every study that used self-monitoring was effective in the current meta-analysis. Likewise, instructions on how to perform the behaviour was a non-significant technique to promote cycling, but not every study that used this technique was ineffective in promoting cycling. These differences might result from different ways in which the techniques were delivered. Future research should therefore seek to test teh effectiveness of different BCTs using a common mode of delivery such as short text messages. Digital mediums offer an easy and cost-effective medium through which to deliver and compare the effectiveness of different BCTs in interventions (Hall et al., 2015; McKay et al., 2018; Webb et al., 2010). This goal is addressed in the next chapter of the thesis.

2.4.4. Conclusion

The findings of the present review suggest that it is possible to promote cycling, although with the caveat that interventions typically only have a small effect. Consideration of variables that were associated with efficacy provides grounds for optimism that larger effects might be observed in the future, particularly if researchers and practitioners draw on existing evidence about what works and for whom. Our primary suggestions are that interventions seeking to increase cycling should target specific groups of people, focus on individuals rather than environments, and prompt people to self-monitor relevant behaviour. Tests of these interventions should employ independent groups pretest-posttest designs and use objective measures of behaviour. Further research is also needed to test other BCTs, or combinations of BCTs, to further increase the effectiveness of interventions, for example as highlighted by Control Theory (Carver & Scheier, 1982).

Footnotes

[1] We also tested if interventions that included a cycling course (including BCTs 4.1, 6.1, and 8.1) had larger effects than other interventions and found that interventions with a cycling course (Hedges' g_+ = 0.10, k = 13) did not have larger effects than the interventions that did not incorporate a cycling course (Hedges' g_+ = 0.15, k = 35); the results were non-significant, Q = .45, p = .503.

[2] We report ethnicity as the percentage of whites in the sample because the majority of the sample in each of the primary studies were white. However, we also investigated whether the percentage of each of the other ethnicities that we coded were associated with effect sizes. None of the beta weights were significant. Specifically, the percentages of Black participants (B = 0.935, p = 0.293), Asian participants (B = 0.418, p = 0.134), or Hispanic participants (B = 0.125, p = 0.821) in the sample were not associated with the effect of the interventions on cycling.

Chapter Three

Developing Short Text Messages to Deliver Behaviour Change Techniques: A Delphi Method Study

Abstract

The meta-analysis in Chapter 2 showed that cycling can be promoted via interventions. However, interventions to promote cycling and behaviour change in general can be expensive and time consuming. The aim of the current chapter was to develop a list of short text messages that could be used to deliver individual behaviour change techniques (BCTs) in a behaviour change intervention. A list of 93 short text messages were designed to capture each of the 93 BCTs included in the BCT taxonomy. These were then subjected to a two-stage Delphi method with 15 experts in behaviour change. The experts were asked to code each message using the BCT taxonomy and to rate whether each message conveyed the intended BCT, could be converted easily to target other behaviours, and could be understood by the general public. High agreement rates were found for 66 of the 93 short text messages. These text messages could therefore be used in future behaviour change interventions. However, the 27 messages with lower agreement might indicate the need for refinement in the next version of the BCT taxonomy.

3.1. Introduction

Behaviour is central to almost all societal grand challenges, whether concerning the environment, health, well-being, or the development of sustainable economic models. Addressing such challenges requires the development of tools and interventions that have the potential to change behaviour – e.g., promoting health behaviour (Glanz et al., 2008), sustainable travel (Bird et al., 2013), recycling (Varotto & Spagnolli, 2017), donating blood

(Karacan et al., 2013), using contraceptives (Berendes et al., 2021; Johnson et al., 2014), or increasing productivity (Hall & Mills, 2019; Hartmann et al., 2018). Research on interventions to change behaviour has increased rapidly over recent years (Fitzgibbon et al., 2014; Michie et al., 2018; Riekert et al., 2013). These interventions typically have more than one active ingredient, i.e., behaviour change techniques (BCTs; Bird et al., 2013; Michie et al., 2018). As outlined in Chapters 1 and 2, BCTs, or ‘active ingredients’, are “observable, replicable, and irreducible component(s) of an intervention designed to alter or redirect casual processes that regulate behaviour” (Michie et al., 2013, p. 82). Michie et al. identified 93 unique techniques clustered under 16 categories that have been used in interventions to change behaviour. While these 93 BCTs provide a solid base for identifying the unique active ingredients of interventions, applying them is not always straightforward or easy. Hence, the current study aims to test if BCTs can be delivered in the form of relatively brief messages.

3.1.1. Digital Modes of Intervention Delivery

With the increase in access to and usage of the internet, smartphones, and social media, technology is increasingly being used in behaviour change interventions (Alkhaldi et al., 2016; Hekler et al., 2016; Moller et al., 2017). Facebook (Comber et al., 2013), Twitter (Sinnenberg et al., 2017), smartphone applications (Alkhaldi et al., 2017; Fedele et al., 2017), phone calls (Denisson et al., 2014), and short message service (SMS; Michie et al., 2012b) are all examples of digital methods that have been utilized in behaviour change interventions. Many of these methods place no character limits for the content that can be conveyed. For example, there are virtually no character limits on emails sent (in major service providers such as Hotmail or Gmail) and Facebook has 63206 characters limit to their posts. There are also no limits to the messages conveyed through smartphone apps or notifications. However, Twitter places a 280 character limit on tweets (changed from 140 characters in 2017) and SMS has a 160 characters limit for the first text message, and a 144 characters limit for each consecutive message. This means that the sender (the interventionist, for example) pays for one SMS for the first 160 characters, and two SMS for text messages between 161 and 304 characters, and so on. This means that SMSs are shortest forms of digital communications currently that can be used in interventions to change behaviour. Hence, in order that text messages can be used via both SMS and other digital methods easily, it is important that their length is limited to 160 characters. Van Genugten et al. (2016) suggested that digital interventions that are easy to use and require little time to understand (i.e., efficient) are more likely to be effective. Furthermore, reading long texts can be cognitively demanding and requires longer attention spans, and people tend to disengage from cognitively demanding tasks (Jackson & Balota, 2012; Subramanian, 2018). Short text messages (≤160 characters) may solve these problems of efficiency and disengaging from interventions.

Using short text messages to deliver BCTs has further advantages such as the potential to automatize the delivery of messages, thereby making it easier to reach larger populations, and tailor delivery to timely moments or places relevant to the behaviour. For example, the use of short text messages to deliver an intervention to promote vaccination in a large population (N = 47306) has recently been tested by Milkman et al. (2021). They found that nudges and reminders sent via SMS messages achieved a 5% increase in vaccination rates. In addition, reaching participants at timely moments can be achieved by using SMS services which deliver text messages at planned times, or by using geolocation services to deliver messages in specific situations (e.g., at a pub or restaurant).

3.1.2. The Current Study

The current study aims to develop a list of short text messages that can be used to convey individual behaviour change techniques. To illustrate how short messages might be used to deliver BCTs, the messages were designed to promote cycling; however, they were written in such a way that they might be easily adapted to target other behaviours. In order to ascertain that the text messages serve the purpose of the current study, a Delphi method (Linstone & Turoff, 1975; Pill, 1971) was used to obtain expert opinion from a panel of researchers working in this field on the extent to which the short text messages (1) convey the specific BCT with fidelity, (2) can be converted easily to target other behaviours, and (3) be understood and followed easily by the general public.

3.2. Method

3.2.1. Development of the Initial List of BCT Messages

A list of 186 short text messages (two messages for each of the 93 BCTs) designed to promote cycling was prepared. This list was entered into Qualtrics online survey service, the order of the text messages were randomized, and the two supervisors of this thesis independently coded which BCT they believed that each message was designed to deliver. The 74 messages (40%) that were assigned to the (50 unique) BCT that they were designed to convey by both supervisors and were taken forward to the next stage of the study. The 86 text messages designed to deliver the remaining 43 BCT were revised/refined by the author and then independently coded by the two supervisors again. Thirty-eight of these 86 messages (45%) were assigned to the (30 unique) BCT that they were designed to convey. Hence, 80 of the 93 BCTs had at least one text message that was correctly assigned to the indented BCT by both supervisors.

The research team then considered the most appropriate text message for each BCT to take forward to Delphi stage to be rated by experts. Where both of the messages designed to deliver a BCT were correctly coded by both coders (31 BCTs), one message was selected by discussion. Where only one of the messages designed to deliver the BCT was correctly coded by both coders (49 BCTs), this message was selected. Finally, where neither message was correctly coded, a new message was prepared following discussion (13 BCTs). The final list of 93 messages (one message for each of the 93 BCTs) was then entered into Qualtrics.

3.2.2. Delphi Method Survey

The next stage of the research involved inviting independent experts to consider the short text messages to ensure that they conveyed the intended BCT, could be easily converted to target other behaviours, and were likely to be understood by the general public. Ethical approval for the Delphi study was provided by the Research Ethics Committee in the Department of Psychology at the University of Sheffield (application #034017).

3.2.3. Participants

There are no clear guidelines for the number of experts required to run a Delphi study (Pill, 1971); instead, the expertise levels of participants is proposed to be more important than their number (Akins, Tolson, & Cole, 2005; Ogbeifun, Agwa-Ejon, Mbohwa, & Pretorius, 2016; Williams & Webb, 1994). The BCT taxonomy that formed the basis of the present research was developed in collaboration with a panel of 14 experts (Michie et al., 2013); therefore, the current study sought to recruit 20 experts to allow some attrition. Experts were required to have published an article in which they used the BCT v1 taxonomy (Michie et al., 2013) to code their own or others' interventions. To identify these experts, Web of Science was used to identify articles that cited the BCT v1 taxonomy and to sort these articles by number of citations. Articles were then screened to identify articles that used the BCT taxonomy to explain own or others' interventions, and the corresponding authors of the 40 articles that were most frequently cited were contacted via email. Nine positive responses were received. The same articles were then sorted by the date published (most recent first) and another 40 corresponding authors of the most recently published articles were contacted and 14 positive responses were received. Recruitment was ceased at this point. Of the 23 experts who agreed to participate in the study, 15 completed both phases of the survey. The mean age of these experts was 36.60 years (*SD* = 7.04), 12 (80%) were female. Twelve had a PhD (80%), two had a master's degree (13%), and one had a bachelor's degree (7%).

Potential participants were told that the study would have two phases; the first of which would take about four and a half to five hours; the second of which would be shorter depending on the responses to the first survey. They were also informed that they would be given a £50 voucher if they completed both phases of the study. Experts who agreed to take part were sent further information and a link to the initial survey. If the experts did not complete the first phase of the survey within a month, they were sent a reminder email. The level of agreement between the experts in phase 1 was then calculated for each text message. Text messages with poor agreement (kappa < .60) were refined and entered into a new survey, which was sent back to the experts who completed the first phase of the survey. After the experts had completed this second survey, they received a code for a £50 voucher.

3.2.4. Measures

The first phase of the survey consisted of informed consent, a short demographic form (age, gender, and education), and five questions about each of the messages designed to convey the 93 BCTs. These questions were; (1) "Which BCT do you think that this message delivers?" (Participants were provided with an open ended text box within which to enter their response to this question), (2) "How confident are you?" (Participants responded on a 5-point likert scale anchored by 'not confident at all' and 'very confident'), (3) "To what extent do you think the message would be easy for a lay person to understand/ follow?" (5-point likert scale anchored by 'very hard' and 'very easy'), (4) "How easy do you think it would be to modify this message to apply to other behaviours?" (Participants responded on a 5-point likert scale anchored by 'very hard' and 'very easy'), and (5) "Do you have any suggestions to improve the message?" (Participants were provided with an open ended text box). The second phase of the survey provided a short reminder of the purpose of the research and then the same five questions with respect to each of the remaining messages.

3.2.5. Approach to Analysis

Fifteen experts completed both parts of the survey and coded an average of 87 of the 93 messages (*SD* = 12). As the experts were not allowed to return to questions that they had not answered, messages that were not coded were considered to be coded incorrectly. The level of agreement between the experts was assessed using Cohen's kappa coefficient. Kappa scores above .60 were taken to indicate a "substantial" level of agreement (Landis & Koch, 1977; Michie & Prestwich, 2010). The formula used to compute kappa for each message was ((observed agreement percentage – chance factor) / (1 – chance factor)), where the chance factor was 1/93 = 0.01075.

3.3. Results

In the first phase of the Delphi component of the study, the experts agreed on which BCTs 63 of the 93 messages (68%) were designed to convey (i.e., 63 of the 93 messages had kappa scores above .60 and 30 messages had kappa scores of .60 or below; see Appendix 5). Table 3.1 shows that, on average, the experts were relatively confident about which BCTs were delivered by each of the messages ($M = 3.86$, $SD = 0.38$), and generally believed that they would be understood by the lay public ($M = 4.33$, $SD = 0.55$), and could be applied to other behaviours ($M = 4.16$, $SD = 0.54$). Independent samples t-test results indicated that the messages the experts agreed upon had significantly higher kappa scores ($p < .001$), confidence levels ($p < .001$), understandability ($p = .01$), and convertibility ($p = .001$) than the messages that were not agreed upon.

Table 3.1

Descriptive statistics reflecting the experts' assessment of the short messages presented in the Phase 1

	Means (*SD*s) for Phase 1 (*N* = 93)	Correctly coded (*N* = 63)	Incorrectly coded (*N* = 30)
Mean kappa score	.68 (.24)	.82 (.10)	.38 (.18)
Mean confidence level	3.86 (0.62)	4.12 (0.43)	3.31 (0.59)
Mean understandable level	4.31 (0.33)	4.37 (0.28)	4.18 (0.38)
Mean convertibility level	4.14 (0.40)	4.23 (0.32)	3.93 (0.47)

In the second phase, the experts agreed on which BCTs 3 of the remaining 30 messages (10%) were designed to convey (i.e., 3 of the 30 messages had kappa scores above .60 and 27 had kappa scores of .60 or below; see Appendix 6). Table 3.2 shows that, on average, the experts were relatively confident about which BCTs were delivered by each of the messages (M = 3.50, SD = 0.41) and believed that they would be understood by the lay public (M = 4.07, SD = 0.39), and could be applied to other behaviours (M = 4.05, SD = 0.29). Independent samples t-test results indicated that the messages the experts agreed upon had significantly higher kappa scores ($p < .001$), and understandability (p = .003) rates than the messages that were not agreed upon, but confidence levels (p = .749), and convertibility (p = .911) rates were not significantly different from each other.

Table 3.2

Descriptive statistics reflecting the experts' assessment of the short messages presented in the Phase 2

	Means (*SD*s) for Phase 2 (*N* = 30)	Correctly coded (*N* = 3)	Incorrectly coded (*N* = 27)
Mean kappa score	.29 (.25)	.75 (.04)	.24 (.21)
Mean confidence level	3.50 (0.41)	3.58 (0.54)	3.50 (0.40)
Mean understandable level	4.07 (0.39)	3.46 (0.53)	4.14 (0.32)
Mean convertibility level	4.05 (0.29)	4.03 (0.28)	4.05 (0.30)

The final list of text messages was created by selecting the messages with the highest level of agreement (i.e., highest kappa scores) from the 30 messages coded in the second phase of the study and combining them with the 60 messages with high levels of agreement (i.e., kappa scores > .60) from the first phase. As shown in Table 3.3, there was a good level of agreement between the coders for the final list of text messages (Mean kappa score = .70, *SD* = 0.22) and, on average, the coders were confident in their judgments (*M* = 3.88, *SD* = 0.56). The experts also believed that these messages would be understood by members of the general public (*M* = 4.27, *SD* = 0.36) and could be easily converted to target other behaviours (*M* = 4.14, *SD* = 0.39). Independent samples t-test results indicated that the messages the experts agreed upon had significantly higher kappa scores ($p < .001$), confidence levels ($p < .001$), understandability ($p = .009$), and convertibility ($p = .001$) than the messages that were not agreed upon.

Table 3.3

Descriptive statistics reflecting the experts' assessment of the final list of short messages

	Means (*SD*s) for Phase 2 (*N* = 93)	Correctly coded (*N* = 66)	Incorrectly coded (*N* = 27)
Mean kappa score	.70 (.22)	.81 (.10)	.41 (.16)
Mean confidence level	3.88 (0.56)	4.09 (0.45)	3.35 (0.44)
Mean understandable level	4.27 (0.37)	4.33 (0.35)	4.12 (0.36)
Mean convertibility level	4.14 (0.39)	4.22 (0.32)	3.92 (0.47)

All of these variables were significantly and positively correlated with each other (see Table 3.4) such that higher kappa scores were associated with higher ratings of confidence, understandability and convertibility.

Table 3.4

Correlations between kappa scores and ratings of confidence, understandability, and convertibility

	1	2	3	4
Kappa scores	-			
Confidence level	.69**	-		
Perceived understandability level	.38**	.38**	-	
Perceived convertibility level	.42**	.55**	.52**	-

Note. * $p < .05$, ** $p < .01$

Text messages for BCT clusters were also examined separately from the final list of text messages (see Appendix 7). Among the 16 clusters, ‘goals and planning’ cluster had the highest average kappa score (.92) and all nine messages in this cluster had kappa scores above .60. Experts also reported high confidence in their responses (4.49), understandability

(4.34), and convertibility (4.48) for the messages in this cluster. The cluster with the lowest average kappa score was ‘associations’ (.41). Of the eight messages in this cluster, only two of the messages had above .60 kappa score. Experts reported relatively lower confidence in their responses (3.45), understandability (4.10), and convertibility (3.91) for the messages in this cluster. Overall, only three clusters (19%) had average kappa scores of .60 or below. These were ‘regulation’ (kappa score = .56) and ‘scheduled consequences’ (kappa score = .51), in addition to ‘associations’ (kappa score = .41), with only a/b, c/d and 2/8 messages with kappa scores above .60, respectively.

3.4. Discussion

The present research tested if a list of short text messages can be prepared to convey BCTs that experts would agree on. This was achieved by developing short messages designed to deliver each of the 93 behaviour change techniques (BCTs) described by the BCTv1 taxonomy (Michie et al., 2013) and utilizing Delphi method to collect expert opinions on these messages. Experts who had worked with the taxonomy coded which BCT they believed that each message was designed to deliver and how confident they were in their judgements. The experts also rated whether they believed that the messages would be understood by members of the general public and could be adapted to target other behaviours.

The experts correctly identified which BCT the majority of the text messages were designed to target. Thus, 66 of the 93 text messages (71%) had substantial agreement between the experts that they conveyed the BCTs they were designed to convey with fidelity. The messages were also considered as easy to understand by lay people and as easy to be converted to target different behaviours. Agreement rates for the 66 short text messages were ‘almost perfect’ (mean kappa score was .81; Holey et al., 2007). This indicates that 66 BCTs can be reliably delivered via short text messages. This finding is especially important in showing that delivering BCTs via short text messages is possible and viable. It can be suggested that, for the correctly sorted BCTs, the messages prepared for the current study can be converted and used in the future digital interventions.

However, it is also the case that the experts could not reliably identify which BCT 27 of the 93 text messages were designed to deliver. These 27 messages were not evenly distributed between the clusters. Seven of them came from the scheduled consequences cluster and six from the associations cluster. In contrast, four clusters, (i.e., goals and planning, comparison of behaviour, repetition and substitution, and comparison of outcomes) had no such messages. Furthermore, some of these messages that had low levels of agreement were commonly mistaken for each other (e.g., messages prepared for specific BCTs were assigned to other BCTs by multiple experts). This might be either due to the messages not being prepared well enough to be distinguished from each other, or due to the BCTs being very similar to each other, or too fine-grained even for the experts to discriminate between. If the latter is the case, then it may also be hard for these BCTs to be distinguished when coding interventions, e.g., for meta-analyses. For instance, the experts were not able to reliably distinguish between short text messages designed to convey punishment (BCT 14.2), future punishment (BCT 10.11), and behaviour cost (BCT 14.1). Similarly, examples of 'fine-grained' pairs of BCTs included remove reward (BCT 14.3) versus remove access to the reward (BCT 7.4), re-attribution (BCT 4.3) versus framing/reframing (BCT 13.2), and cue signalling reward (BCT 7.2) versus situation-specific reward (BCT 14.6). These BCTs are quite close to each other in terms of their definitions in the BCT taxonomy v1. It can be suggested that these BCTs should be revised in the second version of the taxonomy.

While the BCT taxonomy v1 seeks to differentiate active ingredients until the smallest piece, a more liberal approach to categorizing the active ingredients would help the coding and combining some of the BCTs with similar definitions. For instance, punishment (BCT 14.2) requires by definition that "aversive consequence contingent on the performance of the unwanted behaviour" and behaviour cost (BCT 14.1) requires by definition that "withdrawal of something valued if and only if an unwanted behaviour is performed" (Michie et al. 2013). These two BCTs are examples of positive and negative punishment, respectively (Skinner, 1974). In addition to these, the taxonomy also has future punishment (BCT 10.11; "future punishment or removal of reward will be a consequence of performance of an unwanted behaviour") which has both positive and negative punishment attributes in its definition, and remove reward (14.3; "discontinuation of contingent reward following performance of the unwanted behaviour") which also includes negative punishment attributes in its definition. Hence, creating two BCTs which covers either positive or negative punishment attributes would simplify the BCT taxonomy and may lead to more reliable coding of BCTs..

3.4.1. Limitations and Future Directions

It is worth noting several limitations to the current study. First, while SMS is limited to 160 characters, other modes of delivery are not limited to this number and interventions may employ longer messages (or may choose to pay for more than one SMS), which may convey BCTs in a clearer way. However, longer messages may compromise the brief nature of the current list of messages and require more attention and time from the reader. It may also be possible that some BCT messages would still be difficult to discriminate between. Second, the comprehensibility of the text messages was assessed by asking experts "To what extent do you think that the message would be easy for a lay person to understand/follow?" However, one of the experts suggested that 'understanding' the text messages and 'following' them could be examined separately. In other words, understanding what the message (or BCT) asks you to do is different from being able to follow it. Finally, the current research only examines whether BCTs can be delivered via short text messages. However, the research did not examine whether these messages were effective in changing behaviour. In order to test the effectiveness of these messages, behaviour change interventions should be implemented using the messages, especially the ones with high agreement rates. It would also be interesting to test if the same BCTs yield different effect sizes when delivered via common methods (e.g., suggestions by physicians, in-person lessons) and short text messages. For instance, it was found in Chapter 2 that self-monitoring of the behaviour (BCT 2.3) is an effective method in promoting cycling but there are no prior studies testing if this BCT can be effective when delivered via short text messages.

3.4.2. Conclusion

The majority of the text messages prepared for the current study were sorted correctly by the experts, thereby confirming that many BCTs can be delivered via short text messages, and can easily be converted for other behaviour. The effectiveness of these text messages in terms of changing behaviour needs to be tested in future interventions.

Chapter Four

Delivering Behaviour Change Techniques via Short Text Messages in Randomized Controlled Trials to Promote Cycling and Reduce Car Use

Abstract

The meta-analysis reported in Chapter two indicated that cycling can be promoted via interventions, especially with psychosocial interventions and those that contain certain behaviour change techniques (BCTs) such as self-monitoring. In Chapter three, it was demonstrated that many BCTs can be reliably delivered via short text messages. This chapter reports the results of three studies that delivered BCTs via short text messages in interventions targeting bicycle use and (reduced) car use. Study 1 compared participants randomly assigned to three intervention groups to promote cycling that received messages for three BCTs (N = 26), versus one BCT (N = 29), versus no BCTs control group (N = 40). Study 2 compared participants randomly assigned to two intervention groups to promote cycling that received three BCTs (N =8) versus no BCTs (N = 16). Study 3 compared participants randomly assigned to two intervention groups to decrease car use that received three BCTs (N = 29) versus no BCTs (N = 32). Results indicated that participants in the intervention groups increased the number of times they cycled significantly more than the participants in the control group did. However, the other two intervention effects were non-significant. As the studies had small sample sizes, their effect sizes combined in a mini meta-analysis to increase the statistical power. Results of this analysis indicated that, on average, the three interventions had small and non-significant effect sizes (g_+ = 0.24, 95% CI [-0.11, 0.59]). This effect size comparable to the effect size found in Chapter Two for psychosocial

interventions to promote cycling. It can be suggested that delivering BCTs via short text messages have small effect on promoting cycling. Given the relative ease and low cost of delivering psychosocial interventions in this way, the public health impact at a population level is, nonetheless, likely to be important.

4.1. Introduction

As outlined in previous chapters, active travel (i.e., walking and cycling) can be a viable solution to a number of modern problems including air pollution (Tainio et al., 2021), carbon emissions, traffic congestion (Rissel, 2009; Woodcock et al., 2009), sedentary life and consequences associated to it such as heart disease, diabetes, hypertension, and osteoarthritis (Braun et al., 2016; Hartog et al., 2010; Oja et al., 2011; Pucher, Buehler et al., 2010). Despite known benefits, active travel is far from being the main travel mode in the UK, even for the trips between 1 to 2 miles; only 31% and 3% of those trips are made by walking and cycling, respectively (Department for Transport, 2020). Hence, interventions have the potential to promote this behaviour and make a positive impact.

As found in the meta-analysis reported in Chapter 2, cycling can be promoted via interventions. Moreover, the Delphi study reported in Chapter 3 demonstrated that the 'active components' of interventions (i.e., BCTs) can be delivered via short text messages. However, if and the extent to which these BCTs when delivered via short text messages can be effective is still not known. The aim of the current chapter is to explore the use of short text messages (i.e., SMS) to promote active travel – i.e. cycling and reduced car use. Specifically, three studies are reported that sought to deliver self-monitoring of behaviour (BCT 2.3) as this BCT has consistently found to be one of the most effective BCTs in systematic reviews of interventions to promote active travel (Bird et al., 2013), cycling (Chapter 2), and physical activity in general (Kang et al., 2009, Michie et al., 2009). In addition to self-monitoring of behaviour, the three intervention studies presented in this chapter also include short text messages to deliver the BCTs of behavioural goal setting (BCT 1.1) and goal operating (BCT 1.4) given that these are key components of Control Theory (Carver, & Scheier, 1982; 2002) that are often used in conjunction with self-monitoring.

4.1.1. Mode of Delivery

Interventions that have targeted psychological aspects of active travel have mostly used face-to-face communication (such as education in a classroom or workshop setting), counselling, incentives etc. (Bird et al., 2013). However, such methods may be difficult and/or costly to implement in larger populations. The effects of interventions that can reach larger populations easily, such as digital interventions, have not been fully explored to date, as they are typically used along with other methods such as organised walking or cycling events, cycling skills courses, infrastructure changes, etc. (Rissel et al., 2010; Verhoeven et al., 2016).

Using digital technology for promoting health related behaviours has proliferated in the last decade, such as SMS text messages (Gerber et al., 2009; Militello et al., 2012), social media such as Facebook or Twitter (Turner-McGrievy, & Tate, 2011; Wojcicki et al., 2014), smartphone applications (Carter et al., 2013; Stephens, & Allen, 2013; Turner-McGrievy, & Tate, 2011), or biofeedback devices such as pedometers (Griffin et al., 2018; Newton et al., 2009). These digital mediums have also been used to change different behaviours such as weight management (Shaw & Bosworth, 2012), physical activity (Fjeldsoe et al., 2010), adherence to treatment (Coleman et al., 2017; Peimani et al., 2016), smoking (Taylor et al., 2017), alcohol consumption (Crane et al., 2018), etc.

These studies show the usefulness of digital technology to promote behaviour change for physical activity and other health related behaviours which can easily be applied to a larger number of people with convenience, and at little or no cost (Hall et al., 2015; McKay et al., 2018; Webb et al., 2010). For instance, Wojcicki et al. (2014) tested delivering their intervention via Facebook over eight weeks to promote physical activity and found that participants who received behavioural instructions via Facebook increased their physical activity more than the control group. In their systematic review of interventions that have used smartphone apps or SMS to promote physical activity and weight loss, Stephens and Allen (2013) reported that the majority (71%) of the studies produced significant positive results. Shaw and Bosworth (2012) also reported in their systematic review that 79% of the studies which used SMS messages targeting weight loss and physical activity reported significantly positive results. Milkman et al. (2021) also reported an increase in vaccination rates among 47306 participants to whom they sent nudges and reminders via SMS messages. Furthermore, Carter et al. (2013) reported that intervention adherence was significantly higher for their smartphone based intervention than a paper based diary intervention for weight loss. Fjeldsoe et al. (2010) tested the use of tailored SMS messages in addition to face-to-face counselling to promote physical activity in postnatal women and found significant increases in both overall physical activity and walking frequencies. However, to date, interventions specific to cycling and active travel are lacking.

4.1.2. Need for Developing Interventions to Promote Cycling

As one of the two main modes of active travel (Cerin et al., 2017), cycling is essentially different from walking as a form of travel. While walking requires almost no preparation, cycling requires a bicycle, safety equipment (e.g. reflective clothes or a helmet use is mandatory in some countries), bike parking decks, etc. Cycling is also considered as a more intense form of physical activity than walking that helps people to reach recommended levels of physical activity (O'Brian et al., 2015; Yang et al., 2010). Furthermore, there are some factors that are differently related to walking and cycling. For instance, Sener and Lee (2017) reported that attitudes towards walking were different between younger and older participants while attitudes towards cycling did not change by age. They also reported that the link between active travel and life satisfaction was stronger for cycling than walking. Vries et al. (2010) also suggested that the built environment is differentially related to walking and cycling, with cycling being more strongly associated with traffic safety.

Moreover, cycling has been associated with various positive outcomes such as lower rates of obesity and associated illnesses including heart disease, diabetes, hypertension, and osteoarthritis (Braun et al., 2016; Hartog et al., 2010; Oja et al., 2011; Pucher, Buehler et al., 2010), decreased carbon emissions, less traffic congestion (Rissel, 2009; Woodcock et al., 2009), lower expenditure for health care, less absenteeism (Petrunoff, Rissel, & Wen, 2016; Rabl, & Nazelle, 2012), and improved mental health (Sener, & Lee, 2017). Despite the known benefits, relatively few people regularly ride bikes; approximately 6.5% of people in the UK cycle at least once a month, 4.5% cycle once a week, and only 1.5% cycle five or more days a week (DfT, 2016). Hence, cycling and active travel in general should be promoted for both individual and societal benefit.

There are also environmental, demographic, and psychosocial factors have been found to correlate with cycling. Environmental factors include distance (Piwek, Joinson, & Morvan, 2015), topographic features of the city (Nkurunziza et al., 2012), availability (or unavailability) of other vehicles for transport, segregated cycling paths (Ma, & Dill, 2015), traffic signs and regulations (e.g. to decrease maximum speed allowed, or to regulate bicycle and vehicle traffic), weather, showers and bicycle parking decks at destination points such as workplaces or train/metro stations, (Parkin et al., 2008; Schmiedeskamp, & Zhao, 2016). Among demographic factors, being young and being male are consistently found to be related to cycling across countries (Ma & Dill, 2015; Woods & Masthoff, 2017). However, relationship of education and cycling is moderated by countries, while in developed countries higher education is associated with higher cycling rates (Braun et al., 2016; Bruijn et al., 2005; Fyhri et al., 2017) and in less developed countries, lower education is associated with higher cycling rates (Nkurunziza et al., 2012). Psychological factors include attitudes towards cycling behaviour and cycling infrastructure (e.g., believing cycling is good for one's health or having a more positive perception of environment; Sener & Lee, 2017), confidence in cycling abilities (Shanon et al., 2006), perceived descriptive norms (i.e., whether if others also cycle), intention to cycle, perception of traffic safety, capability, incentives given, etc. (Bamberg, 2012; Jones, 2012; Nkurunziza et al., 2012).

4.1.3. Interventions to Promote Cycling

To date, most of the interventions that have been designed to promote cycling have sought to change environmental factors such as traffic-free paths, cycling paths (Jones, 2012; Pucher, Dill, & Handy, 2010), improving existing cycle routes (Goeverden et al., 2015), establishing bike share schemes (Braun et al., 2016), implementing showers and lockers to the destination (work place, or train stations), and discouraging private car use for commuting (Petrunoff et al., 2015) mostly with significant effects. However, few interventions have targeted the psychological factors that influence cycling (e.g., extent to which people monitor their cycling frequency, setting themselves the goal to cycle more, etc.). Targeting psychological aspects to promote cycling behaviour may be beneficial as (a) these aspects can affect cycling behaviour independent from external factors and/or moderate the effects of infrastructural changes (e.g., perceptions about infrastructural changes affect cycling frequency independently from actual changes; or people can cycle despite a lack of specific cycling paths; Ma, & Dill, 2015; Thigpen et al., 2015), (b) psychological factors could explain the existing environmental factors affecting cycling behaviour (i.e., such interventions can stimulate usage of new cycle paths through attitude change, or increasing awareness), and (c) interventions targeting psychological factors may be easier and cheaper to implement than infrastructure changes. Furthermore, it has also been shown that the effects of objective environmental correlates on actual behaviour may be mediated through changes in perceptions (Ma et al., 2014).

As suggested by the Theory of Planned Behaviour, behaviour is predicted by intention which, in turn, is predicted by attitudes, social norms, and perceived behavioural control (Ajzen, 1991). Intention is the strongest/most proximal predictor of behaviour in most social cognition models (Sheeran & Webb, 2016; Webb & Sheeran, 2006). Intentions and theory of planned behaviour constructs has also been used to study cycling behaviour and observed to explain a large amount of variance in cycling behaviour (Jones, 2012; Munoz et al., 2016). Intention to cycle (measured as willingness to cycle in the future) is positively and significantly related to cycling frequency (Ma, & Dill, 2015). Nonetheless, there is often an intention-behaviour gap that highlights the need to identify variables (and techniques) that help people to act on their intentions. Control theory identifies some of these techniques (e.g. goal setting, action planning) and control theory is specifically focused on acting on goals – therefore, these techniques should be more effective among participants with strong intentions (Carver, & Scheier, 1982; 2002). Hence it can be suggested that effectiveness of interventions might change depending on the baseline intentions to cycle (Bruijn et al., 2005; Munoz et al., 2016).

4.1.4. The Current Research

A series of interventions was conducted in order to test whether BCTs (from control theory) that are delivered by SMS messages can promote cycling (as assessed by use of bike share schemes) and reduce car use (as assessed by car parking). For the intervention, it was aimed to use a structured intervention method to improve the replicability and fidelity.

Hence, behaviour change techniques (BCTs) defined by Michie et al. (2013) were adopted. Reviews and meta-analyses indicate that BCTs taken from Control Theory are among the most effective and most frequently used BCTs to promote physical activity, namely; goal setting, action planning, and self-monitoring (Bird et al., 2013; Michie et al., 2009; O'Brian et al., 2015; Rose et al., 2017), with self-monitoring having the largest share among those.

These three techniques are also the core tenets of the Control Theory (Carver, & Scheier, 1982; 2002) which suggests that setting goals, monitoring progress, and taking action when needed (termed goal operating), are central to achieving desired outcomes (e.g., cycling rather than taking the car). Despite being frequently associated with effective interventions to promote physical activity and active travel, self-monitoring has not been used in isolation in the previous studies (Bird et al., 2013). So it is not known if self-monitoring is effective on its own or in combination with other techniques. The interventions reported in the current chapter uses these techniques from Control Theory to promote cycling and reduce car use. The effectiveness of these techniques when delivered via short text messages have been demonstrated in a recent intervention reported by Griffin et al. (2018) related to physical activity and dietary behaviour. Specifically, they prepared 350 text messages for BCTs such as "goal setting", "self-monitoring", or "instructions on how to perform the behaviour" and sent 2 or 3 messages per day. They found that participants receiving text messages had improved dietary and physical activity behaviours at follow-up. However, evidence for effectiveness of these BCTs delivered by SMS on cycling, and active travel in general, is still lacking.

The current study aimed to address these gaps and had two hypotheses. The first hypothesis was that participants who receive short text messages designed to deliver three BCTs specified by Control Theory Carver & Scheier, 1982) would increase their cycling frequency (or decrease their car use frequency) more than the participants who do not receive text messages. The second hypothesis was that the intervention would be more effective among participants who have higher intention to increase their cycling frequency (or decrease their car use frequency) prior to the study.

4.2. Study 1 – The Use of BCTs from Control Theory to Promote Cycling

It was decided to promote cycling via a city-wide dockless bike share scheme. Promoting cycling in a general population might fail because not everyone would have access to a bicycle, and convincing people to obtain a bike would be subject to other barriers than convincing people to cycle. For this reason, bike share schemes were used which have been growing in number around the world and have the potential to help increase cycling and decrease car use (Braun et al., 2016). It is easy to start using such bikes as it only needs a smartphone to unlock the bikes and begin riding. Hence, the current study aims to use digital technology (smartphone apps for tracking cycling and SMS for applying BCTs) to promote cycling, which is a promising method for promoting health related behaviours (Armanasco et al., 2017).

The primary aim of the present study was to test whether BCTs targeting the self-regulatory processes described by the Control Theory are effective in promoting the use of a bike share scheme when delivered via short messages. Specifically, we sent text messages about BCTs from Control Theory (i.e., goal setting, goal operating, and self-monitoring) to the first intervention group and we sent text messages only about self-monitoring (as this was the single most effective technique in the aforementioned meta-analysis studies) to the second intervention group over three weeks (see Appendix 9 for messages and the schedule). It was decided to use self-monitoring in isolation because in none of the prior studies self-monitoring was used in isolation (Bird et al., 2013). In other words, even though self-monitoring seems to be the most effective technique in prior review studies by a large margin, it is still not known if this technique is effective by itself or if it is only effective when combined with other techniques. Meanwhile, the control group received no messages during the intervention period. It was hypothesized that participants in the first intervention group would increase their usage of the bike share scheme more than participants in the second intervention group and that participants in the second intervention group would increase their usage more than participants in the control group. Furthermore, it was hypothesized that the intervention effect will be moderated by the strength of the participants' intentions to use the OFO bikes, i.e., that the intervention will be more effective in participants with stronger baseline intentions to use the OFO bikes.

4.2.2. Method

4.2.2.1. Bike Share Scheme

Study 1 focused on the use of the OFO Bikes dockless bike share scheme. OFO Bikes can be used by downloading a smartphone app and registering with an online payment method. At the time of the data collection (April to June 2018), OFO bikes charged £0.50 for every half an hour that the bicycles were used. After the transaction is made, one can unlock the bikes using the app and start cycling. When the trip is over, the bikes can be left at any public place in the operating area marked as GeoFence which covers a large proportion of the city in which the study was conducted (Sheffield).

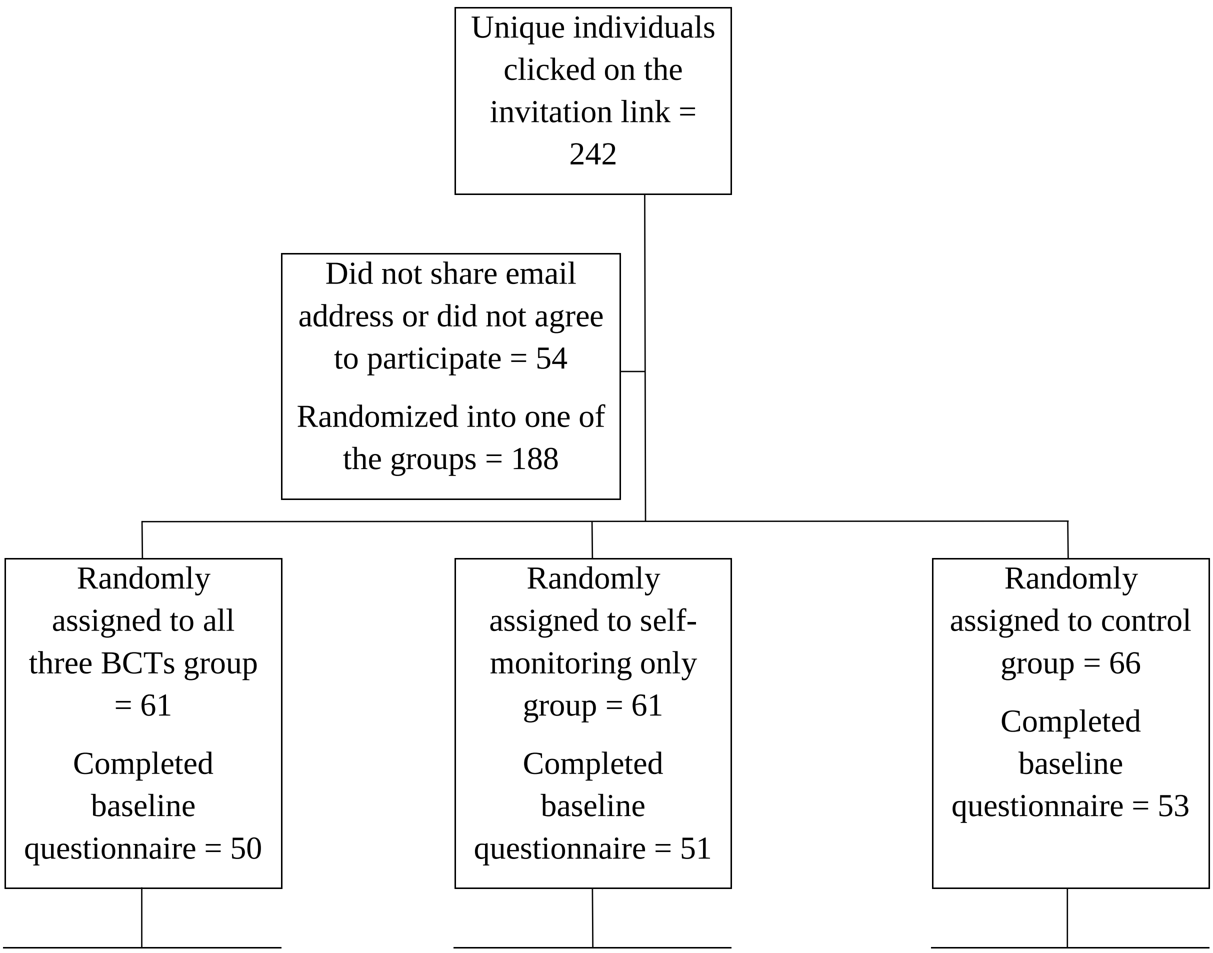
4.2.2.2. Participants

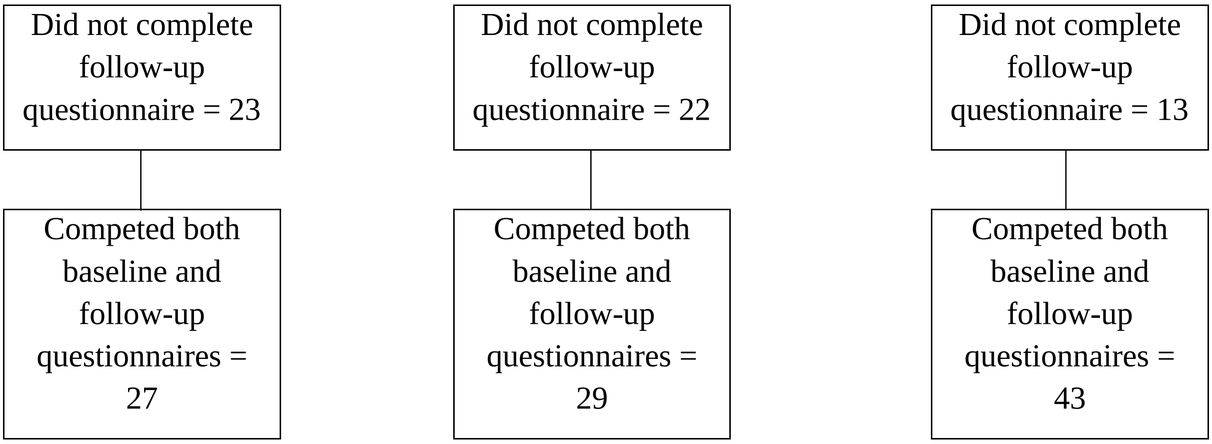
An a priori power analysis indicated that the required sample size for detecting medium effect size (f = 0.25) for this study with three groups was 189 participants. A medium-sized effect was anticipated on the basis of the effects observed in the meta-analysis in Chapter 2. Specifically, for interventions that include self-monitoring of behaviour (BCT 2.3), the average effect size was d = 0.48 (95% CI [0.36, 0.59]), which equals to f = 0.24 (Lenhard & Lenhard, 2016). Participants were recruited from the university staff and students volunteers email lists. The study ran from mid-April 2018 until the end of June 2018. It was only possible to collect baseline data from 131 participants as the OFO bikes company withdrew from Sheffield at the beginning of July.

The baseline sample comprised of 59 females (45%) and 72 males (55%) with mean age of 29.07 (*SD* = 10.07). Of these participants, 92 (70%) were White-Caucasian, 27 (21%) were Asian, and 12 (9%) were from other ethnicities (none reported Black ethnicity). Participants were asked if they already had the application on their smartphones before the study; 106 (81%) did and the remaining were instructed to download the app for the study. Participation was incentivised with a chance to win one of three £25 vouchers for those completing both baseline and follow-up questionnaires. Ninety-nine (76%) of the participants also completed the one-month follow-up survey (see Figure 4.1).

Figure 4.1

Participant flow-through experiment





4.2.2.3. Measures

Demographics (e.g., age, gender, ethnicity, first part of post codes, etc.), intention and cycling behaviour were collected in a self-report online questionnaire at the beginning of the study. In order to have an objective measure of cycling, participants were asked to report the number of times they used the OFO bikes in the past month, which can be found easily in the app, in both the baseline and follow-up questionnaires. Intention was measured at the baseline by two items (i.e. "*I intend to use OFO bikes in the next month.*" and "*Do you intend to use OFO bikes in the next month?*"; Participants responded on a 7-point likert scale anchored by 'definitely don't' and 'definitely do'). Cronbach's alpha (α) for intention was α = .87. In order to control for overall cycling, participants were also asked if they cycled with any bike other than OFO in the last week, i.e., "*Have you cycled with any other bike than OFO bikes in the past 7 days? Yes/No*" in the follow-up questionnaire and if they respond "Yes", they were further asked to type how many times they used other bikes.

4.2.2.4. BCT Messages

Short messages were designed to target the three central processes specified by control theory (Carver, & Scheier, 1982); namely, behavioural goal-setting (BCT 1.1), action planning (BCT 1.4), and self-monitoring of behaviour (BCT 2.3). To target these processes, 15 text messages were prepared (three for behavioural goal-setting, three for action planning, and nine for self-monitoring of behaviour) by the author in consultation with the supervisors of this thesis. These text messages were very similar to the ones prepared in Chapter 3 but as it was aimed to prepare at least three text messages for each of the BCTs, the text messages are not identical to the ones in Chapter 3. The text messages were also prepared to have 160 or fewer characters each as they were in Chapter 3. Thus, the short text messages targeted three specific BCTs from the Behaviour Change Techniques Taxonomy (v1) (Michie et al., 2013): (i) behavioural goal-setting (e.g., "*How many times can you ride an OFO bikes over the next week? Set yourself a goal and challenge yourself!*"), (ii) action planning (e.g., "*Make plans about when you could use an OFO bike, such as at particular times or for particular journeys next week.*"), and (iii) self-monitoring of behaviour (e.g., "*Studies show that keeping track of progress can help people to achieve their goals. This is what the OFO app can do for you!")*. (See Appendix 9 for the full list of text messages and the schedule for the messages sent).

4.2.2.5. Procedure

After receiving ethics approval from the University's Research Ethics Committee (application #018732), invitation emails were sent to university staff and students who were members of a volunteers list (see CONSORT Checklist in Appendix 12). Volunteers who agreed to participate in the study continued to the online baseline questionnaire by following a link in the invitation email. At the beginning of the questionnaire participants were randomly allocated into one of three conditions, comprising two intervention groups and one control group, in a factorial design using the randomisation function within Qualtrics. Participants were blinded to condition as neither the information sheet or the consent form mentioned that there were different experimental conditions.. The experimenter was not blinded in the study as the data files included details of which experimental condition participants had been allocated to. This information was also used by the experimenter to send out the correct text messages to each participant (by condition).

Participants in the intervention groups were sent nine messages over the next three weeks via an online SMS broadcasting service. The order of the messages was arranged for the first intervention group so that participants would receive text messages for the constructs of the Control Theory respectively (i.e., goal-setting, action planning, and self-monitoring). Participants in the first intervention group received messages designed to promote goal setting in the first week, messages designed to promote goal operating in the second week, and messages designed to promote self-monitoring messages in the third week (three messages per BCT). In contrast, participants in the second intervention group only received messages designed to promote self-monitoring for three weeks (nine messages for the same BCT). Frequency of thrice per week was selected because more than once a week and less than once a day is reported to be the optimum frequency for effectiveness of physical activity interventions that use text messages (Armanasco et al., 2017; Hall et al., 2015; Rose et al., 2017). Participants in the control group received no text messages over the three weeks. One month after completing baseline surveys, participants received another email asking them to fill the follow-up survey about their use of OFO bikes in the past month.

4.2.2.6. Data Analytic Strategy

Outliers (scores that were more than three standard deviations away from the group mean) were removed from the data set (5 removed in total). Then, a 3 (group: all 3 messages, self-monitoring only, control) x 2 (time: baseline vs. follow-up) mixed measures ANOVA was conducted to test for differences in OFO bike use between the groups to test the first hypothesis. Next, in order to test if intention moderated intervention effectiveness, dummy variables were formed for each intervention group separately, as well as interaction terms (by multiplying the standardized scores of intention to use OFO bikes at baseline with dummy variables). A hierarchical regression analysis was conducted by entering standardized scores of pre-intervention OFO bike use, intention to use OFO bikes in the future, dummy variables for each intervention group, and group x intention interaction terms, respectively, to test whether intention moderated the effect of the interventions on the use of OFO bikes.

4.2.3. Results

4.2.3.1. Effects of Intervention Group Membership and Time on the Use of OFO Bikes

A 3 (group: all three constructs, self-monitoring only, control) x 2 (time: baseline vs. follow-up) mixed-measures ANOVA showed that the main effect of time was non-significant, $F(1, 92) = 1.73$ $p = .189$, indicating that participants' levels of OFO bike use did not differ from baseline to follow-up, as was the main effect of group, $F(2, 92) = .45$ $p = .636$. The interaction between group and time, however, approached significance, $F(2, 92) = 2.74$ $p = .070$.

Table 4.1

Group means (and standard deviations) for OFO bike use by time

	All three constructs group ($N = 26$)	Self-monitoring only group ($N = 29$)	Control group ($N = 40$)
Baseline	1.20 (2.29)	1.82 (3.00)	2.35 (3.59)
Follow-up	1.96 (2.66)	2.14 (2.91)	1.90 (2.70)

Given that the relatively small sample may have led the primary analyses to be underpowered the first hypothesis was tested again by nesting two intervention groups into one. In this analysis, the main effect of time remained non-significant, $F(1, 93) = 0.30$, $p = .588$, as did the main effect of group, $F(1, 93) = .69$ $p = .409$. In contrast to the previous analysis, the interaction between group and time was significant, $F(1, 93) = 5.32$, $p = .023$. Repeated measures t-test indicated a significant increase for combined intervention group ($t(54) = -2.26$, $p = 0.028$) and non-significant decrease for the control group ($t(39) = 1.12$, $p =$

0.27). These results indicated that the change in the use of OFO bikes from baseline to follow-up for participants of intervention groups (combined) was significantly different to the change in the participants of the control group (see Figure 4.2).

Table 4.2

Group means (and standard deviations) with combined intervention groups for OFO bike use by time

	Combined intervention group (N = 55)	Control group (N = 40)
Baseline	1.33 (2.19)	2.04 (3.31)
Follow-up	2.05 (2.77)	1.90 (2.70)

4.2.3.2. Is the Effect of the Intervention on Cycling Moderated by Intentions to Cycle?

It was originally proposed that the moderation analysis would be conducted with three groups (hence two interaction terms) but due to the small sample size, this analysis was run with two groups (combined intervention groups and the control group). The hierarchical regression with combined intervention groups was conducted to test if there was an interaction between the group and baseline intentions to use OFO bikes. Standardized scores of baseline OFO use and baseline intentions were controlled for, and then dummy variables for intervention groups versus control, and interactions between groups and intention were added to the model, respectively (Table 3). This analysis showed that baseline OFO use was significantly and positively associated with follow-up use (β = .561, p < .001) even after controlling for baseline intentions, assigned group, and group x intention interactions. The interaction effect was not associated significantly with follow-up OFO use (β = -.001, p = .995). As the interaction term for intention to use the OFO bikes prior to the intervention and allocated group was not significantly related to the use of OFO bikes at follow-up, further moderation analysis was not run.

Figure 4.2

Baseline and follow-up cycling rates for two intervention groups combined and control group

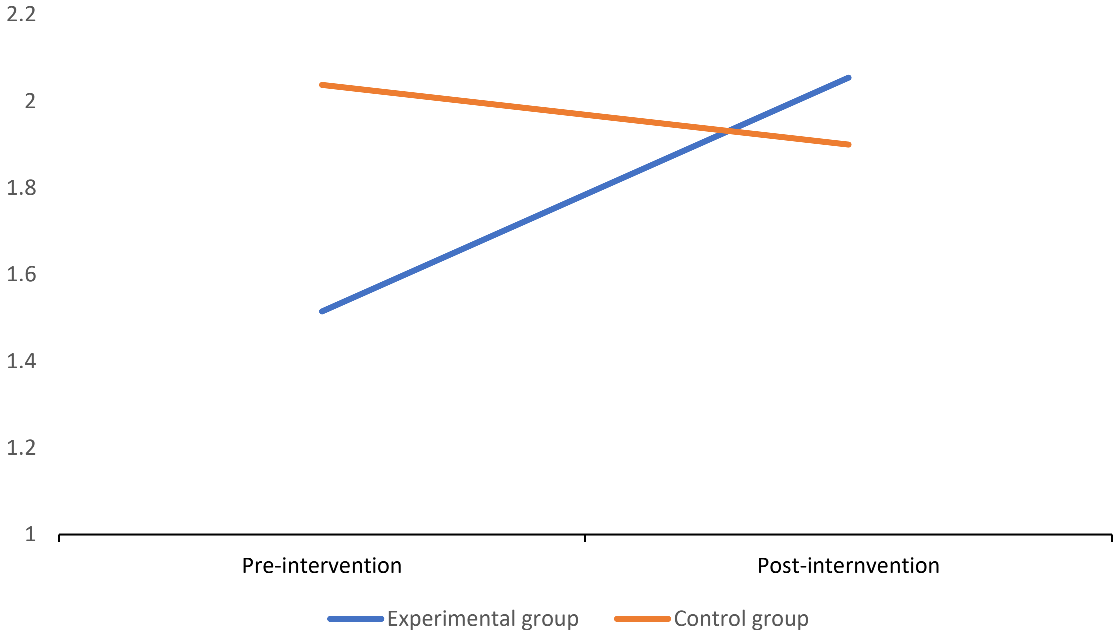


Table 4.3

Summary of moderated regression analysis testing the interaction between intervention group and intention on OFO bike use.

		Model 1		Model 2		Model 3		Model 4	
		B Coefficients	SE	B Coefficients	SE	B Coefficients	SE	B Coefficients	SE
1	Baseline OFO use (centred)	**.576*****	.197	**1.170*****	.208	**.538*****	.211	**.561*****	.214
2	Intention to use (centred)			.173	.238	**.183***	.237	-.001	.432
3	Dummy for two nested intervention groups					.122	.428	-.278	1.544
4	Interaction							.431	.304

Note. R^2 = .332, p < .001 for Step 1; ΔR^2 = .026, p = .060 for Step 2; ΔR^2 = .014, p = .165 for Step 3; ΔR^2 = .012, p = .189 for Step 4.

* p < .05. ** p < .01. *** p < .001

4.2.4. Discussion

Study 1 tested if sending short text messages based on BCTs related to the processes specified by Control Theory can promote cycling. The results were promising; the analysis with three groups indicated that interaction of time and group approached significance (p = .070) and analysis with combined intervention groups yielded a significant interaction between time and group (p = .023), despite the relatively small sample size. This significant interaction of time and group membership indicated that the increase in the number of times the participants used OFO bikes was greater in the intervention groups than in the control group (which showed a slight reduction in use over time). The current findings are therefore promising. However, it would be beneficial to replicate the current findings with a larger sample size (i.e., to obtain greater statistical power), and to focus on the intervention group that utilized all three BCTs from control theory, as this group had the largest difference between the baseline and follow-up measures. Furthermore, the current findings are only generalizable for the University of Sheffield staff and students, as the participants were invited through the university volunteers email list. Cycling would be subject to different barriers for a different group of participants and in a different city with different sets of bike share schemes and different geography. Hence, the current intervention should be tested in other settings.

4.3. Study 2 – Second Intervention to Promote Cycling

As the OFO shared bike scheme was withdrawn during data collection in Sheffield, which constrained the sample size, it was decided to repeat the intervention with a larger group of participants. It was also decided to only include the intervention with all three BCTs given that it showed the largest difference in bike use between the baseline and follow-up surveys. With this aim, cities were looked for with more established bike share schemes in the UK. Newcastle, Oxford, and London were identified as potential targets as these cities had several bike share schemes operating for a longer period of time.

4.3.2. Method

4.3.2.1. Participants

A priori power analysis with the effect size obtained from the previous study (d = 0.23) indicated that 184 participants were required for the second study with two groups. It was aimed to contact students' unions at universities in the UK, student clubs, transport managers, and independent cycling clubs. Emails and direct messages from social media accounts were sent to those whose contact information were found. These emails and messages included a short description of our study and the incentives offered. None of the invitees agreed to circulate our study invitation in their network, except one who had access to an email group in Oxford. From their email group, 11 (4 females) participants (mean age = 37.92 years, *SD* = 8.49) were recruited. Next, we tried Facebook ads targeted to people in London specifically. From this advertisement, an additional 23 (4 females) participants (mean age = 32.43 years, *SD* = 10.12) were recruited. After contacting more than 40 cycling clubs and 5 students' union officers from these three cities over 3 months, any further participants could not be recruited. Of the 34 participants who were recruited into the second intervention study, 24 participants completed both the baseline and follow-up surveys (see Table 4.4).

4.3.2.2. Methods, Measures, and Procedures

All of the details that participants were required to provide were identical to those in Study 1 after clicking on the link to the baseline survey, except that, Study 1 asked participants only about the use of OFO Bikes, whereas Study 2 also asked about the use of other bike share schemes such as Mobike, Santander Cycles, Lime-E, and others, in addition to OFO bikes, as other bike share schemes were also available in those cities (see CONSORT Checklist in Appendix 13). Participants were asked to report the use of all these bike share schemes separately and then these numbers were summed up for the outcome variable. The text messages that participants received in the period between baseline and follow-up surveys were also identical to those in Study 1, in the same order to replicate the previous study.

4.3.3. Results

4.3.3.1. Effect of the Intervention on Cycling Behaviour

The two data sets from Oxford and London were combined and tested if the use of the bike share schemes among the experimental group participants would increase more than the control group participants, using a repeated measures ANOVA. Both the main effect of time, $F(1, 22) = 0.018$ $p = .896$, the main effect of group, $F(1, 22) = 0.511$ $p = .482$, and the interaction between time and group membership, $F(1, 22) = 0.085$ $p = .773$, were non-significant (see Table 4.4).

Table 4.4

Means (standard deviations) and sample sizes for data collected from Oxford and London

	Intervention group (*N* = 8)	Control group (*N* = 16)
Baseline	2.75 (2.76)	4.31 (6.48)
Follow-up	2.25 (2.87)	4.50 (9.14)

4.3.3.2. Moderating Effect of Intention

As there were not enough participants to conduct a moderated regression analysis, moderating effect of baseline intentions to cycle was not tested.

4.4.4. Discussion

Study 2 sought to replicate the previous findings with a larger sample size by seeking to recruit participants from a number of large cities with established bike sharing schemes. Unfortunately, it was possible to recruit only 24 participants who provided baseline and follow-up data. The use of bike share schemes represents a promising solution to many problems participants may encounter, such as owning, maintaining, and safekeeping bicycles, as well as recalling the number of trips they had in the last 30 days. However, we were unable to recruit a sufficient number of participants to test the effectiveness of the intervention to increase usage of the bikes. Yet, this study can be replicated in any other city or country with an established bike share scheme, which are quite common across the world now, where it is possible to recruit a large number of participants. For example, a larger participant base could be reached via governmental organizations, hospitals, or companies in much the same way as participants were recruited via the volunteers email list at the University of Sheffield. The number of participants recruited in Studies 1 and 2 were not enough to reach a confident conclusion about the effectiveness of SMS interventions in promoting cycling. However, they do provide the basis for testing whether SMS interventions might be used to promote cycling or active travel in general. Given the difficulties experienced recruiting participants to the studies on bike share scheme usage, it was decided to test the intervention in another (similar) behaviour. Specifically, the intervention was directed to decrease car use, for which we could recruit participants within our university network. This approach would also allow the intervention to be tested in another aspect of active travel given that the text messages can be easily converted to target another behaviour.

4.5. Study 3 – Using BCTs from Control Theory to Decrease Car Use

Private car use is the main mode of transport across the world since the proliferation of car production and roads made for motorized transport (Anable, 2005; DfT, 2018a). In the UK, 76% of all households own at least one car (DfT, 2018b) and 75% of all trips (78% for urban areas only) are made by private cars, while just 8% are made by walking, 7% by bus, and 2% by bicycle (DfT, 2018a). About half of all car trips are shorter than five miles, and about one third are shorter than two miles in the UK (Jones, 2012). Targeting those trips could be a good way to decrease car use. However, car travel is seen as a more positive mode of travel. For instance, participants report that car travel offers more privacy, protection, autonomy, freedom, and control over other travel modes (Woods & Masthoff, 2017). Yet, these attitudes about travel modes might depend on travel habits, with people having more positive attitudes towards travel modes that they usually use (Sener & Lee, 2017; Thigpen et al., 2015).

Reducing car use is somewhat similar to promoting cycling as, mainly, both of them are about promoting sustainable (or active) travel. Both behaviours are studied by the same fields (e.g. public health, city and regional planning, civil engineering, etc.), targeted to decrease carbon emissions and improve public health (de Nazelle et al., 2011; Graham-Rowe et al., 2011), and affected by the infrastructure (Pucher, Dill, & Handy, 2010; Schoner et al., 2015), habits (Heinen & Ogilvie, 2016; Mantzari et al., 2015) and weather (Schmiedeskamp & Zhao, 2016). Hence, it can be suggested that using the previously prepared text messages to decrease car use would yield similar effects to using these messages to promote cycling.

As a measure of car use, the primary outcome for this third intervention study is the number of parking scratch cards used during the intervention period by students and staff at the University of Sheffield. To be able to use parking spots, either an annual permit card (£41 per month), or scratch cards (books of 20 scratch cards costing £41 in total) need to be acquired. University of Sheffield staff and students can buy these cards in books from Estates Facilities Management helpdesk, and from Students Union Welcome desk. These cards do not guarantee a parking space and are valid for one day only. Obviously, scratch cards are more suitable for those who do not want to commit to commuting by car every day, as they can choose not to commute by car and not to pay for parking space any time they want.

In short, the current intervention aimed to decrease car use (measured by the use of scratch cards) for commuting by delivering BCTs taken from the Control Theory (i.e. goal setting, action planning, and self-monitoring) via short text messages. It is hypothesized that the participants who receive text messages would use fewer scratch cards than the participants who do not receive text messages. It is also hypothesized that intention to decrease car use will moderate the intervention effectiveness.

4.4.2. Method

4.4.2.1.Procedure and Data Collection

Ethical approval was obtained from the university ethics committee (application #027511) and permission to contact university staff and students for the intervention from the university transport manager (see CONSORT Checklist in Appendix 14). Then invitation emails were sent to the university volunteers list. In addition, leaflets were distributed with a short explanation, a written link, and a QR code to the study in parking lots and desks where these cards are sold from June 2019 to February 2020, when the pandemic has started. The participants who followed the link to the current study (either via the invitation email or via the leaflets) found a Qualtrics survey with the informed consent form at the first page. Those who agree to participate were then randomly assigned either to the intervention or the control group. The participants who were assigned to the intervention group were sent three SMS messages per week for three weeks (nine messages in total). Each participant received the follow-up survey 30 days after they completed the baseline survey. Those who did not complete the follow-up surveys were sent two reminder emails after a week.

4.4.2.2. BCT Text Messages

Text messages sent to decrease car use were adopted from the previous interventions. Only the wordings were changed to target decreasing car use, instead of promoting cycling. Example text messages are as follows: (i) behavioural goal-setting (e.g., "*How many times can you skip using your car to commute to the university over the next week? Set yourself a goal and challenge yourself!*"), (ii) action planning (e.g., "*Make plans about when you could not use your car to commute to the university next week - such as a particular day next* *week.*”), and (iii) self-monitoring of behaviour (e.g., “*Studies show that keeping track of progress can help people to achieve their goals. You can use your scratch cards to keep track of your car use!”)*. (See Appendix 10 for the full list of text messages and the schedule for the messages sent).

4.4.2.3.Participants and Measures

The effect size from Study 1 was calculated from the means and standard deviations (Cohen’s *d* = 0.23) and the power analysis yielded that 248 participants were required. In total, 134 people clicked on the link to the study information and 83 participants (62%) completed the baseline survey (66 females, mean age = 40.58 (*SD* = 10.89), 90% white ethnicity), of whom 34 were randomly allocated to the intervention group and 49 to the control group. Sixty-one participants (46%) completed both baseline and follow-up surveys (47 females, mean age = 41.10, *SD* = 10.64), 91% white ethnicity), of whom 29 were in the intervention group and 32 in the control group. In addition to the demographics and intentions to decrease car use, participants were asked how many scratch cards they had at the time of baseline as well as at follow-up data collection, which was sent 30 days exactly after the baseline survey. Then, the number of scratch cards used between two time points was calculated. Measuring the number of days that participants commuted by car via asking participants the number of scratch cards they had at the times of data collection did not require participants to remember how many journeys they had made by car and allowed us to have an objective measure.

4.4.2.4.Data Analytic Strategy

Independent samples t-test was conducted with two groups to test the hypothesis that participants in the intervention group would use fewer scratch cards than the participants in the control group. Specifically, the number of scratch cards used was calculated for each participant between the baseline and follow-up surveys. The period of time between baseline and follow-up differed between participants, so this was controlled for in the analysis. Hence, the number of scratch cards used was divided by the number of days between the baseline and the follow-up measures because it was not possible to compute working days for each participant. Weekends and holidays are assumed to be equally distributed between the participants as they were randomly assigned to intervention and control groups. Then the outliers were cleared by excluding the scores more than three standard deviations from the mean. In order to test the second hypothesis, it was aimed to run a moderation analysis to test if the intervention was more effective on participants with stronger intentions.

4.4.3. Results

4.4.3.1. Effect of the Interventions on Car Use

Next, it was tested whether participants in the intervention group used fewer scratch cards than participants in the control group over the course of our intervention. An independent samples t-test indicated that the difference in the number of scratch cards used by the intervention (*M* = 31.03, *SD* = 12.16) and control (*M* = 36.64, *SD* = 12.54) groups approached significance, *t* = -1.78, *p* = .080.

There was also a large range for the time between baseline and follow-up. Specifically, follow up surveys were sent 30 days after initial data collection but it took up to 48 days for some participants to reply. The intervention (*M* = 35.47, *SD* = 2.20) and control (*M* = 36.95, *SD* = 4.01) groups were not different from each other in terms of number of days between baseline and follow-up response days. However, this factor might also affect the number of scratch cards used over the same period. For the previous studies, it was possible to control the time by asking participants to report the number of times they used shared bikes in the last 30 days. So, the number of scratch cards used per day was also computed as a variable. Independent samples t-test results indicated that the intervention (*M* = 0.61, *SD* = 0.17) and control (*M* = 0.64, *SD* = .16) groups were not significantly different from each other in terms of the scratch cards used per day ($t(59) = -0.73$, $p = .471$). Then, it was tested if the groups were different from each other in terms of the number of scratch cards used per day, while also controlling for the number of days participants needed to commute per week. ANCOVA yielded non-significant results for both the main effect of group membership ($F(1, 56) = 0.35$ $p = .556$) and interaction of group membership and number of days participants needed to commute per week ($F(2, 56) = 0.32$ $p = .969$).

4.4.3.2. Moderating Effect of Intention

As there were not enough participants to conduct a moderated regression analysis, moderating effect of baseline intentions to decrease car use was not tested.

4.4.4. Discussion

Study 3 indicated that the current intervention to decrease car use was non-significant. There are no prior meta-analysis studies that report average effect size for interventions to reduce car use. Graham-Rowe et al. (2011) suggest in their review that interventions to reduce car use are inconsistently significant. Similar to the first two studies, Study 3 was also not able to collect data from a sample large enough to reach enough statistical power and the effect size of Study 3 was also small and non-significant. Taken together, the findings of the interventions yielded similar results both for promoting cycling and for reducing car use, suggesting that the findings might be generalizable across different target behaviours. It can be suggested that combining the effect sizes of the interventions across three studies is appropriate given that each study was underpowered. Hence, it was decided to combine these studies in a mini meta-analysis in an effort to further reveal the true nature of the intervention designed.

4.5. Study 4 – Mini Meta-analysis of the Three Interventions

Combining small studies in mini meta-analyses can be a way to tackle the lack of statistical power in the previous studies (Goh et al., 2016). Studies with small sample sizes or non-significant effects can still indicate/reveal important messages (e.g., whether a particular intervention is, or is not, actually significant). Combining the three interventions that have been conducted in a mini meta-analysis would increase the statistical power by adding up the number of participants and aggregating the findings across the studies into a combined effect size. Summarizing these studies in a mini meta-analysis would also yield a more robust conclusion about the effectiveness of the interventions designed. Therefore, it was decided to combine the interventions previously conducted to promote cycling, as well as the intervention we conducted in to decrease car use for commuting in a single mini meta-analysis.

4.5.1. Effect Size Calculation and Meta-Analytic Strategy

Cohen's *d* was used as the index of effect size as it indicates the standardized difference between group means. Cohen's *d* scores were calculated using the group means and standard deviations from the outcome variables from both time points from the first two interventions. As pretest-posttest designs were used for the first two interventions, the *d* scores were adjusted according to the procedures described by Morris (2008). For the third intervention, the *d* score was computed from the means and standard deviations for the scratch cards used per day. Then, the sample-weighted average effect (Hedges g_+) of the interventions was calculated using Meta-Essentials version 1.4 (Suurmond et al., 2017).

4.5.2. Results

The mini meta-analysis of the three interventions with 181 participants in total yielded a small and non-significant combined effect size ($g_+ = 0.24$, 95% CI [-0.11, 0.59]; Table 4.5). Cochrane's Q was not statistically significant ($Q = 0.59$, $p = .744$), indicating that the effect sizes were not heterogeneous. Overall, these results suggest that the three-week interventions delivering BCTs via short text messages were not effective in changing the travel behaviour in the short term.

Table 4.5

List of interventions and characteristics

Study	Study design	Sample	Target behaviour	N_E	N_C	*d*
Study 1	Independent groups pre-post	Specific group of adults	Cycling frequency	55	40	0.23
Study 2	Independent groups pre-post	Members of general population	Cycling frequency	8	16	-0.04
Study 3	Single group pre-post	Specific group of adults	Driving frequency	29	32	0.35

4.5.3. Discussion

The intervention designed was non-significant according to the data collected from the three separate interventions in this chapter. Yet, the overall effect size is still promising, as the meta-analysis reported in the Chapter 2 found that psychosocial interventions on cycling behaviour have almost exactly the same effect size ($g_+ = 0.24$, 95% CI [0.14, 0.35]). The current total sample size of 181 for this mini meta-analysis is also still not as large when compared with previous interventions to promote active travel (Heinen et al., 2015; Hemmingson et al., 2009).

4.6. General Discussion

The interventions designed in the current chapter were the first interventions to deliver three BCTs specific to Control Theory via short text messages to promote cycling and to decrease car use. Results indicated that the first intervention conducted in Sheffield with OFO bikes was effective in promoting cycling, when two intervention groups were combined and compared to the control group. The second intervention conducted in Oxford and London severely lacked statistical power to yield any significant results. The third intervention conducted in Sheffield to decrease car use also lacked adequate statistical power but approached significance. However, when the effect sizes from these three interventions were combined in a mini meta-analysis, the results were still non-significant, although the combined effect size was comparable to the effect sizes obtained in the meta-analysis conducted in Chapter 2.

The studies reported in this chapter have a number of strengths. First, a key strength of the current interventions is that they provide an easily replicable intervention method for the future studies. While the BCTs used in the current interventions were not effective in promoting active travel, future studies could easily use other and/or new combinations of BCTs to promote active travel, especially those with messages with high agreement rates from the Chapter 3. It would take only a couple of hours for a single interventionist to apply the same or a similar intervention on a million participants that have access to a bike share scheme, or use scratch cards in their work or school area. This is important as the relatively small effect of the current interventions could, nonetheless, have a large public health impact on a population level (West, 2007). The interventions designed in the current chapter used a structured approach by using three specific BCTs and conveyed them via short text messages, which can easily be converted for promoting other health related behaviours (see Chapter 3). Second, the focus on bike share schemes as a means to promote cycling is a strength of Studies 1 and 2. As mentioned before, cycling is distinct from walking as a form of active travel because it requires more preparation, e.g., having a bicycle. The use of bike share schemes resolves this problem, as people can easily and cheaply access dockless shared bikes. These bikes also remove the barrier of having a safe storage space at destination points such as home, work, or school, etc. As found in Chapter 2, adding objects to the environment (making bicycles available, in this case) is a useful method to promote cycling. Third, objective measures of behaviour were used in both interventions. In Studies 1 and 2, smartphone apps kept the record of bicycle use automatically. In Study 3 the scratch card use could be tracked by simply counting the missing pieces, instead of recalling the scratch card use over the intervention period. Objective measures of physical activity tend to be more reliable than self-report measures (Milton et al., 2013, also see Chapter 2).

It should be noted that the current interventions could also be delivered through different mediums such as social media, emails, and smartphone app notifications, in addition to SMS messages. Because we targeted the shortest form of digital medium (i.e., SMS) to convey the BCTs, the messages were limited to 160 characters. Other digital mediums allow more characters; for example, Twitter allows 280 characters and other mainstream social media websites, smartphone app notifications, or email services do not have character limits). As a result, the current messages could easily be incorporated into other digital interventions using other modes of delivery. The wording of the text messages used are also quite simple and straightforward (see Chapter 3). So the current intervention is still easily replicable across countries and digital mediums.

There are also a number of shortcomings of the studies reported in this chapter. First, the follow-up periods for the intervention effect were relatively short, as baseline and follow-up data were only collected one month apart. In addition, the follow-ups occurred only about 10 days after the last text messages were sent. It is important for future tests to include longer follow-up periods. Second, due to the circumstances that could not be controlled (i.e., OFO bikes were withdrawn from our city before the end of our data collection, and cycling clubs or organizations did not agree to participate in the study), it was not possible to reach to recruit sufficient participants in each study to research adequate statistical power. In a study with larger sample size, an active control group (which receives text messages without the BCTs) should also be incorporated in addition to the passive control group (which receives no messages). Nonetheless, a significant result was found in Study 1, albeit when examining the effect of the combined intervention groups. Future replication would benefit from recruiting larger samples. Lastly, the experimenter was not blind to the condition, which could introduce biases. Experimenter effects are typically minimized by hiding participant identities and condition membership from researchers (Holman et al., 2015; Schulz et al., 2010; see CONSORT Checklist in Appendix 12). The current research sought to to minimize any experimenter effects through participants providing data on cycling behaviour through Qualtrics and through participants reporting objective information from their smartphone apps. In addition, the data were handled according to certain rules explained above (e.g., outliers were selected as cases with three or more standard deviations above or below the mean, and removed regardless of their group membership). Not being blind in this case could lead to data peeking, where data are analysed before the aimed number of participants are reached and stopping data collection if the results are significant (John et al., 2012; Simonsohn et al., 2014). Hence, double blind experiments should be sought and established in future interventions, and be seen as the gold standard for intervention designs (Holman et al., 2015; Nickerson, 1998).

The current research developed a digital intervention that can be easily and cheaply applied on larger groups, albeit currently yielding nonsignificant results. Three BCTs suggested by Control Theory (Carver, & Scheier, 1982; 2002) – i.e., behavioural goal-setting, action planning, and self-monitoring of behaviour – were conveyed to participants in the intervention group by SMS messages. However, the findings of three studies did not support the idea that conveying these three BCTs via short text messages was effective in promoting active travel in the short term. However, given the small sample sizes, this conclusion should be treated with some caution. Encouragingly though, the overall effect size from the mini-meta analysis was similar to that found in the meta-analysis of psychosocial interventions for cycling behaviour reported in Chapter 2. Given the above limitations, it is clear that effectiveness of the current interventions should be tested with longer intervention and follow-up periods, as well as with larger sample sizes. However, the studies presented in this chapter still represent a promising contribution to the growing literature of digital behaviour change interventions (Craig et al., 2020; Hedin et al., 2019).

Chapter Five

General Discussion

Overview

The final chapter summarises and considers the implications of the findings for promoting cycling, delivering behaviour change techniques via short text messages, attempting to change behaviour at a population level and potential revisions to the BCT taxonomy. This chapter also considers the strengths and limitations of the research presented in this thesis and suggests directions for future research. In particular, it is suggested that future studies should test the effectiveness of the methods used in the current thesis with other behaviours and different BCT combinations, as well as the effectiveness of delivering the same BCTs via different mediums. Finally, more studies are needed to understand the difference between the effects of behaviour and outcome oriented BCTs. Overall, current findings can contribute to our understanding of promoting cycling and digital behaviour change literature.

5. Introduction

The aim of the current thesis was to explore ways to change behaviour more effectively and efficiently. Cycling behaviour was used as a context for investigating this question and, following a review of the effectiveness of interventions designed to promote cycling, the empirical work focused on the potential of short text messages designed to deliver behaviour change techniques (BCTs) described by the BCT v1 taxonomy (Michie et al., 2013). The BCT taxonomy was selected as it provides a detailed and a systematic list of ‘active ingredients’ of interventions that have been used to change wide range of behaviours. Using this taxonomy enabled the empirical studies in the current thesis to be replicable and their findings to be compared to other studies using the same techniques. Development and usage of short text messages, on the other hand, allowed the studies to be easily applicable to different behaviours and to large populations.

The effects of the short text messages are examined on promoting active travel behaviour as travel behaviour is common for almost everyone, and has potential to be changed for the better. Specifically, cycling has many beneficial for many aspects such as effects on physical (Warburton et al., 2006) and mental (Sener & Lee, 2017) health, the economy via less absenteeism and lower health expenditure (Petrunoff et al., 2016; Rabl & Nazelle, 2012), and the environment via less noise and air pollution (Brand et al., 2014). Yet, it also has potential to be promoted, especially for short trips, as even for them, cycling is not the main mode of travel (Department for Transport, 2020).

5.2. Implications from the Current Thesis

The first section of this chapter will identify the main theoretical and practical implications of the research presented in the thesis. It is aimed here to combine the findings from the previous chapters to interpret and understand general points that can be taken from the current thesis.

5.2.1. Cycling Can Be Promoted via BCTs Delivered by SMS

Through the empirical chapters in the current thesis, it has been demonstrated that cycling (and active travel) can be promoted via BCTs and delivering these BCTs by SMS can be a viable solution (according to Chapter 3 and Study 1 in Chapter 4). Specifically, Chapter 2 reviewed and quantitatively summarized interventions designed to promote cycling. There were no previous meta-analyses on this topic. Even though prior systematic and narrative reviews suggested that most of the interventions are effective to promote cycling (Bird et al., 2013; Yang et al., 2010), the size and significance of the effects of the interventions of cycling behaviour were not understood before. In Chapter 2, it was found that interventions to promote cycling, on average, have a small but significant effect ($g+ = 0.14$, 95% CI [0.05, 0.23]). Specific BCTs that increase intervention effectiveness were also identified in this chapter, such as self-monitoring and adding objects to the environment.

Chapter 3 used the Delphi method to develop a list of short text messages designed to deliver BCTs. Expert opinions were collected from 15 researchers that had published studies using the BCT taxonomy v1 (Michie et al., 2013). In Chapter 3, it was found that the experts agreed on 66 out of 93 BCTs that could be delivered via short text messages, understood by general public, and converted easily to be used to change different behaviours. Chapter 4 investigated the efficacy of delivering BCTs via these short text messages to promote active travel. All three studies had relatively small sample sizes and the overall results indicated that the intervention designed was not effective in promoting active travel. Hence it was not possible to suggest that cycling and/or active travel can be promoted with the intervention designed in Chapter 4 but future studies can test delivering different BCTs and BCT combinations to change these behaviours. Yet, individual interventions Study 1 and 3 approached significance despite their small effect sizes and the three interventions had a combined effect size of $g+ = 0.24$, which is the same effect size found in the meta-analysis for psychosocial interventions reported in Chapter 2.

Findings that cycling can be promoted via interventions, that BCTs can be delivered via short text messages, and that BCTs delivered via short text messages can also yield comparable effect sizes when promoting active travel indicates a promising approach for future interventions for several reasons. First, being able to change cycling and active travel behaviours, especially with a convenient method of delivering BCTs via short text messages is important for policy makers. Travel behaviour is part of almost everyone’s lives, whether it is for school, for work, for shopping, and/or for other reasons. Active travel has the potential to be impactful when achieved on larger scales for health (Sener & Lee, 2017; Warburton et al., 2006), economical (Petrunoff et al., 2016; Rabl, & Nazelle, 2012), and environmental (Brand et al., 2014) reasons. While there were also prior interventions that were effective (e.g., doctor/physician meetings, Hemmingson et al., 2009), applying them to larger numbers would be hard, expensive, and/or time consuming (Boarnet et al., 2005). Research presented in this thesis demonstrated that it is possible to deliver interventions via methods that can easily be applied to larger populations, in a cheaper and easier way, and still achieve comparable effect sizes in changing behaviours. Applying the same intervention methods to larger populations is also possible via a number of mediums such as SMS, social media, email, billboards, etc. Even though the effect sizes were small in both the mini meta-analysis and the interventions ($g = 0.24$), achieving this effect size on a larger population can have a large impact for the good of the society (West, 2007), whether it is in terms of public health, the environment, or the economy. Quantifying the average effects of these interventions can inform policy makers about the level of health and/or economic impact (de Nazelle et al., 2011; Jarrett et al., 2012) they can expect from their investments. For instance, promoting active travel by about 4% on national level could result in saving more than £6 billion of NHS expenditure in the UK over 20 years (Jarrett et al., 2012) and policy makers can consider their investment with these numbers.

Second, studies in the current thesis indicate a promising approach for future interventions targeting other behaviours. From meta-analyses in different fields, the most effective BCTs to change different behaviours such as smoking (e.g., commitment, feedback on behaviour, Black et al., 2020), weight management (e.g.. behavioural goal setting, self-monitoring of outcomes, Ashton et al., 2020; Samdal et al., 2017), diabetes prevention (e.g. behavioural goal setting, self-monitoring of behaviour, Van Rhoon et al., 2020), etc. have been discovered. Obviously, the most effective BCTs are not the same for different behaviours and these meta-analyses identify the most effective techniques that could inform future interventions in different fields. Similar to promoting active travel, other methods that require one-to-one interaction or expensive setups to apply BCTs for different behaviours are also hard to apply to large populations. However, methods from the current thesis such as using short text messages to deliver BCTs or sending them via SMS can easily be applied to future interventions or projects to change other behaviours in large populations and being able to change these behaviours in larger populations can tackle many societal challenges (Brand et al., 2014). There are also meta-analyses suggesting that interventions that utilize SMSs to promote healthy behaviour are generally effective (Orr & King, 2015; Spohr et al., 2015). Orr and King (2015) reported that studies that used SMS to deliver interventions to promote physician appointment attendance, chronic disease management, disease related medication adherence, preventive behaviour, and unhealthy behaviour modification were generally effective. Spohr et al. (2015) also reported that smoking cessation interventions that use SMS were effective in general. Furthermore, for promoting cycling, it was found in Chapters 2 and 4 that delivering BCTs via SMS had about the same effect size as other psychosocial interventions (i.e., those did not restructure the physical environment).

It can also be suggested that effective BCTs identified in other meta-analyses can be delivered via short text messages (as reported by the experts in Chapter 3) and that they may be effective in changing other behaviours in large populations. For instance, Black et al. (2020) identified the BCTs that make interventions to cease smoking more effective and these BCTs are commitment (BCT 1.9), feedback on behaviour (BCT 2.2), social reward (BCT 10.4), and identity associated with changed behaviour (BCT 13.5). The research presented in Chapter 3 suggests that all of these BCTs can be delivered via text messages. In other words, the short text messages prepared for these BCTs in Chapter 3 could reliably deliver these BCTs with fidelity. So, new studies can easily adapt the messages prepared in Chapter 3 and use them to deliver the BCTs specified by Black et al. (2020) to cease smoking. For example, the text message prepared for feedback on behaviour (BCT 2.2) was "You have cycled for … minutes in the last week." which can easily be converted for smoking behaviour as "You have smoked … times/cigarettes in the last week." It can also be tested if these BCTs are effective in isolation or in combination with others. Following up from the previous example, Black et al. (2020) have also reported the most effective BCT clusters which are different than the most effective individual BCTs used in interventions for smoking cessation. Specifically, studies that used BCTs related to rewards (BCT cluster 10) are more effective than others, especially when delivered via written methods rather than interpersonal methods. Hence, testing this is also easier when the BCTs are delivered via short text messages.

5.2.2. *Delivering BCTs via Short Text Messages Can Be as Effective as Other Delivery Methods*

In the meta-analysis conducted in Chapter 2, it was estimated that psychosocial interventions (i.e., those that did not restructure the physical environment) to promote cycling had an average effect size of g = 0.24. In Chapter 4, the interventions that utilized short text messages to promote active travel also had an effect size of $g+ = 0.24$. Observing the same effect size is reassuring in terms of the validity of the intervention and the fidelity of the short text messages prepared. Shifting from traditional, expensive and/or time consuming intervention methods (e.g., doctor appointments, face-to-face lessons) to digital methods (e.g., SMS) that can be applied on large populations without losing effectiveness of interventions would be a big step in behaviour change.

There is also evidence from a number of meta-analyses to suggest that longer interventions are not necessarily more effective than shorter interventions (Ashton et al., 2020; Heber et al., 2017). For instance, in the meta-analysis reported in Chapter 2, the length of the intervention did not have a significant relationship with the effectiveness of interventions for promoting cycling. Ashton et al. (2020) reported that the length of the intervention was not associated with the effectiveness of interventions for weight loss. Black et al. (2020) also reported that the length of the intervention did not have significant association with the effectiveness of interventions for smoking cessation. Furthermore, Castillo-Eito et al. (2020) have found that shorter interventions to reduce adolescent aggression were actually more effective than longer interventions. Hence, it can be suggested that the briefness of interventions that use short text messages to deliver BCTs might not be a problem in terms of the effectiveness of interventions, and for some target behaviours, may even be a facilitating factor.

Certain situations are key in decision making about behaviours to be changed. For instance, sending a text message to promote active travel to a person who has already commuted by car might not be very effective. Instead, sending the text message before the person makes a decision and leaves home can be more useful in promoting active travel. Digital mediums such as SMS, app notifications, etc. allow researchers to apply BCTs in timely moments such as specific times of the day (e.g., early in the morning, for smoking cessation), certain locations (e.g., before the person leaves home, for promoting active travel), conditional situations (e.g., if the person goes to a bar, for decreasing binge drinking), etc. Delivering BCTs in those timely moments might also increase intervention effectiveness further and can be considered as the advantage of using short text messages via digital mediums over mediums that require in-person contact (Orr & King, 2015; Spohr et al., 2015).

5.2.3. Implications of the Present Research for the BCT V1 Taxonomy

While working with the BCT taxonomy v1 (Michie et al., 2013) throughout the current thesis, it was also observed that some of the BCTs are often overlooked either by researchers who design interventions, or by experts who code BCTs from others' interventions (e.g., for systematic reviews). The BCT taxonomy is very useful in systematically identifying active ingredients of interventions that are designed to change different behaviours. Many of the techniques are frequently used in the field while developing interventions, yield significant intervention effects, and are coded by experts for systematic reviews. Naturally, some of the BCTs are more frequently used for certain behaviours than others while some BCTs are not even quite suitable to be used to change certain behaviours (Samdal et al., 2017; Suls et al., 2020). For example, outcome related goal setting BCT can be used for promoting cycling and the goal could be losing weight or saving money, but this BCT might not be very suitable for promoting blood donations, as one does not donate blood, for instance, to lose weight or get free cookies, and it is unlikely to know where the donated blood goes and if it saves lives or not (Karacan et al., 2013). It was observed in Chapter 2 that only 24 of the 93 BCTs were coded among the interventions to promote cycling and the most frequently used technique was restructuring the physical environment (by building new bicycle paths, segregating car and bicycle paths, etc.), which was used in 18 of the 48 interventions. However, certain BCTs are not very suitable to promote cycling such as the BCTs in the covert learning cluster (e.g., imaginary punishment) and they have never been used for this purpose. There are also BCTs that are suitable to be used to promote cycling but they have not been tested (e.g., incentivizing or rewarding outcome of the behaviour). Furthermore, among the studies included in the meta-analysis in Chapter 2, none of the interventions to promote cycling used BCTs from the ‘associations’ BCT cluster (e.g., prompts/cues, satiation, exposure). BCTs in this cluster have also been overlooked to change other behaviours according to several other meta-analyses (Ashton et al., 2020; Black et al., 2020; Castillo-Eito et al., 2020). Furthermore, in Chapter 3, experts also mostly overlooked this category while trying to identify which BCTs the text messages were referring to and only two of the messages prepared for the eight BCTs in this cluster were coded correctly by the experts. In other words, experts have not only not identified the messages prepared for this cluster, but they have also not confused other messages for the BCTs in this category.

The 27 messages that were not correctly coded in Chapter 3 are also often the ones that were overlooked in the interventions and/or systematic reviews. Among these 27 incorrectly coded messages, only two of them (BCT 4.2: Information about antecedents, BCT 12.5: Adding objects to the environment) were coded in the meta-analysis in Chapter 2. This is also the case for meta-analyses from other fields. For instance, Black et al. (2020) included 113 interventions designed to cease smoking in their meta-analysis and identified 32 unique BCTs in total. Again, only two of those 32 BCTs (BCT 5.2: Salience of consequences, and BCT 13.2: Framing/reframing) were among the 27 BCTs that were not correctly coded in Chapter 3. Castillo-Eito et al. (2020) identified 53 unique BCTs in total in their meta-analysis of interventions designed to reduce adolescent aggression and only 9 of them were among the 27 BCTs that were not correctly coded in Chapter 3. Similarly, Ashton et al. (2020) identified 55 unique BCTs in total in their meta-analysis for interventions to promote weight loss and only 6 of them were among the 27 BCTs that were not correctly coded in Chapter 3.

These examples are not problems on their own but they can indicate a problem when taken together such that some of the BCTs are overlooked either during designing interventions, during coding interventions, or both. This could be due to two reasons; (1) the concepts that these BCTs cover are rather ambiguous or peripheral ones to behaviour change and disregarded when designing interventions (i.e., they are not used in interventions); or (2) those BCTs are too ‘fine grained’ so they cannot be distinguished from each other when coding BCTs from others’ interventions. While it can be hard to distinguish BCTs from each other by looking at the short text messages, if they are actually too ‘fine grained’, it can also be hard to distinguish them from each other while preparing interventions with them or coding them from the interventions in which they are used. Hence, it can be suggested that some of the BCTs (e.g., the BCTs that are usually overlooked) should be refined/revised for the second version of the BCT taxonomy.

5.2.4. Behaviour Change at a Population Level is Possible

The research presented in the current thesis developed short text messages to deliver BCTs which were then used to promote active travel. The use of short pieces of text allows the adoption of different mediums of communication other than in SMS format, such as Facebook, Twitter, emails, app notifications, flyers, billboards, television, etc. In other words, the same short text messages could be delivered via a number of different mediums. This ease in delivery of BCTs via different mediums could allow future studies to reach larger populations in a faster and cheaper way. Also, it has been observed in Chapter 4 that there are no large differences in the effect sizes obtained from BCTs/interventions delivered via other methods and SMS messages (i.e., the effect size observed for psychosocial interventions in Chapter 2 and the effect size observed for interventions designed in Chapter 4 were the same; g = 0.24).

Obtaining the same effect sizes on a population level can actually make a big impact. For instance, Martineau et al., (2013) suggested in their review of reviews that reducing excessive alcohol consumption or drink-driving on population level is possible, especially through collective effort of policies and laws. Yet, they also suggest that the evidence of effectiveness is mixed for family- and community-level interventions, and mass media campaigns. These findings can be combined with other meta-analyses examining the most effective BCTs to reduce alcohol consumption (Garnett et al., 2018; Michie et al., 2012), and with the findings from Chapter 3 of the current thesis to develop population wide campaigns. In these campaigns, BCTs suggested by the meta-analyses (e.g., providing information on consequences, behavioural goal setting) could be delivered in short texts prepared Chapter 3 via digital methods (Black et al., 2016). The same method could be applied to smoking cessation as well (Black et al., 2020). Achieving even a small change on population level can make a big impact (West, 2007). For instance, West (2007) suggested that stopping smoking before 40 years of age can increase life expectancy for about nine years, and that 1% of extra effectiveness of intervention can extend life expectancy by three years for every 100 smokers targeted.

5.3. Limitations of the Current Thesis and Future Directions

The current thesis aimed to explore ways to promote active travel (mainly cycling) via BCTs that are delivered by short text messages. However, current methods (e.g., converting the list of short text messages and testing their validity, applying the intervention with the three BCTs delivered via short text messages) have not been directly tested on other behaviours yet. As cycling stands as a rather distinct behaviour, and even though there is evidence to suggest that the same methods can be used to change other behaviours (Heber et al., 2017; Suls et al., 2020), this suggestion requires further scrutiny and testing. In order to adopt cycling as a form of travel or to change different travel behaviours for cycling, further preparation is needed (e.g., owning and maintaining a bike, having appropriate clothes for visibility or weather). Furthermore, cycling can be adopted for personal health, economic, and/or environmental reasons (Braun et al., 2016; Tainio et al., 2021). Physical and/or cardiovascular condition is also an important factor in the adoption of cycling (Hemmingson et al., 2009) which is not always the case for changing other behaviours such as smoking, binge drinking, recycling, donating blood. In fact, not being physically fit (rather than being fit) can actually be a facilitating factor for changing some of these behaviours (Martineau et al., 2013). Hence, the current findings should be interpreted with some caution when applied to change other behaviours, and the unique features and effective BCTs of other behaviours should be considered.

Using SMS to deliver BCTs could be considered a shortcoming of the research presented in the current thesis. While cell phone ownership is quite high across the world and SMS can be sent to almost everyone via the cell phones now (Vangeepuram et al., 2018), SMS does not guarantee engagement with the intervention, e.g., that the message will be read, taken seriously, or that the message content will be implemented (Donkin et al., 2011; Perski et al., 2019). Kelders et al. (2012), for instance, reported in their systematic review that adherence to digital interventions varies greatly, based on the type of behaviour targeted, setup, frequency of engagement, etc. It is also suggested that, in order to increase intervention engagement, the mental and physical health conditions of participants as well as practical, cultural, and social factors should be considered when designing interventions (Hasselle et al., 2020). With the common usage of social media and messaging services such as WhatsApp, people use SMS less than before for communication (Udenze, 2017). Yet, SMS is used for many other reasons such as advertisement, verification, notification, etc. However, these reasons might decrease the importance or attention allocated to SMS messages and the receivers might take SMS messages less seriously. Consequently, BCTs delivered by SMS might not always yield the desired behaviour change (Griffiths et al., 2018; Mclaughlin et al., 2021). However, short text messages prepared to deliver BCTs can also be delivered via other digital or non-digital methods. Indeed, the text messages prepared for the current study could have been delivered to all OFO Bike users via the app notification system. This option would have also allowed reaching out to a larger (and possibly more representative) sample of participants. In addition, smartphone application notifications can inform the experimenter about levels of engagement, at least with the message. For example, it is possible to know if the participant just dismissed the message or clicked on it, and for how long they kept it open. These data on engagement could then be used as a covariate in analyses, or even as a moderator of intervention effectiveness. Furthermore, it can also be argued that advantages of the ability to be used in different platforms outweigh the disadvantages of SMS messages.

Finally, many different BCTs or combinations of BCTs can be used to change behaviours and the present thesis only focused on a subset of these. As stated before, only 24 of the 93 BCTs have been used in interventions to promote cycling, according to the meta-analysis presented in Chapter 2. Furthermore, only three BCTs were tested in Chapter 4, which have not been tested together before to promote cycling. While the number of BCTs used is larger for other behaviours (e.g., it was 32 for smoking cessation, Black et al., 2020; 53 for decreasing adolescent aggression, Castillo-Eito et al., 2020), there are still many more BCTs or BCT combinations left to be tested to change many different behaviours. For instance, the meta-analysis in Chapter 2 suggested that the self-monitoring of behaviour (BCT 2.3) and adding objects to the environment (BCT 12.5) are the most effective BCTs to promote cycling. The first intervention reported in Chapter 4 sought to test if the usage of the new bike share scheme implemented in Sheffield (i.e., adding objects to the environment) can be promoted via self-monitoring of behaviour as well as via the combination of three BCTs (behavioural goal setting, action planning, and self-monitoring). Due to the low sample size, it was not possible to conclude if the combination of the three BCTs was (or was not) more effective in promoting active travel than self-monitoring only.

However, there could be many other combinations of possible BCTs to promote cycling (Bird et al., 2013) and/or other behaviours (Black et al., 2020; Van Rhoon et al., 2020). Obviously, it is vital to build a cumulative science of behaviour change and future interventions should benefit from the meta-analyses done in their field (Michie & Johnston, 2012). While the BCT taxonomy v1 (Michie et al., 2013) is very useful in identifying and replicating the active ingredients of interventions, meta-analyses in different fields also show that many ineffective BCTs are being used and many techniques are not even used at all

(Ashton et al., 2020; Black et al., 2020; Castillo-Eito et al., 2020; Cradock et al., 2017). This means that the effectiveness of many BCTs are not even tested and future studies should test the effectiveness of other BCTs and their combinations. Yet, there is almost endless possibility of BCT combinations for many different behaviours and only a small proportion of them have been tested so far. Hence, the selection of untested BCTs and/or BCT combinations, might benefit from consideration of theories such as the Theory of Planned Behaviour (Ajzen, 1991; Ajzen, & Madden, 1986), Transtheoretical Model (Prochaska, & DiClemente, 1982), or Health Belief Model (Rosenstock, Strecher, & Becker, 1988).

Among the BCTs used in Chapter 4, behavioural goal setting has been used for the first time to promote cycling, according to the meta-analysis in Chapter 2. Furthermore, action planning and self-monitoring BCTs has only been used in four studies according to the meta-analysis in Chapter 2 and the intervention combining these three BCTs in Chapter 4 yielded promising results. Restructuring the social environment (BCT 12.2) also indicated promising (marginally significant) results in Chapter 2 and 10 other studies have used this BCT to promote cycling. Combining restructuring the social environment (BCT 12.2) with adding objects to the environment (BCT 12.5), and the three BCTs used in the intervention in Chapter 4 can be used and an intervention can be designed with these BCTs. If, for instance, the University of Sheffield were to introduce a bike share scheme (which would represent an example of BCT 12.5: Adding objects to the environment), an inter-departmental challenge to cycle more (e.g., similar to the "Cycle Challenge" which was carried out in the University of Sheffield in 2009 and 2010, Uttley & Lovelace, 2016) could be implemented to promote a social event (BCT 12.2: Restructuring the social environment), and the text messages designed to deliver the three BCTs suggested by Control Theory (Carver & Scheier, 1982) (e.g., BCT 1.1: Behavioural goal setting, BCT 1.4: Action planning, and BCT 2.3: Behavioural self-monitoring) can be sent to the participants of the challenge. While adding objects to the environment (e.g., making bicycles available by giving out free bicycles or establishing bike share schemes) solves the problem of owning and maintaining bicycles for cycling (Hemmingson et al., 2009; Lathia et al., 2012), setting goals for cycling, planning to achieve them, and monitoring the progress can improve self-regulation towards the behaviour (Carver & Scheier, 2002). There are no prior studies that have used this approach to promote cycling (see Chapter 2) and according to the results from the empirical research presented in Chapters 2 and 4 of the present thesis, this intervention to promote cycling might well be effective.

In addition to trying different BCT combinations to change different behaviours, it would also be worth considering the efficacy of delivering personalized/tailored BCTs or messages. For instance, the majority of the participants who received the intervention described in Chapter 4 had already been using bike share schemes. This means that the majority of the participants were already at least in the preparation stage of the Transtheoretical Model (TTM, Prochaska & DiClemente, 1982) and already had the intention to cycle. Therefore, goal setting (BCT 1.1), for instance, might be suitable for the participants who are already planning to cycle and self-monitoring of behaviour (BCT 2.3) might be suitable for participants who are in the action or maintenance stage. For people who are in the early stages of the TTM, an intention to cycle should be created first to lead to behaviour change (e.g., via applying BCT 5.1 Information about health consequences). This can also be the case for other behaviours, e.g., for people who have no intention to cease smoking, or decrease alcohol consumption. Delivering BCTs such as information about health consequences, incentives, and rewards via short text messages can also tackle this problem and future studies can/should identify people’s needs and apply BCTs accordingly (i.e., tailoring intervention material according to the participants). It has been suggested that tailoring interventions increase their effectiveness and that digital interventions ease the tailoring process (Head et al., 2013; Krebs et al., 2010; Lustria et al., 2013).

Furthermore, the BCT taxonomy includes BCTs that focus on behaviours and outcomes. For instance, incentives and rewards have been found to be effective in interventions for smoking cessation (Black et al., 2020) and there are BCTs reflecting both behavioural (BCT 10.1) and outcome related (BCT 10.8) incentives, as well as behavioural (10.2) and outcome related (10.10) rewards. There are also different BCTs for behaviour related (BCT 1.1) and outcome related (1.3) goal setting, self-monitoring of behaviour (2.3) and self-monitoring of outcome(s) of behaviour (2.4), and so on. The difference between targeting the behaviour and the outcome might also yield different results (Ashton et al., 2020; Black et al., 2020), especially for the long-term effectiveness of interventions to change different behaviours. For example, Deci, Koestner, and Ryan (1999) suggested that extrinsic rewards undermine intrinsic motivation and might lead to loss of interest in the activity. It can be suggested that setting goals, monitoring, incentivizing, and rewarding the behaviour rather than the outcome can foster intrinsic motivation, rather than extrinsic motivation, and lead to stronger and longer lasting intervention effects. Yet, there are no prior interventions or meta-analyses that have examined this effect with different BCTs for any behaviour. Interventions to test effects of these different BCTs not only for cycling, but also for different behaviours, are needed.

Finally, a meta-analysis that compares delivering the same BCTs through different mediums is needed. Even though the studies in the current thesis suggest that delivering BCTs via short text messages yield comparable results to delivering BCTs via other methods on promoting cycling, delivering BCTs via different mediums are not directly compared here. The different mediums can be compared in a meta-analysis by dividing the mediums as digital vs. non-digital (Wantland et al., 2004), or separate mediums such as in-person, written, SMS, social media notifications, physician suggestions, flyers, etc. These different mediums have, obviously, been used to change different behaviours (Krebs et al., 2010; Lustria et al., 2013) and some are more effective in changing certain behaviours then others. For instance, Lustria et al. (2013) suggested that web-based interventions are more effective in changing smoking and dieting behaviours than physical activity and drinking behaviours. Head et al. (2013) suggested that text-message based interventions are effective in changing smoking, physical activity, weight loss, and primary care appointment behaviours, but not effective in changing others such as medication adherence, or contraceptive use. However, the effectiveness of different mediums in delivering a BCT can be combined and analysed using meta-analysis. Such a meta-analysis could combine the most recent meta-analyses for changing different behaviours, update the studies published after the meta-analysis was conducted, then combine interventions to change different behaviours and compare different mediums in a single study. With such a meta-analysis, best ways to deliver different BCTs can be truly understood.

5.4. General Conclusion

The current thesis sought to explore best ways to promote active travel. The findings of the current thesis have contributed to our understanding of behaviour change in active travel in small but important ways. Overall, the research presented in the thesis suggests that (i) it is possible to promote cycling, especially via specific BCTs, (ii) it is possible to deliver the majority of the BCTs via short text messages, and (iii) combining these two findings yield promising results. Current methods can and should be used in the future interventions to understand the most effective ways to change different behaviours. By understanding the most effective ways to change certain behaviours and applying those to larger populations, it can be possible to tackle big societal challenges such as global warming or pandemics.

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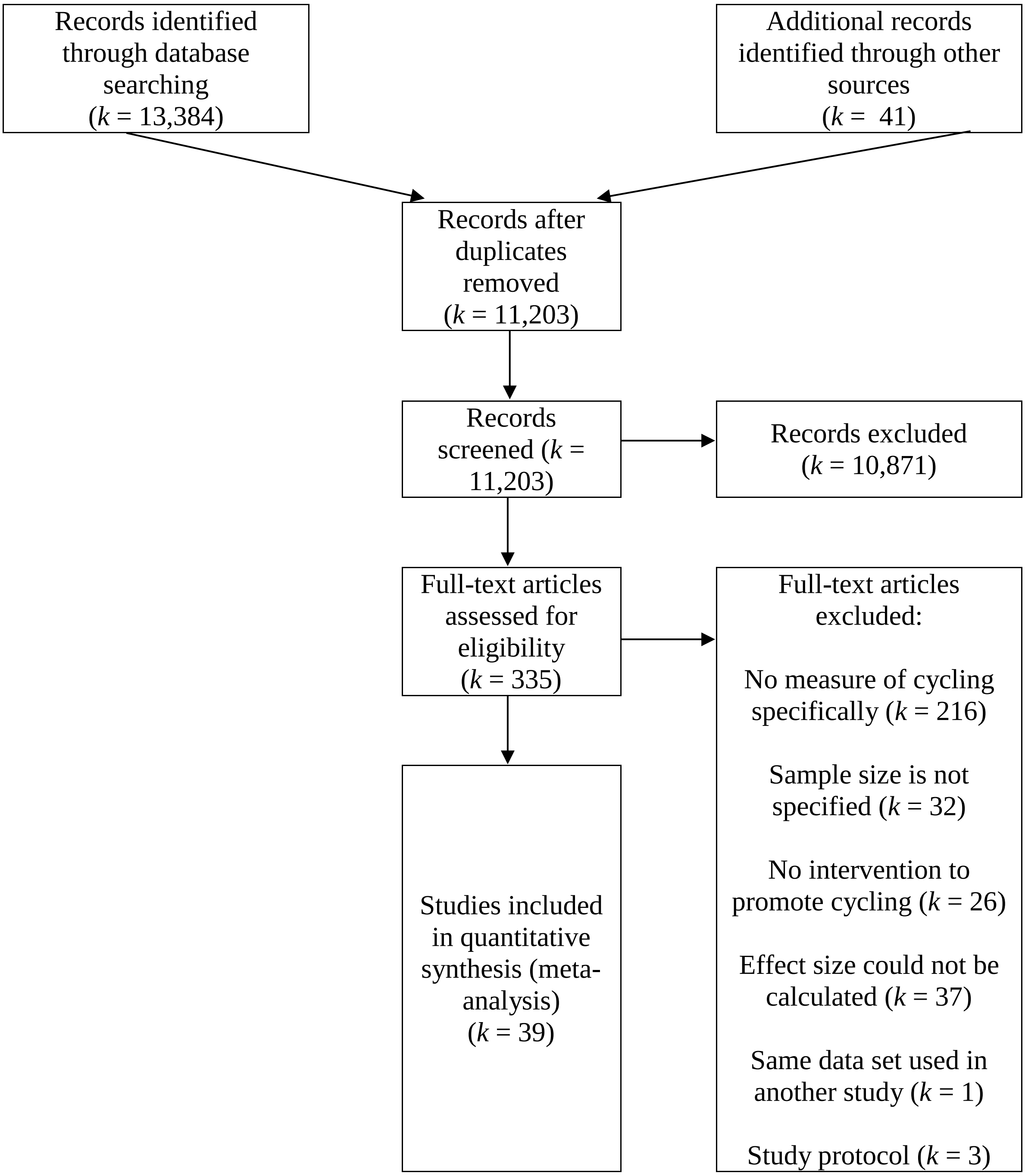
Appendix 1

Figure 2.1

Flow of Information through the Review



Appendix 2

Table 2.1

Characteristics of the studies included in the meta-analysis

Authors (year)	Study design	Sample	Number of BCTs used in the intervention	BCTs used in the intervention [a]	Measure of cycling	N_E	N_C	*d*
Aittasalo et al. (2019)	Single group pre-post	Specific group of adults	1	12.1	Cycling frequency	402	402	0.00
Aittasalo et al. (2019)	Independent groups pre-post	Specific group of adults	1	1.4	Cycling frequency	319	124	0.12
Boarnet et al. (2013)	Independent groups pre-post	Members of general population	1	12.1	Cycling frequency	103	100	0.12
Bourdeaudhuij et al. (2010) [b]	Independent groups pre-post	12-13 year-olds	0	-	Minutes cycled	581	469	0.15
Brown et al. (2016)	Independent groups pre-post	Members of general population	1	12.1	Cycling status	268	268	0.27
Burbidge & Goulias (2009)	Single group pre-post	Members of general population	1	12.1	Cycling status	98	98	-0.01
Cook et al. (2014)	Independent groups pre-post	13-15 year-olds	8	2.2, 3.1, 4.1, 4.2, 5.3, 6.2, 9.1, 12.2	Minutes cycled	278	277	0.13
	Independent groups pre-post	16-18 year-olds	8	2.2, 3.1, 4.1, 4.2, 5.3, 6.2, 9.1, 12.2	Minutes cycled	127	127	0.40
Crane et al. (2017)	Independent groups pre-post	Members of general population	1	12.1	Cycling frequency	189	229	-0.24
Dill et al. (2014)	Independent groups pre-post	Members of general population	1	12.1	Minutes cycled	63	38	-0.47

	Independent groups pre-post	Members of general population	1	12.1	Number of trips	81	64	-0.09
Diniz et al. (2015)	Independent groups pre-post	Specific group of adults	4	4.1, 6.1, 8.1, 10.2	Cycling status	438	438	0.07
Dogru et al. (2018) (1 BCT vs control)	Independent groups pre-post	Specific group of adults	1	2.3	Cycling frequency	27	20	0.35
Dogru et al. (2018) (3 BCTs vs control)	Independent groups pre-post	Specific group of adults	3	1.1, 1.4, 2.3	Cycling frequency	26	20	0.53
Droomers et al. (2015) (18 neighbourhoods vs control)	Independent groups pre-post	Members of general population	1	12.1	Cycling frequency	870	115	-0.41
Droomers et al. (2015) (24 neighbourhoods vs control)	Independent groups pre-post	Members of general population	1	12.1	Cycling frequency	1,018	114	-0.37
Dubuy et al. (2013)	Independent groups	Specific group of adults	3	10.1, 10.2, 12.2	Cycling frequency	422	227	0.37
Ducheyne et al. (2014) (I vs CG)	Independent groups pre-post	Primary school students	3	4.1, 6.1, 8.1	Minutes cycled	12	18	-0.26
Ducheyne et al. (2014) (I+PI vs CG)	Independent groups pre-post	Primary school students	4	4.1, 6.1, 8.1, 12.2	Minutes cycled	17	17	-0.27
Ducheyne et al. (2014) (I+PI vs I)	Independent groups pre-post	Primary school students	1	12.2	Minutes cycled	17	13	-0.02
Fuller et al. (2013)	Independent groups pre-post	Members of general population	1	12.5	Cycling status	802	1590	0.58
Fyhri & Fearnley (2015)	Independent groups pre-post	Specific group of adults	2	2.3, 12.5	Cycling share	22	53	0.56
	Independent groups pre-post	Specific group of adults	2	2.3, 12.5	Distance cycled/day	22	54	0.78

	Independent groups pre-post	Specific group of adults	2	2.3, 12.5	Number of trips	22	53	0.45
Gase et al. (2015)	Independent groups	Members of general population	4	4.1, 6.1, 8.1, 12.5	Cycling frequency	304	318	0.19
Goodman et al. (2013a)	Single group pre-post	Members of general population	1	12.1	Cycling status	1,235	1,235	0.13
Goodman et al. (2013b)	Independent groups pre-post	Members of general population	6	3.1, 4.1, 6.1, 8.1, 12.1, 12.2	Cycling status	2563 (Winzorized)	2881 (Winzorized)	0.01
Goodman et al. (2016)	Independent groups	10-11 year old children	3	4.1, 6.1, 8.1	Cycling status	2563	773	-0.01
Groesz (2007)	Independent groups pre-post	Primary school children	5	3.1, 4.1, 4.2, 6.1, 8.1	Cycling status	63	38	0.09
Heinen et al. (2015)	Independent groups	Members of general population	1	12.1	Cycling status	227	226	0.46
Hemmingsson et al. (2009)	Independent groups	Specific group of adults	3	3.1, 8.2, 12.2	Cycling status	27	22	1.03
	Independent groups	Specific group of adults	3	3.1, 8.2, 12.2	Cycling status	27	23	1.06
Hosford et al. (2019)	Independent groups pre-post	Members of general population	1	12.5	Cycling status	2563 (Winzorized)	2881 (Winzorized)	0.40
Houston et al. (2015)	Independent groups pre-post	Members of general population	1	12.1	Cycling frequency	104	69	0.10
Jia & Fu (2019)	Independent groups	Members of general population	1	12.5	Cycling status	289	102	0.43
Keall et al. (2015)	Independent groups pre-post	Members of general population	1	12.1	Moderate cycling minutes	123	50	-0.09
	Independent groups pre-post	Members of general population	1	12.1	Moderate cycling occurrence	122	51	0.10

	Independent groups pre-post	Members of general population	1	12.1	Vigorous cycling minutes	122	51	-0.21
	Independent groups pre-post	Members of general population	1	12.1	Vigorous cycling occurrence	123	50	0.10
Krizek et al. (2009)	Single group pre-post	Members of general population	1	12.1	Cycling status	2563 (Winzorized)	2881 (Winzorized)	0.02
Mendoza et al. (2017)	Independent groups pre-post	10-12 year-old children	5	4.1, 6.1, 8.1, 12.2, 12.5	Minutes cycled	24	30	1.83
Merom et al. (2003)	Independent groups pre-post	Members of general population	1	12.1	Minutes cycled	96	163	0.28
Moser et al. (2019)	Single group pre-post	Specific group of adults	1	10.8	Cycling status	70	70	0.54
Ostergaard et al. (2015)	Independent groups pre-post	10-11 year-old children	4	3.1, 12.1, 12.2, 12.5	Cycling status (Other than to school)	462	332	0.05
	Independent groups pre-post	10-11 year-old children	4	3.1, 12.1, 12.2, 12.5	Cycling status (Cycling to school)	461	331	0.07
Panter et al. (2016)	Single group pre-post	Members of general population	1	12.1	Minutes cycled	305	305	-0.41
Piwek et al. (2015)	Independent groups pre-post	Specific group of adults	1	2.3	Cycling frequency	5	5	0.14
	Independent groups pre-post	Specific group of adults	1	2.3	Cycling frequency	6	6	0.32
Rissel et al. (2010)	Independent groups pre-post	Members of general population	5	4.1, 5.1, 6.1, 8.1, 8.7	Cycling status	520	389	-0.01

Rissel et al. (2015)	Independent groups	Members of general population	1	12.1	Cycling status	240	272	0.08
Sersli et al. (2019)	Independent groups pre-post	Members of general population	5	4.1, 5.1, 6.1, 8.1, 8.7	Cycling frequency	135	43	0.17
Stralen et al. (2010) (EG1 vs CG)	Independent groups pre-post	Members of general population	11	1.2, 1.4, 1.6, 2.2, 3.1, 4.1, 6.2, 8.3, 9.1, 9.2, 10.4	Minutes cycled for leisure	104	114	0.01
	Independent groups pre-post	Members of general population	11	1.2, 1.4, 1.6, 2.2, 3.1, 4.1, 6.2, 8.3, 9.1, 9.2, 10.4	Minutes cycled for transportatio n	105	115	0.04
Stralen et al. (2010) (EG2 vs CG)	Independent groups pre-post	Members of general population	12	1.2, 1.4, 1.6, 2.2, 3.1, 4.1, 4.2, 6.2, 8.3, 9.1, 9.2, 10.4	Minutes cycled for leisure	113	115	0.13
	Independent groups pre-post	Members of general population	12	1.2, 1.4, 1.6, 2.2, 3.1, 4.1, 4.2, 6.2, 8.3, 9.1, 9.2, 10.4	Minutes cycled for transportatio n	112	114	0.06
Stralen et al. (2010) (EG2 vs EG1)	Independent groups pre-post	Members of general population	1	4.2	Minutes cycled for leisure	113	105	0.11
	Independent groups pre-post	Members of general population	1	4.2	Minutes cycled for transportatio n	112	104	0.02
Teyhan et al. (2016)	Independent groups	14 year-old children	3	4.1, 6.1, 8.1	Cycling status	2041	2881	0.19
	Independent groups	16 year-old children	3	4.1, 6.1, 8.1	Cycling status	1779	2347	0.17
Villa et al. (2016)	Independent groups pre-post	8-11 year-old children	3	4.1, 6.1, 8.1	Cycling status	117	89	0.00

Note. [a] BCT No = number of the behaviour change technique as given in the original taxonomy (Michie et al., 2013). [b] This study compared a tailored versus a non-tailored intervention.

Appendix 3

Table 2.2

Sample-weighted average effect sizes (ES) for interventions including vs. excluding specific BCTs

BCT No.	BCT	*k*	g_+ present (95% CI)	g_+ absent (95% CI)	Q for difference	*p*-value
1.1	Goal setting (behaviour)	1	-	-	-	-
1.2	Problem solving	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
1.4	Action planning	4	0.09 (-0.01, 0.19)	0.14 (0.05, 0.23)	0.52	0.470
1.6	Discrepancy between current behaviour and goal	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
2.2	Feedback on behaviour	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
2.3	Self-monitoring of behaviour	4	0.48 (0.36, 0.59)	0.12 (0.03, 0.21)	8.50	0.004
3.1	Social support (unspecified)	8	0.16 (-0.03, 0.34)	0.13 (0.03, 0.23)	0.13	0.718
4.1	Instruction on how to perform a behaviour	16	0.11 (0.00, 0.22)	0.15 (0.04, 0.26)	0.31	0.577
4.2	Information about antecedents	5	0.14 (0.03, 0.26)	0.14 (0.04, 0.23)	0.01	0.903
5.3	Information about social and environmental consequences	2	0.25 (-0.02, 0.52)	0.13 (0.04, 0.22)	0.66	0.415
6.1	Demonstration of the behaviour	13	0.10 (-0.03, 0.24)	0.15 (0.05, 0.25)	0.45	0.503
6.2	Social comparison	4	0.14 (-0.01, 0.29)	0.14 (0.04, 0.23)	0.01	0.939
8.1	Behavioural practice/rehearsal	13	0.10 (-0.03, 0.24)	0.15 (0.05, 0.25)	0.45	0.503
8.2	Behaviour substitution	1	-	-	-	-
8.3	Habit formation	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
8.7	Graded tasks	1	-	-	-	-
9.1	Credible source	4	0.14 (-0.01, 0.29)	0.14 (0.04, 0.23)	0.01	0.939
9.2	Pros and cons	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
10.1	Material incentive (behaviour)	1	-	-	-	-
10.2	Material reward (behaviour)	2	0.22 (-0.08, 0.52)	0.13 (0.04, 0.22)	0.29	0.591
10.4	Social reward	2	0.06 (-0.01, 0.13)	0.14 (0.05, 0.23)	1.24	0.266
12.1	Restructuring the physical environment	18	-0.01 (-0.12, 0.10)	0.24 (0.14, 0.35)	18.16	0.000

12.2	Restructuring the social environment	10	0.27 (-0.02, 0.56)	0.11 (0.03, 0.19)	3.00	0.083
12.5	Adding objects to the environment	8	0.45 (0.15, 0.75)	0.08 (0.00, 0.15)	14.72	0.000

Note: BCT No = number of the behaviour change technique as given in the original taxonomy (Michie et al., 2013), BCT = name of the behaviour change technique

Appendix 4

Table 2.3

Other moderators of the effect of interventions on cycling: sample-weighted average effect sizes (ES)

			Categorical			Continuous	
Moderators	*N*	*k*	Levels of the moderator	*Q*	*g+* [95 % CI]	*β*	SE
Sample moderators							
Age (in years)	19,190	24				-0.002	0.00
Ethnicity (percentage of whites)	12,302	15				-0.248	0.21
Gender (percentage of females)	34,110	39				0.380	0.29
Modal level of education	30,505	31		0.15			
	5,182	4	No education		0.22 [-0.41, 0.85]		
	11,102	9	Primary school		0.17 [0.14, 0.21]		
	3,203	8	High school		0.19 [0.05, 0.34]		
	11,018	10	Undergraduate or above		0.18 [0.01, 0.36]		
Type of sample	46,102	48		6.99*			
	16,284	13	Children or adolescents		0.16 [-0.03, 0.35]		
	2,880	10	Specific group of adults		0.33 [0.14, 0.52]		
	26,938	25	General population		0.07 [-0.03, 0.18]		
Methodological moderators							
Blinding (assessors)	46,102	48		2.03			
	93	2	Blind		0.43 [0.26, 0.61]		
	46,009	46	Not blind		0.13 [0.04, 0.22]		
Blinding (participants)	46,102	48		2.03			
	93	2	Blind		0.43 [0.26, 0.61]		

	46,009	46	Not blind		0.13 [0.04, 0.22]		
Intervention length	46,102	48				-0.016	0.02
Nature of the measure of cycling	46,102	48		6.72**			
	7,021	11	Objective		0.37 [0.08, 0.66]		
	39,081	37	Self-report		0.09 [0.02, 0.17]		
Outcomes measured	46,102	48		3.50			
	3,919	12	Time		0.13 [-0.12, 0.39]		
	6,362	16	Distance		0.05 [-0.10, 0.19]		
	35,821	20	Frequency		0.21 [0.10, 0.31]		
Randomization	46,102	48		2.80			
	10,620	21	Randomized		0.10 [-0.01, 0.21]		
	35,482	27	Not randomized		0.18 [0.05, 0.32]		
Rate of participation	28,229	33				-0.071	0.16
Recruitment method	46,102	48		2.30			
	404	2	Self-initiated		0.36 [0.01, 0.72]		
	1,447	4	By medical professionals		0.24 [-0.19, 0.68]		
	31,303	30	By researchers		0.10 [0.00, 0.20]		
	12,948	12	By school		0.16 [0.01, 0.32]		
Representativeness of population	44,754	45		0.01			
	15,700	15	Representative		0.15 [0.03, 0.27]		
	29,054	30	Not representative		0.14 [0.02, 0.27]		
Theory use in intervention development	46,102	48					
	4283	9	Used		0.17 [0.01, 0.33]		
	41819	39	Not used		0.13 [0.03, 0.23]		

Note: *N* = number of participants included this analysis, *k* = number of unique effect sizes measured for this analysis, CI = confidence interval, SE = standard error, BCTs = behaviour change techniques.

* $p < .05$, ** $p < .01$, *** $p < .001$

Appendix 5

Table 3.5

List of BCTs, text messages, kappa scores, and confidence, understandability, and convertibility scores from phase 1

BCT	Text message	Kappa score	Mean confidence	Mean understandability	Mean convertibility
Goals and planning					
1.1 Goal setting (behaviour)	Set yourself the goal to cycle in the next two days.	1.00	4.67 (0.52)	4.67 (0.62)	4.80 (0.56)
1.2 Problem solving	Think about what stops you from using your bike and think of ways to overcome these problems.	.80	4.07 (1.07)	4.40 (0.74)	4.53 (0.64)
1.3 Goal setting (outcome)	Set yourself the goal of losing weight by cycling.	.80	4.47 (0.64)	4.36 (0.63)	4.23 (0.83)
1.4 Action planning	Make a plan detailing when and where you will cycle – e.g. next Wednesday to get to work.	1.00	4.60 (0.51)	4.60 (0.63)	4.60 (0.63)
1.5 Review behaviour goal(s)	Have you achieved your goal of cycling a certain number of times each week? Do you need to set a new goal or keep the same goal?	1.00	4.36 (0.63)	4.43 (0.76)	4.43 (0.76)
1.6 Discrepancy between current behaviour and goal	Is there a discrepancy between the amount that you currently cycle and your cycling goals?	.93	4.60 (0.51)	4.00 (1.07)	4.27 (0.96)

1.7 Review outcome goal(s)	Have you achieved your goal of being fitter by riding your bicycle? Do you need to set a new goal or keep the same goal?	.73	4.07 (0.62)	4.36 (0.84))	4.62 (0.65)
1.8 Behavioural contract	Make and sign a behavioural contract (witnessed by someone else) to cycle a certain number of days each week.	1.00	4.80 (0.41)	3.71 (1.33)	4.47 (0.74)
1.9 Commitment	Reaffirm your commitment to riding your bicycle. Say "I am strongly committed to riding my bicycle".	1.00	4.53 (0.52)	4.53 (0.74)	4.53 (0.64)
Feedback and monitoring					
2.1 Monitoring of behaviour by others without feedback	We are measuring the amount that you cycle.	.93	4.20 (0.86)	4.29 (0.83)	3.86 (1.03)
2.2 Feedback on behaviour	You have cycled for … minutes in the last week.	.73	4.57 (0.65)	4.79 (0.43)	4.29 (0.99)
2.3 Self-monitoring of behaviour	You can keep track of your cycling using a smartphone app to see how often or how far you cycle.	.93	4.27 (0.70)	4.57 (0.65)	4.07 (1.03)
2.4 Self-monitoring of outcome(s) of behaviour	If you want to lose weight by cycling, then weigh yourself each week to see how you are doing.	.87	4.53 (0.64)	4.57 (0.76)	4.07 (0.96)
2.5 Monitoring outcome(s) of behaviour by others without feedback	There are apps that keep track of your daily progress towards your goals, even without letting you know.	.12	2.93 (1.39)	4.08 (1.04)	3.85 (0.99)

2.6 Biofeedback	Your current heart rate is ...	.87	4.64 (0.63)	4.36 (0.75)	3.64 (1.22)
2.7 Feedback on outcome(s) of behaviour	You have lost ... kilograms since you have started cycling.	.80	4.40 (0.83)	4.53 (0.64)	3.93 (1.00)
Social support					
3.1 Social support (unspecified)	Ask a close friend to support you to cycle.	.93	4.20 (0.68)	4.07 (0.88)	4.47 (0.83)
3.2 Social support (practical)	Think about what practical help you could get to cycle more. For example, you could ask someone to help you to fix your bike or show you good routes.	.80	4.00 (1.31)	4.40 (0.83)	4.07 (0.96)
3.3 Social support (emotional)	Inviting friends to cycle with you would make it more fun and encouraging for you to cycle more!	.46	3.53 (0.83)	4.67 (0.62)	4.47 (0.64)
Shaping knowledge					
4.1 Instruction on how to perform a behaviour	When going uphill, change gear, so that it is easier to pedal.	.80	3.64 (0.93)	4.47 (0.74)	3.07 (1.28)
4.2 Information about antecedents	Keep a record of what makes you feel like cycling or not cycling on different days, so that you know what determines your behaviour.	.53	3.80 (1.15)	4.14 (0.77)	4.29 (0.83)
4.3 Re-attribution	Try attributing your tiredness to inactivity due to NOT cycling regularly rather than cycling.	.53	4.07 (1.03)	3.57 (1.45)	3.71 (1.27)
4.4 Behavioural	Try cycling at different time of the day or for	.46	2.85 (1.28)	4.08 (0.95)	4.00 (1.00)

experiments	different amounts of time, so that you can identify when and how you like to cycle.				
Natural consequences					
5.1 Information about health consequences	Cycling has lots of health benefits such as improved cardiovascular and mental health, and better weight management.	1.00	4.73 (0.59)	4.53 (0.74)	4.07 (1.28)
5.2 Salience of consequences	Keep the benefits of regularly cycling in your mind.	.33	1.92 (0.86)	3.92 (1.04)	4.08 (1.04)
5.3 Information about social and environmental consequences	Cycling can reduce traffic congestion – everyone can get around easier and the air is cleaner as a result!	.93	4.53 (0.64)	4.43 (0.76)	3.73 (1.34)
5.4 Monitoring of emotional consequences	How do you feel after you cycle for half an hour?	.60	3.14 (1.35)	4.29 (0.83)	4.21 (0.89)
5.5 Anticipated regret	Imagine the regret that you would feel if you used a vehicle, instead of your bike to go to work / school today.	.87	4.40 (1.12)	4.27 (0.96)	4.47 (0.83)
5.6 Information about emotional consequences	Cycling decreases the likelihood of depression, improves your mood, and can make you happier!	.87	4.40 (0.63)	4.73 (0.59)	4.27 (0.88)
Comparison of behaviour					
6.1 Demonstration of the behaviour	Watch videos that demonstrate how to cycle safely.	.66	4.20 (0.78)	4.43 (0.85)	4.14 (0.95)

6.2 Social comparison	Do you know anyone else who cycles? Do they cycle more or less frequently than you?	.87	4.46 (0.52)	4.42 (0.79)	4.25 (1.06)
6.3 Information about others' approval	Your colleagues and friends will approve of you cycling more.	.73	4.33 (0.72)	4.53 (0.64)	4.53 (0.64)
Associations					
7.1 Prompts/cues	If your bike is kept in a shed, then put a picture or model of a bike somewhere where you will see it before you leave your house to prompt you to cycle.	.87	3.86 (0.95)	4.29 (0.73)	4.21 (0.70)
7.2 Cue signalling reward	You will be given a £2 reward for cycling to work when it's raining, but not when it's dry.	.06	4.07 (0.92)	4.38 (0.77)	3.85 (0.69)
7.3 Reduce prompts/cues	We will send you less frequent reminders to cycle over time.	.87	4.07 (1.03)	4.67 (0.62)	4.33 (0.90)
7.4 Remove access to the reward	To make yourself cycle more, let's agree that if you don't cycle, the cupboard of snacks is locked for you that day!	.26	3.60 (0.83)	4.20 (0.78)	4.13 (0.74)
7.5 Remove aversive stimulus	Set an alarm to go off every half an hour and only dismiss it when you cycle that day.	.39	3.00 (1.20)	4.21 (0.70)	4.21 (0.89)
7.6 Satiation	Avoid any form of exercise - you will soon get fed up of it!	.00	3.23 (1.24)	3.33 (1.30)	3.08 (1.31)
7.7 Exposure	If you are not used to cycling when it is dark, cycle your route in the daytime first.	.00	2.43 (1.02)	4.50 (0.76)	3.79 (0.98)
7.8 Associative learning	Put a picture of yourself cycling next to something else you like, like pictures of your	.53	2.43 (1.16)	4.31 (0.86)	3.85 (1.07)

	family or friends.				
Repetition and substitution					
8.1 Behavioural practice/rehearsal	Practice cycling to improve your skills and confidence.	.73	3.80 (0.86)	4.53 (0.64)	4.40 (0.74)
8.2 Behaviour substitution	Identify something you could stop doing (like watching TV) to go cycling instead.	.80	3.80 (1.27)	4.43 (0.85)	4.21 (0.89)
8.3 Habit formation	Try to cycle at the same times and for the same reasons (e.g., to meet friends or go shopping) so that cycling becomes a habit.	.87	4.43 (0.76)	4.71 (0.61)	4.43 (0.76)
8.4 Habit reversal	Try to break your bad habits. Instead of always driving to the shop near your home, ride your bike instead.	.73	4.07 (0.70)	4.60 (0.74)	4.33 (0.82)
8.5 Overcorrection	If you haven't cycled as much as you wanted to one week, then make up for it by cycling more than usual the following week.	.73	3.00 (1.24)	4.36 (0.84)	4.14 (0.77)
8.6 Generalization of a target behaviour	Do you cycle on weekends? How about cycling to work as well?	.66	3.79 (1.25)	4.27 (1.22)	3.80 (1.21)
8.7 Graded tasks	Take small steps – for example, start cycling a short distance or just one day a week and then build up.	.87	4.13 (0.83)	4.50 (0.86)	4.14 (0.86)
Comparison of outcomes					
9.1 Credible source	Doctors are quick to point out the health benefits of cycling.	.73	3.57 (0.94)	4.31 (1.03)	4.23 (0.93)

9.2 Pros and cons	List and compare the advantages and disadvantages of cycling.	.93	4.67 (1.05)	4.47 (0.92)	4.67 (0.62)
9.3 Comparative imagining of future outcomes	Would you feel better tomorrow if you cycled today or if you did not cycle today?	.73	3.40 (1.35)	4.20 (1.01)	4.14 (0.77)
Reward and threat					
10.1 Material incentive (behaviour)	We will give you a £2 voucher for every day that you cycle for at least 30 minutes.	.80	3.87 (0.74)	4.53 (0.64)	4.40 (0.74)
10.2 Material reward (behaviour)	You have earned a £2 voucher for cycling today.	.80	4.50 (0.52)	4.73 (0.59)	4.60 (0.74)
10.3 Non-specific reward	You have just earned a reward for cycling today!	.66	3.93 (0.96)	4.57 (0.65)	4.64 (0.63)
10.4 Social reward	Congratulations for cycling today!	.73	3.50 (1.02)	4.50 (0.76)	4.50 (0.76)
10.5 Social incentive	If you cycle to work everyday next week, your work colleagues will congratulate you.	.46	4.27 (0.70)	4.67 (0.62)	4.36 (0.84)
10.6 Non-specific incentive	You will gain a reward if you cycle tomorrow.	.73	4.27 (0.70)	4.50 (0.65)	4.57 (0.65)
10.7 Self-incentive	Reward yourself if you cycle next week.	.39	4.00 (0.93)	4.60 (0.63)	4.60 (0.63)
10.8 Incentive (outcome)	You will receive a £10 voucher for every kilogram of weight that you lose by cycling.	.66	4.33 (0.72)	4.53 (0.74)	4.60 (0.63)
10.9 Self-reward	Have you been using your bike? If so, why not give yourself a little reward to say well done!	.93	4.33 (0.72)	4.29 (0.73)	4.64 (0.63)

10.10 Reward (outcome)	You have been awarded a £30 voucher for losing 3 kilograms of weight by cycling.	.93	4.27 (0.46)	4.67 (0.62)	4.53 (0.74)
10.11 Future punishment	If you do not cycle next week, then your membership to the cycling club will be cancelled.	.60	3.47 (1.13)	4.43 (1.09)	3.77 (0.83)
Regulation					
11.1 Pharmacological support	Caffeine tricks your body into feeling less tired and can improve cycling. Have a cup of coffee before you head out on your bike.	.33	2.87 (1.41)	4.00 (1.18)	2.79 (1.12)
11.2 Reduce negative emotions	Find a way to deal with your stress – that way you can get on with the things that you want to do – like cycling more!	.66	3.47 (1.25)	3.57 (1.09)	4.00 (1.04)
11.3 Conserving mental resources	Do not try to change too many things at the same time. Concentrate your mental resources on trying to cycle more.	.87	3.80 (1.47)	4.00 (0.85)	4.07 (0.80)
11.4 Paradoxical instructions	Try not doing any form of exercise until you feel like you really want to cycle.	.39	2.31 (1.44)	3.67 (1.16)	3.42 (1.00)
Antecedents					
12.1 Restructuring the physical environment	Place your bicycle in a convenient place to grab and go on your way out.	.87	4.07 (0.70)	4.73 (0.59)	4.13 (1.25)
12.2 Restructuring the social environment	Spend less time with your friends who do not cycle.	.73	4.21 (0.89)	4.15 (0.99)	4.23 (1.01)
12.3 Avoidance/reducing	Hide your car keys or bus pass to avoid cues to use other models of transport.	.66	3.53 (1.13)	4.14 (0.95)	3.92 (1.04)

exposure to cues for the behaviour					
12.4 Distraction	If you find yourself thinking about other modes of transport, then distract yourself so you can refocus on cycling.	.73	4.27 (0.88)	3.71 (0.91)	3.86 (0.95)
12.5 Adding objects to the environment	Get yourself new cycling gear.	.60	2.93 (1.22)	4.29 (0.83)	3.29 (1.33)
12.6 Body changes	Hit the gym or do squats at home to strengthen the muscles you use for cycling.	.53	3.47 (1.30)	4.50 (0.76)	3.57 (1.02)
Identity					
13.1 Identification of self as role model	You can be the one starting cycling a trend among your friends!	.80	3.60 (1.40)	4.07 (0.80)	3.87 (0.99)
13.2 Framing/reframing	Let’s call your bike the “life cycle” So that it reminds you why you are cycling.	.39	2.73 (1.53)	3.14 (1.17)	3.00 (1.24)
13.3 Incompatible beliefs	There’s a discrepancy between your view of yourself as a cyclist and how often you’ve actually cycled in the past year.	.66	4.21 (0.80)	3.92 (0.86)	4.08 (0.95)
13.4 Valued self-identity	What are your 5 most important strengths? Think about them and elaborate them to yourself. These could help you to cycle more.	.80	3.87 (0.99)	4.00 (0.96)	4.07 (0.92)
13.5 Identity associated with changed behaviour	From now on, think of yourself as a cyclist.	.87	4.33 (0.72)	4.33 (0.72)	4.27 (0.88)
Scheduled consequences					

14.1 Behaviour cost	£2 has been subtracted from your account as you did not cycle today.	.53	3.87 (0.92)	4.73 (0.59)	4.60 (0.74)
14.2 Punishment	Because you have not cycled over the last week, your phone's alarm will go off twice at random hours today.	.73	3.07 (1.16)	3.64 (1.08)	3.71 (1.07)
14.3 Remove reward	Because you have not cycled over the last week, you have lost your chance to earn a £2 voucher the next time you cycle.	.66	3.20 (0.78)	4.29 (0.83)	4.14 (0.86)
14.4 Reward approximation	You have earned a £2 voucher for cycling 15 minutes today. You will need to cycle for 30 minutes next time to earn the voucher.	.12	3.13 (1.06)	4.40 (0.83)	4.30 (0.72)
14.5 Rewarding completion	You have earned a £2 voucher for cycling today. To get this reward next time you will also need to wear a helmet.	.26	3.29 (1.14)	4.38 (0.65)	3.62 (1.26)
14.6 Situation-specific reward	You have earned a £5 voucher for cycling during the rush hour but you will not get these vouchers if you cycle at other times.	.80	3.53 (1.46)	4.29 (0.83)	3.71 (1.20)
14.7 Reward incompatible behaviour	You have received a reward for not driving your car to the shops.	.33	3.67 (0.82)	4.20 (0.94)	4.07 (0.80)
14.8 Reward alternative behaviour	We have arranged for you to be rewarded every time that you find an alternative to using the car.	.26	3.80 (0.86)	4.00 (0.88)	4.00 (0.88)
14.9 Reduce reward frequency	For cycling today you have earned a voucher but you will need to cycle two days in a row to earn your next voucher.	.33	3.80 (0.68)	4.36 (0.75)	4.14 (0.86)

14.10 Remove punishment	To make yourself cycle more, arrange removal of a chore you don't like doing. If you cycle, you don't do the chore!	.60	3.14 (1.10)	3.86 (0.95)	4.14 (1.03)
Self-belief					
15.1 Verbal persuasion about capability	You can cycle today! Even though it seems far, you can do it!	.87	4.33 (0.72)	4.57 (0.64)	4.60 (0.63)
15.2 Mental rehearsal of successful performance	Close your eyes and imagine cycling successfully somewhere.	.60	3.67 (1.59)	4.47 (0.73)	4.47 (0.83)
15.3 Focus on past success	Think of all the times in the past that you didn't want to cycle but you did it anyway.	.66	4.36 (0.63)	4.46 (0.66)	4.54 (0.66)
15.4 Self-talk	Tell yourself (aloud or silently) that cycling today will be enjoyable.	.87	4.57 (1.09)	4.71 (0.47)	4.79 (0.43)
Covert learning					
16.1 Imaginary punishment	To convince yourself to cycle more, imagine yourself suffering because of not cycling.	.80	3.53 (0.92)	3.93 (0.73)	3.93 (0.83)
16.2 Imaginary reward	Imagine cycling regularly and getting compliments on your looks from your significant other or someone attractive to you.	.80	4.00 (0.56)	4.29 (0.73)	4.00 (0.78)
16.3 Vicarious consequences	Observe the benefits that other people who cycle regularly get, such as being fitter or receiving compliments.	.53	3.80 (1.32)	4.13 (0.83)	4.13 (0.83)

Appendix 6

Table 3.6

List of BCTs, text messages, and kappa, confidence, understandability, and convertibility scores from Phase 2

BCT	Text message	Kappa score	Mean confidence	Mean understandability	Mean convertibility
2.5 Monitoring outcome(s) of behaviour by others without feedback	Your saddle has a sensor that automatically records your weight.	.06	4.20 (0.94)	4.53 (0.52)	4.67 (0.62)
3.3 Social support (emotional)	Asking a friend to cycle with you would be much more enjoyable!	.39	3.47 (0.83)	4.33 (0.82)	4.13 (0.92)
4.2 Information about antecedents	You typically go cycling in the morning.	.00	3.50 (0.86)	4.08 (0.76)	4.23 (0.73)
4.3 Re-attribution	Try to attribute your tiredness to inactivity rather than cycling too much.	.53	4.00 (0.76)	3.73 (0.96)	3.80 (0.86)
4.4 Behavioural experiments	Experiment with cycling at different times of the day to work out when works best for you.	.73	3.00 (1.24)	3.86 (1.10)	4.29 (0.91)
5.2 Salience of consequences	Keep the image of a healthy heart in your mind to remind yourself of the benefits of cycling.	.46	2.87 (1.19)	3.93 (1.07)	4.00 (1.11)
5.4 Monitoring of emotional consequences	Keep a record of how you feel after cycling - what emotions do you experience?	.00	4.00 (0.96)	4.21 (0.89)	4.29 (0.83)
7.2 Cue signalling reward	The weather will be used to decide if you will get	.06	3.47 (1.13)	3.47 (1.41)	3.33 (1.29)

	a reward - If the weather is bad when you are cycling, then you will be more likely to get the reward.				
7.4 Remove access to the reward	Your free gym membership will be removed because you did not cycle twice in the past week.	.06	3.87 (0.74)	4.53 (0.52)	4.13 (0.92)
7.5 Remove aversive stimulus	We will stop sending you nagging texts if you cycle twice this week, in order to encourage you to cycle more.	.19	2.79 (1.31)	3.77 (1.24)	3.92 (1.24)
7.6 Satiation	Don't cycle for a month - you'll soon want to start again.	.06	3.13 (0.92)	3.67 (1.18)	3.93 (1.10)
7.7 Exposure	If you're frightened about cycling to work, then cycle the route on the weekend to reduce your fear.	.26	3.53 (1.06)	4.33 (0.72)	3.60 (1.12)
7.8 Associative learning	Tape a picture of something that you really like on to your bike, so that you come to love cycling more!	.53	2.93 (1.39)	3.93 (0.88)	3.53 (0.99)
10.5 Social incentive	Your friends will congratulate you if you cycle more - this is your incentive!	.60	3.80 (0.86)	4.40 (0.91)	4.47 (0.74)
10.7 Self-incentive	Incentivise yourself to cycle more!	.73	3.67 (1.29)	2.87 (0.92)	3.73 (1.28)
10.11 Future punishment	If you do not cycle now, then you will be punished for it later.	.80	4.07 (0.80)	3.67 (1.11)	4.07 (1.10)
11.1 Pharmacological support	Caffeine and vitamin supplements can make it easier to cycle.	.00	3.20 (1.15)	3.93 (0.96)	3.93 (0.96)
11.4 Paradoxical	Try not doing any exercise until you feel like you	.00	3.73 (1.16)	4.47 (0.64)	4.13 (0.83)

instructions	really want to cycle.				
12.5 Adding objects to the environment	Get yourself cycling gear appropriate for different weather conditions (or even a new bike)!	.06	3.20 (1.21)	4.20 (0.68)	4.13 (0.92)
12.6 Body changes	Do some squats or lunges at home - this will strengthen the muscles that you use for cycling.	.00	3.33 (1.29)	4.27 (0.88)	3.71 (1.27)
13.2 Framing/reframing	Think of cycling to work as an easy way to stay fit rather than as a mode of transport.	.00	3.47 (1.30)	4.20 (1.01)	4.40 (0.83)
14.1 Behaviour cost	£2 has been subtracted from your account as you did not cycle today.	.60	4.13 (0.99)	4.67 (0.49)	4.27 (0.96)
14.4 Reward approximation	You have earned a £2 voucher for cycling 15 minutes today (as part of your 30 minute target).	.33	3.20 (0.94)	4.40 (0.74)	4.29 (0.73)
14.5 Rewarding completion	You will receive a reward for completing your goal of cycling safely - that means cycling AND wearing a helmet.	.33	3.47 (1.13)	4.40 (0.63)	3.93 (0.96)
14.7 Reward incompatible behaviour	You will receive a reward when you do not drive your car to work.	.19	3.79 (1.19)	4.23 (0.73)	4.08 (1.19)
14.8 Reward alternative behaviour	You will receive a reward if you find an alternative to using the car.	.33	3.60 (1.06)	4.00 (1.00)	4.07 (0.96)
14.9 Reduce reward frequency	This week you will receive a voucher if you cycle to work every day. You will receive the next voucher when you have done this every day for a month.	.46	3.87 (0.92)	4.33 (0.62)	4.40 (0.83)
14.10 Remove punishment	Arrange for someone else to do a chore that you	.33	3.57 (0.94)	3.92 (1.04)	4.00 (1.29)

	don’t like doing, if you cycle to work.				
15.2 Mental rehearsal of successful performance	Close your eyes and imagine cycling somewhere and enjoying the experience.	.39	3.57 (1.09)	4.29 (0.73)	4.21 (0.80)
16.3 Vicarious consequences	See what other people seem to get out of cycling regularly.	.39	2.73 (1.16)	3.47 (1.13)	3.73 (1.28)

Appendix 7

Table 3.7
Kappa scores, and confidence, understandability, and convertibility scores for BCT groupings

BCT message	Messages correctly coded	Kappa score	Mean confidence	Mean understandability	Mean convertibility
1. Goals and planning	9/9	.92	4.49 (0.26)	4.34 (0.30)	4.48 (0.15)
2. Feedback and monitoring	6/7	.75	4.22 (0.59)	4.46 (0.23)	3.96 (0.21)
3. Social support	2/3	.73	3.91 (0.34)	4.38 (0.30)	4.40 (0.31)
4. Shaping knowledge	2/4	.65	3.61 (0.43)	4.10 (0.42)	3.86 (0.58)
5. Natural consequences	4/6	.79	4.01 (0.79)	4.36 (0.27)	4.16 (0.25)
6. Comparison of behaviour	3/3	.75	4.33 (0.13)	4.46 (0.06)	4.31 (0.20)
7. Associations	2/8	.41	3.45 (0.41)	4.10 (0.39)	3.91 (0.37)
8. Repetition and substitution	7/7	.77	3.86 (0.45)	4.49 (0.15)	4.21 (0.21)
9. Comparison of outcomes	3/3	.80	3.88 (0.69)	4.39 (0.25)	4.35 (0.28)
10. Reward and threat	10/11	.76	4.05 (0.32)	4.30 (0.55)	4.43 (0.28)
11. Regulation	2/4	.56	3.11 (0.66)	3.81 (0.22)	3.57 (0.60)
12. Antecedents	4/6	.69	3.75 (0.53)	4.25 (0.35)	3.83 (0.35)
13. Identity	4/5	.70	3.75 (0.64)	3.89 (0.45)	3.86 (0.50)
14. Scheduled consequences	3/10	.51	3.49 (0.35)	4.21 (0.30)	4.07 (0.23)

15. Self-belief	3/4	.75	4.23 (0.39)	4.55 (0.12)	4.60 (0.14)
16. Covert learning	2/3	.71	3.78 (0.24)	4.12 (0.18)	4.02 (0.10)

Appendix 8

Table 3.8

BCTs that were frequently confused

4.3 Re-attribution	13.2 Framing/reframing
7.1 Prompts/cues	7.3 Reduce prompts/cues
7.1 Prompts/cues	12.3 Avoidance/reducing exposure to cues for the behaviour
7.3 Reduce prompts/cues	12.3 Avoidance/reducing exposure to cues for the behaviour
7.4 Remove access to the reward	14.3 Remove reward
7.5 Remove aversive stimulus	14.10 Remove punishment
7.6 Satiation	11.4 Paradoxical instructions
7.7 Exposure	8.7 Graded tasks
8.1 Behavioural practice/rehearsal	8.7 Graded tasks
8.2 Behaviour substitution	8.4 Habit reversal
9.3 Comparative imagining of future outcomes	16.2 Imaginary reward
10.11 Future punishment	14.2 Punishment
14.1 Behaviour cost	14.2 Punishment
14.1 Behaviour cost	14.3 Remove reward
14.7. Reward incompatible behaviour	14.7. Reward alternative behaviour

Appendix 9

List of text messages that were sent to the participants in the intervention groups:

Prompt Goal-Setting (1.1):

1) Setting realistic but challenging goals can help you to progress. So, set yourself the goal to use an OFO bike tomorrow!
2) Set yourself the goal to use OFO bikes in the next two days.
3) How many times can you use OFO bikes over the next week? Set yourself a goal and challenge yourself!

Prompt Goal-Operating (1.4):

1) Make a plan detailing when and where you will use OFO bikes – e.g., next Wednesday to get to work.
2) Make plans about when you could use OFO bikes, such as at particular times or for particular journeys next week.
3) Make a plan to use OFO bikes this weekend.

Prompt Self-Monitoring (2.3):

1) Studies show that keeping track of progress can help people to achieve their goals. This is what the OFO app can do for you!
2) Monitoring your behaviour can help you to achieve your goals. Check your OFO app to see how often or how far you cycle.
3) Look at the "My Trips" section of the OFO app to see how often you have used OFO bikes.
4) Compare the number of times that you used OFO bikes this week with the number of times that you used them last week. How are you doing?
5) Did you check your trip records today on the OFO app?
6) Use the OFO app to look at the distance that you have cycled this week.
7) Your OFO app can help you to keep track of progress and therefore help you to achieve your goals.
8) Check your OFO app to see how often or how far you cycle. This information can help you to achieve your goals.
9) See how often you have used OFO bikes by looking at the "My Trips" section of the OFO app.

The schedule of the text messages sent:

Times of messages	**All three constructs**	**Self-monitoring only**
1st week		
Tuesday, 9 am	Set yourself the goal to use OFO bikes in the next two days.	Studies show that keeping track of progress can help people to achieve their goals. This is what the OFO app can do for you!
Thursday, 6 pm	Setting realistic but challenging goals can help	Look at the "My Trips" section of the OFO app to

	you to progress. So, set yourself the goal to use an OFO bike tomorrow!	see how often you have used OFO bikes
Sunday, 5 pm	How many times can you use OFO bikes over the next week? Set yourself a goal and challenge yourself!	Monitoring your behaviour can help you to achieve your goals. Check your OFO app to see how often or how far you cycle.
2nd week		
Tuesday, 6 pm	Make a plan detailing when and where you will use OFO bikes – e.g., next Wednesday to get to work	Did you check your trip records today on the OFO app?
Friday, 4 pm	Make a plan to use OFO bikes this weekend.	Use the OFO app to look at the distance that you have cycled this week.
Sunday, 6 pm	Make plans about when you could use OFO bikes, such as at particular times or for particular journeys next week.	Compare the number of times that you used OFO bikes this week with the number of times that you used them last week. How are you doing?
3rd week		
Tuesday, 9 am	Studies show that keeping track of progress can help people to achieve their goals. This is what the OFO app can do for you!	Your OFO app can help you to keep track of progress and therefore help you to achieve your goals.
Wednesday, 11 am	Look at the “My Trips” section of the OFO app to see how often you have used OFO bikes	See how often you have used OFO bikes by looking at the “My Trips” section of the OFO app.
Saturday, 3 pm	Monitoring your behaviour can help you to achieve your goals. Check your OFO app to see how often or how far you cycle.	Check your OFO app to see how often or how far you cycle. This information can help you to achieve your goals.

Appendix 10

List of text messages sent to deliver BCTs to decrease car use:

Prompt Goal Setting:

1) Set yourself the goal to cycle, walk, or use public transport instead of using your car to get to University one day next week!
2) Setting realistic but challenging goals can help you to progress. So, set yourself the goal to reduce the number of times you commute by car this week!
3) How many times can you skip using your car to commute to the university over the next week? Set yourself a goal and challenge yourself!

Action Planning:

4) Make plans about when you could not use your car to commute to the university next week - such as a particular day next week.
5) Plan when and how you will commute to the university next week without using your car – e.g. next Wednesday by catching the bus.
6) Make a plan detailing how to commute without your car next week, such as getting up earlier to walk or looking up for times for public transport.

Prompt Self-Monitoring:

7) Keep your old scratch cards to see how many times you have commuted to the university by car.
8) Studies show that keeping track of progress can help people to achieve their goals. You can use your scratch cards to keep track of your car use!
9) Monitoring your behaviour can help you to achieve your goals. Check your scratch card book to see how many times you commuted by car this week.

Schedule of the Text Messages:

Times of messages	**Three different BCTs in each week**
1st week	
Monday, 9 am	Setting realistic but challenging goals can help you to progress. So, set yourself the goal to reduce the number of times you commute by car this week.
Thursday, 6 pm	Plan when and how you commute to the university next week without using your car – e.g. next Wednesday by catching the bus.
Sunday, 5 pm	Studies show that keeping track of progress can help people to achieve their goals. You can use your scratch cards to keep track of your car use!
2nd week	
Tuesday, 6 pm	Set yourself the goal to cycle, walk, or use public transport instead of using your

	car to get to University one day next week!
Friday, 4 pm	Make plans about when you could skip using your car to commute to the university next week - such as at a particular time or day next week.
Sunday, 6 pm	Monitoring your behaviour can help you to achieve your goals. Check your scratch card book to see how many times you commuted by car this week.
3rd week	
Tuesday, 9 am	How many times can you skip using your car to commute to the university over the next week? Set yourself a goal and challenge yourself!
Wednesday, 11 am	Make a plan detailing how to commute without your car next week, such as getting up earlier to walk or looking up for times for public transport.
Saturday, 3 pm	Keep your old scratch cards to see how many times you have commuted to the university by car.

Appendix 11

Table 2.4

PRISMA Checklist for the Meta-analysis in Chapter 2

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	p. 40
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	p. 40
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	p. 41-44
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	p. 44
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	p. 46
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.	p. 46

Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	p. 46
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.	p. 46-47
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.	p. 47
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.	p. 47-48
	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.	p. 47-48
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.	p. 48-49
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.	p. 48
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)).	p. 46
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	p. 48
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	n.a.

	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.	p. 48
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	p. 49
	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).	p. 49
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	p. 48
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.	p. 49 & p. 168
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	n.a.
Study characteristics	17	Cite each included study and present its characteristics.	p. 169-174
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	n.a.
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. 169 – 174

Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	p. 175 - 178
	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.	p. 175 – 178
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	p. 49 & p. 175 – 178
	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.	p. 50
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	p. 51
	23b	Discuss any limitations of the evidence included in the review.	p. 55-56
	23c	Discuss any limitations of the review processes used.	p. 55-56
	23d	Discuss implications of the results for practice, policy, and future research.	p. 54-56
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	p. 49
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	p. 49

	24c	Describe and explain any amendments to information provided at registration or in the protocol.	n.a.
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	p. 49
Competing interests	26	Declare any competing interests of review authors.	n.a.
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.	p. 49

Appendix 12

Table 4.6

CONSORT 2010 checklist of information for Chapter 4 – Study 1 to include when reporting a randomised trial

Section/Topic	Item No	Checklist Item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	p. 73
	1b	Structured summary of trial design, methods, results, and conclusions	p. 73-74
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	p. 74-80
	2b	Specific objectives or hypotheses	p. 80-81
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	p. 85
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	p. 83
Participants	4a	Eligibility criteria for participants	p. 82
	4b	Settings and locations where the data were collected	p. 82

Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	p. 84-86
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	p. 84
	6b	Any changes to trial outcomes after the trial commenced, with reasons	n.a.
Sample size	7a	How sample size was determined	p. 82
	7b	When applicable, explanation of any interim analyses and stopping guidelines	n.a.
Randomization			
Sequence generation	8a	Method used to generate the random allocation sequence	p. 85
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	p. 85
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	p. 85
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	p. 85
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	p. 85
	11b	If relevant, description of the similarity of interventions	p. 86
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	p. 86
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	p. 86-87
Results			

Participant flow	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	p. 83-84
	13b	For each group, losses and exclusions after randomisation, together with reasons	p. 83-84
Recruitment	14a	Dates defining the periods of recruitment and follow-up	p. 82
	14b	Why the trial ended or was stopped	p. 82-83
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	p. 83
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	p. 87
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	p. 87-88
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	n.a.
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	p. 88-90
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms [28])	n.a.
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	p. 91
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	p. 91
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	p. 91
Other information			

Registration	23	Registration number and name of trial registry	n.a.
Protocol	24	Where the full trial protocol can be accessed, if available	n.a.
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	n.a.

Appendix 13

Table 4.7

CONSORT 2010 checklist of information for Chapter 4 – Study 2 to include when reporting a randomised trial

Section/Topic	Item No	Checklist Item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	p. 73
	1b	Structured summary of trial design, methods, results, and conclusions	p. 73-74
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	p. 92-93
	2b	Specific objectives or hypotheses	p. 93
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	p. 94
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	n.a.
Participants	4a	Eligibility criteria for participants	p. 94
	4b	Settings and locations where the data were collected	p. 94

Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	p. 197-198
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	p. 93
	6b	Any changes to trial outcomes after the trial commenced, with reasons	n.a.
Sample size	7a	How sample size was determined	p. 92
	7b	When applicable, explanation of any interim analyses and stopping guidelines	n.a.
Randomization			
Sequence generation	8a	Method used to generate the random allocation sequence	p. 94-95
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	p. 94
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	p. 94-95
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	p. 94-95
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	p. 94-95
	11b	If relevant, description of the similarity of interventions	n.a.
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	p. 94

	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	p. 94-95
Results			
Participant flow	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	p. 95
	13b	For each group, losses and exclusions after randomisation, together with reasons	p. 94
Recruitment	14a	Dates defining the periods of recruitment and follow-up	p. 94
	14b	Why the trial ended or was stopped	p. 94
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	p. 93
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	p. 94
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	p. 94
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	n.a.
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	n.a.
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms [28])	n.a.
Discussion			

Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	p. 95-96
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	p. 95-96
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	p. 95-96
Other information			
Registration	23	Registration number and name of trial registry	n.a.
Protocol	24	Where the full trial protocol can be accessed, if available	n.a.
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	n.a.

Appendix 14

Table 4.8

CONSORT 2010 checklist of information for Chapter 4 – Study 3 to include when reporting a randomised trial

Section/Topic	Item No	Checklist Item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	p. 73
	1b	Structured summary of trial design, methods, results, and conclusions	p. 73-74
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	p. 95-96
	2b	Specific objectives or hypotheses	p. 96-97
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	p. 97
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	p. 97
Participants	4a	Eligibility criteria for participants	p. 97
	4b	Settings and locations where the data were collected	p. 97

Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	p. 199-200
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	p. 98
	6b	Any changes to trial outcomes after the trial commenced, with reasons	p. 97
Sample size	7a	How sample size was determined	p. 98
	7b	When applicable, explanation of any interim analyses and stopping guidelines	n.a.
Randomization			
Sequence generation	8a	Method used to generate the random allocation sequence	p. 97
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	p. 97
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	p. 897
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	p. 99-100
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	p. 99-100
	11b	If relevant, description of the similarity of interventions	p. 99-100
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	p. 98-99

	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	p. 98-99
Results			
Participant flow	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	p. 97
	13b	For each group, losses and exclusions after randomisation, together with reasons	p. 97
Recruitment	14a	Dates defining the periods of recruitment and follow-up	p. 98
	14b	Why the trial ended or was stopped	p. 98
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	p. 100
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	p. 100-101
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	p. 100-101
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	n.a.
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	p. 101
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms [28])	n.a.
Discussion			

Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	p. 104-105
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	p. 103-105
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	p. 103-105
Other information			
Registration	23	Registration number and name of trial registry	n.a.
Protocol	24	Where the full trial protocol can be accessed, if available	n.a.
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	n.a.