ANGLIA RUSKIN UNIVERSITY

FACULTY OF HEALTH, EDUCATION, MEDICINE AND SOCIAL CARE

INVESTIGATING DIGITAL BEHAVIOUR CHANGE INTERVENTIONS FOR PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR IN SOCIALLY ISOLATED OLDER ADULTS

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A thesis in partial fulfilment of the requirements of Anglia Ruskin University for the degree of Doctor of Philosophy

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ABSTRACT

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Many older adults, especially those who are socially isolated, are insufficiently physically active and spend prolonged periods of time engaging in sedentary behaviours. Social isolation, insufficient physical activity (PA) and increased sedentary behaviour (SB) are independently associated with negative health outcomes. Traditional PA/SB interventions have achieved limited success, particularly in the long term, therefore novel interventions are required.

This thesis followed the Medical Research Council (MRC) guidance on complex intervention development and used the Behaviour Change Wheel (BCW) to make recommendations for a digital behaviour change intervention (DBCI) for PA/SB in socially isolated older adults. This included undertaking four studies that addressed the three stages of the development phase of the MRC guidance.

First, a systematic review and meta-analysis (n = 22 studies) found DBCI were effective in increasing total PA and moderate-to-vigorous PA by 52min/week, and reduced SB by 58min/day in older adults (≥ 50 years). A minimum of three behaviour change technique (BCT) clusters were found to increase efficacy of the DBCI, including social support, goal setting, feedback on behaviour and self-monitoring. Second, an analysis of data from the English Longitudinal Study of Ageing, found over two thirds of socially isolated older adults used the internet/email at least once a week and were more likely to access it via a laptop than any other device. Non-linear relationships were found between frequency of use and social isolation. Third, semi-structured interviews highlighted that socially isolated older adults preferred individual/small-group PA that they could undertake either at home or from their home, and their physical capabilities prevented them from engaging in certain types of PA. Fourth, socially isolated older adults' experiences of using two commercially available DBCI for PA/SB, and their ideas for future DBCI for PA/SB, were explored via semi-structured interviews. Generally, participants enjoyed using the DBCI and found it useful for increasing their PA, but they require a DBCI that is better tailored to their needs.

The aim of this thesis was to use the MRC guidance on developing and evaluating complex interventions, in combination with the BCW, to make recommendations for the design of a DBCI for PA and/or SB in socially isolated older adults.

Key words: social isolation, older adult, digital behaviour change interventions, physical activity, sedentary behaviour

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Publications and conference proceedings

Publications relating to this thesis

Stockwell, S., Stubbs, B., Jackson, S.E., Fisher, A., Yang, L. and Smith, L. (2020). Internet use, social isolation and loneliness in older adults. Ageing and Society, 1-24. doi.org/10.1017/S0144686X20000550.

To date this paper has been cited once and has an altmetric score of 151. Ageing and Society is a Q1 journal and has an impact factor of 2.04.

Stockwell, S., Schofield, P., Fisher, A., Firth, J., Jackson, S.E., Stubbs, B. and Smith, L. (2019). Digital behavior change interventions to promote physical activity and/or reduce sedentary behavior in older adults: A systematic review and meta-analysis. Experimental Gerontology 120, 68-87. doi.org/10.1016/j.exger.2019.02.020.

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Stockwell, S., Trott, M., Tully, M., Shin, J.I., Barnett, Y., Butler, L.T., McDermott, D. and Smith, L. (In Press). Changes in physical activity and sedentary behaviours from before to during the COVID-19 pandemic lockdown: A Systematic Review. *BMJ Open Sport & Exercise Medicine.*

BMJ Open Sport & Exercise Medicine is a Q2 journal and has an impact factor of 1.51.

Olanrewaju, O., **Stockwell, S.**, Stubbs, B. and Smith, L. (2020). Sedentary behaviours, cognitive function, and possible mechanisms in older adults: a systematic review. *Aging Clinical and Experimental Research.* doi.org/10.1007/s40520-019-01457-3.

To date this paper has been cited seven times and has an altmetric score of 9. Aging Clinical and Experimental Research is a Q2 journal and has an impact factor of 2.37

Stockwell, S.L., Smith, L.R., Weaver, H.M., Hankins, D.J. and Bailey, D.P. (2019). Associations of Sitting Behavior Patterns with Cardiometabolic Risk in Children: The Sit Less for Health Cross-Sectional Study*. Journal of Physical Activity and Health*, 1-7. doi.org/10.1123/jpah.2018-0469.

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Smith, L., **White, S.,** Stubbs, B., Hu, L., Veronese, N., Vancampfort, D., Hamer, M., Gardner, B. and Yang, L. (2018). Depressive symptoms, handgrip strength, and weight status in US older adults. *Journal of Affective Disorders*, 238, 305-310. doi.org/10.1016/j.jad.2018.06.016.

To date this paper has been cited 24 times and has an altmetric score of 8. The Journal of Affective Disorders is a Q1 journal and has an impact factor of 1.95.

Champion, R.B., Smith, L.R., Smith, J., Hirlav, B., Maylor, B.D., **White, S.L.** and Bailey, D.P. (2018). Reducing prolonged sedentary time using a treadmill desk acutely improves cardiometabolic risk markers in male and female adults*. Journal of Sports Sciences*, 1-8. doi.org/10.1080/02640414.2018.1464744.

To date this paper has been cited 11 times and has an altmetric score of 14. The Journal of Sport Sciences is a Q1 journal and has an impact factor of 1.20.

List of abbreviations

BCTs – Behaviour Change Techniques

BCW – Behaviour Change Wheel

BMI – Body Mass Index

CI – Confidence Interval

DBCI – Digital Behaviour Change Intervention

DBP – Diastolic Blood Pressure

ELSA – English Longitudinal Study of Ageing

GB – Great Britain

HDL – High Density Lipoproteins

HR – Heart rate

ICT – Information Communication Technologies

IMD – Indices of Multiple Deprivation

IPAQ-SF – International Physical Activity Questionnaire – Short Form

IQR – Interquartile Range

JBI – Joanna Briggs Institute

LDL – Low Density Lipoproteins

METs – Metabolic Equivalent Tasks

MD – Mean Difference

MRC – Medical Research Council

MVPA – Moderate to Vigorous Physical Activity

NCD – Non-communicable Disease

NHS – National Health Service

OR – Odds Ratio

PA – Physical Activity

PAR – The Stamford 7-day Physical Activity Recall questionnaire

PPI – Patient and Public Involvement

QoL – Quality of Life

QR Code – Quick Response code

RAPA – Rapid Assessment of Physical Activity

RCTs – Randomised Controlled Trials

RoB – Risk of Bias

SB – Sedentary Behaviour

SBP – Systolic Blood Pressure

SD – Standard Deviation

SES – Socioeconomic Status

SMD – Standardised Mean Difference

SMS – Short Message Service

SPPB – Short Physical Performance Battery

T2DM – Type 2 Diabetes Mellitus

TC – Total Cholesterol

TV – Television

UCLA – University of California Los Angeles

UK – United Kingdom

USA – United States of America

VR – Virtual Reality

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Thank you very much for your email. You do have permission to publish your paper as part of your PhD thesis.

Best regards
Miles

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CHAPTER 1: INTRODUCTION

This chapter outlines the physical, mental, cognitive and social changes that are associated with the natural aging process, particularly in socially isolated older adults, and the impact of these changes on their health. It considers how increasing physical activity (PA) and reducing sedentary behaviour (SB) can help attenuate some of these health risks. This chapter highlights some of the issues with traditional PA interventions for older adults and makes a case for the need to develop a new digital behaviour change intervention (DBCI), specifically for those who are socially isolated. Finally, the process of intervention design using the Medical Research Council (MRC) guidance and behaviour change wheel (BCW) is described.

1.1. Ageing population

Population ageing is a global phenomenon, with older adults making up a substantial and growing proportion of the population. Older adults (age ≥ 50 years old) comprise 39% of the population in England and Wales and life expectancies are projected to continue to increase (Office for National Statistics, 2017). The per person financial cost to the National Health Service (NHS) increases beyond the age of 50 years, escalates further after age 70, with the average cost per year for an 89 year old person being nine times that of a 50 year old person (Kelly, Stoye and Vera-Hernandez, 2015). The proportion of the population that uses hospital services also increases with age. For instance in 2010-2011 64% of 80 year olds received hospital care compared with 30% of 40 year olds (Kelly, Stoye and Vera-Hernandez, 2015). This growth in the ageing population has consequences for health systems that struggle to cope with the increasing demand.

The term ‘older adult’ lacks a consistent definition. Throughout the literature, older adults may be defined as those ≥ 50 years old (The Register of Exercise Professionals, 2010) (Dobrosavljevic, et al., 2020), ≥ 55 years old (Petry, 2002, Stenner, Buckley and Mosewich, 2019, Olanrewaju, et al., 2016), ≥ 60 years old (World Health Organisation, 2018a) (Notthoff, Reisch and Gerstorf, 2017), ≥ 65 years (Office for National Statistics, 2018b) (Age UK, 2019). Many councils provide PA and leisure programmes for older adults aged ≥ 50 years (Tower Hamlets Council, 2020, Hackney Council, 2020, Oxford City Council, 2020). As the physical ageing process begins around the age of 40, by the age of 50 many people require exercise to be adapted to account for changes in the musculoskeletal, cardiovascular and neuromuscular systems (The Register of Exercise Professionals, 2010). The aim of this thesis is to engage a target population in PA, therefore older adults are defined as people aged ≥ 50 years old.

1.1.1. Ageing and health

Despite people today living longer than previous generations, quality of life and health are not guaranteed to be better (Beard, et al., 2016) and many are living more years with disability (James, et al., 2018, Murray, et al., 2012). To complete everyday tasks such as climbing stairs, many older adults' function close to their maximum capacity, meaning that further decline or physical setback could increase their risk of falling and/or becoming dependent on carers (Rikli, 1999, Deandrea, et al., 2010). The process of ageing leads to changes in physical health, mental and cognitive health, and changes in one's social environment, which, in turn, can lead to adverse health outcomes.

The natural ageing process leads to structural and functional decline in musculature, cardiorespiratory systems, body composition and metabolism (Chodzko-Zajko, et al., 2009). Sarcopenia, the age-related loss of skeletal muscle mass and quality, is a leading cause of functional decline and disability (Rosenberg, 1997, Morley, et al., 2001, Lauretani, et al., 2003, Doherty, 2003). The loss of muscle mass and functional decline have been linked to underlying muscle strength (Visser, et al., 2005). After the age of 50 years old, the average rate of muscle mass loss per year is 1-2% (Lauretani, et al., 2003, Doherty, 2003), which translates to approximately a 1.5% annual decline in muscle strength between the ages of 50-60 years old, increasing to 3% in ages 60 and over (von Haehling, Morley and Anker, 2010). Independent of age in both males and female, however, low muscle strength and power have been strongly associated with poor mobility (Lauretani, et al., 2003). Muscle atrophy not only affects mobility and locomotion, but it can also impair other physiological functions such as glucose regulation, hormone production and cellular communication (Moon, 2014, Buford, et al., 2010), which in turn influences risk markers for non-communicable diseases (NCDs), particularly obesity, diabetes, and cardiovascular disease. This is significant because NCDs, such as cardiovascular disease, diabetes, certain cancers and chronic respiratory diseases, are the leading cause of death in older age globally (Beard, et al., 2016).

As populations are living longer, the number of people with age-associated neurodegenerative dementias and cognitive decline is increasing (Murman, 2015). Normal ageing is associated with declines in attention, memory, executive cognitive function, processing speed, reasoning and visuospatial abilities, which are correlated with structural and functional changes in the brain (Harada, Natelson Love and Triebel, 2013). Cognitive decline can also be a risk factor for the development of NCDs such as diabetes and cardiovascular disease (Deary, et al., 2009). In addition to the effects on physical health, ageing has been associated with an increased risk of depressive symptoms (Alexopoulos, 2005). Elevated depressive symptoms have been associated with a steep trajectory of increasing functional disability in older adults aged 65 and older (Lenze, et al., 2005, Lenze, et al., 2001). Depression has been shown to be associated with handgrip strength, a measure of physical functioning, in older adults (Gale, et al., 2011). This indicates a cyclical relationship of spiralling health decline between depression and physical functioning (Kelley-Moore and Ferraro, 2005). Ageing is also associated with an increased risk of multimorbidity, where a person has more than one disorder or condition simultaneously, which may lead to interactions and complications between disorders (Beard, et al., 2016). This suggests a complex interaction exists between cognitive and physical factors associated with functional decline and ageing. For instance, decline in walking speeds in participants aged 70 years and over with intact cognition has been found to be a potential early marker for mild cognitive impairment (Dodge, et al., 2012). Maintaining physical health impacts older adults' quality of life and ability to live independently (Sazlina, et al., 2012), and intact cognition is also important in older adults for maintaining functional independence and the ability to effectively communicate with other people (Murman, 2015).

1.2. Social isolation, loneliness and ageing

Older adults are at greater risk of social isolation due to life changes that occur simultaneously or in a short space of time, such as retirement, decreased finances, mobility impairments, and changes in social networks (Steptoe, et al., 2013b). The death of friends and family, retirement, relocation, limitations in physical and mental health may lead to social isolation and feelings of loneliness in older adults (Cotten, Anderson and McCullough, 2013, Courtin and Knapp, 2017).

Social isolation refers to the objective status of a person's social relationships including network size, diversity and frequency of contact, whereas loneliness refers to the subjective psychological experience of the gap between a person's desired and actual levels of social contact (Cacioppo, et al., 2011, Hawkley and Cacioppo, 2007, Steptoe, et al., 2013b, Kobayashi and Steptoe, 2018, Shankar, et al., 2011, Age UK, 2018b, Perlman and Peplau, 1984, Peplau, 1985, Peplau and Perlman, 1982). Although the two constructs have been shown to be positively correlated (Petersen, et al., 2016a, Steptoe, et al., 2013b, Cornwell and Waite, 2009a, Shankar, et al., 2011), persons who are socially isolated may not experience loneliness and loneliness may occur without social isolation (Kobayashi and Steptoe, 2018, Cornwell and Waite, 2009b, de Jong Gierveld and Havens, 2004, Beneito-Montagut, Cassián-Yde and Begueria, 2018, Coyle and Dugan, 2012, Hawkley and Cacioppo, 2007, Hawkley and Cacioppo, 2010, Perlman and Peplau, 1984, Peplau, 1985). This thesis focuses on socially isolated older adults, but due to the two constructs often being confused in the public domain, and reported together within the literature, it is necessary at points within this thesis to also report on loneliness.

Prevalence estimates of loneliness among older adults (60-80 years) in Europe range from 8.1% to 46.8% (Hansen and Slagsvold, 2016). Results from the English Longitudinal Survey of Ageing reported that in 2016/17, 6.8% of older adults (aged ≥ 50 years) are often lonely, and 24.2% are lonely some of the time (Age UK, 2018a). It is estimated that up to 30% of older adults (≥50 years) in Europe are socially isolated (Cantarero-Prieto, Pascual-Sáez and Blázquez-Fernández, 2018). Of older adults aged ≥ 65 years in Great Britain in 2001, between 11-17% are socially isolated (Age UK, 2012, Victor, et al., 2002). There are no up to date figures available on the prevalence of social isolation in older adults aged ≥50 years in the UK. The work in chapter four contributes to knowledge by updating these figures.

1.2.1 Social isolation, loneliness and health

Social isolation and loneliness are important issues because they are reciprocally related to health and wellbeing; that is, they are both a risk factor for and a consequence of poor health (Hawkley, 2017). For instance, a scoping review found both social isolation and loneliness can detrimentally affect the physical and mental health of older adults (Courtin and Knapp, 2017). Conversely, physical and mental health problems can lead to increased risk of social isolation and/or loneliness (Fokkema and Knipscheer, 2007). The health risks associated with social isolation and loneliness are many and varied and may be mediated by negative effects on health behaviours (Lauder, et al., 2006).

1.2.1.1. Social isolation and health outcomes

Social isolation is a predictor of mortality, independent of loneliness (Steptoe, et al., 2013b). Older adults (≥50 years) in the UK who are socially isolated had a 73% greater risk of all-cause mortality than those not socially isolated, even when adjusted for age, sex, ethnicity, chronic disease (Elovainio, et al., 2017). This reduced to 26% greater risk when further adjusted for socioeconomic factors, health-related behaviours, depression, biological factors, cognitive performance and self-rated health (Elovainio, et al., 2017). Social isolation has been independently associated with cardiovascular disease risk in older adults (Leigh-Hunt, et al., 2017, Grant, Hamer and Steptoe, 2009) and is associated with increases in systolic and diastolic blood pressure (Shankar, et al., 2011). Socially isolated older adults have a 24% increased risk of mortality from circulatory system diseases, a 32% increased risk of mortality from cancer, and a 22% increased risk of mortality from other causes (Elovainio, et al., 2017). People who are socially isolated have a 20% increased risk of being diagnosed with multiple chronic illnesses, and are likely to be older, be physically inactive, have a lower education level and a lower quality of life (Cantarero-Prieto, Pascual-Sáez and Blázquez-Fernández, 2018). Interventions targeting older adults who are socially isolated are required to attenuate these increased risk factors.

1.2.1.2. Loneliness and health outcomes

Like social isolation, loneliness is associated with increased risk of premature all-cause mortality in older adults (Perissinotto, Stijacic Cenzer and Covinsky, 2012, Luo, et al., 2012, Rico-Uribe, et al., 2018). Compared with never lonely older adults, those who reported often feeling lonely had a 130% increased risk of cardiovascular disease risk and 22% increased risk of ischemic heart disease, even when controlling for age and sex (Patterson and Veenstra, 2010). Loneliness is also an independent risk factor for cognitive decline in older adults, for instance poorer cognitive performance, hastened cognitive decline, poorer executive functioning, slower processing speed and poorer memory (Cacioppo and Hawkley, 2009, Boss, Kang and Branson, 2015, Wilson, et al., 2007). It is also associated with 17% higher odds of having a mental health condition in older adults (≥ 50 years) (Coyle and Dugan, 2012). Interventions targeting older adults who are lonely are needed to reduce these increased risk factors.

1.3. Physical activity and health in older adults

PA can help attenuate the health risks associated with ageing, social isolation, and loneliness. PA is defined as any bodily movement produced by skeletal muscles that results in energy expenditure (World Health Organisation, 2018b, Caspersen, Powell and Christenson, 1985). In 2013-14, physical inactivity cost the NHS an estimated £455m a year (Public Health England, 2016) and contributes to 1 in 6 deaths in the UK (Public Health England, 2020).

1.3.1. Physical activity guidelines

The recommendations for PA among people aged ≥50 years span across two age categories: 19-64-year olds and ≥65-year olds (Department for Health and Social Care, 2019). Adults aged 19-64 should accumulate 150 minutes per week of moderate intensity PA, or 75 minutes per week of very vigorous exercise, which can be achieved in bouts of any length whilst still leading to health benefits (Department for Health and Social Care, 2019) (Figure 1). In addition, adults should undertake resistance training activities at least twice a week to increase or maintain muscle strength (Department for Health and Social Care, 2019). The guidelines for those aged ≥65-year olds are the same but also include doing activities that maintain physical function aimed at improving or maintaining balance and flexibility on two days per week (Department for Health and Social Care, 2019). In addition, the ≥65-years guidelines mention the importance of weight bearing PA to maintain bone health and they highlight that light intensity PA is better than none.

PA has been shown to significantly reduce the risks of chronic diseases and physical and cognitive decline, which are independently associated with ageing, social isolation and loneliness (Chodzko-Zajko, et al., 2009, Deary, et al., 2009). Regular and sustained participation in PA and reductions in time spent sedentary have been found to be associated with healthy ageing, greater independent living and quality of life in older adults (Smith, et al., 2015, Westerterp, 2000, Daskalopoulou, et al., 2017, Tak, et al., 2013, Gomes Neto and Castro, 2012, Acree, et al., 2006).

Figure 1. Physical activity guidelines for adults and older adults (Department for Health and Social Care, 2019).

1.3.2. Physical activity and physical health

PA is influential in the prevention and/or management of NCDs (Global Advocacy for Physical Activity and the Advocacy Council of the International Society for Physical Activity and Health, 2012). Low levels of PA are associated with multiple NCDs such as musculoskeletal, respiratory, heart, circulatory, digestive, and kidney/bladder/urinary conditions in older adults (Chad, et al., 2005, Wirth, et al., 2017). Negative relationships have been independently found between PA and the occurrence of coronary heart disease, type 2 diabetes mellitus (T2DM), in a systematic review of longitudinal studies (N = 15; n = 288,724) (Reiner, et al., 2013). Higher levels of PA are associated with healthy ageing (Daskalopoulou, et al., 2017) and are protective against ageing-related decline in physical function (Tak, et al., 2013). A comprehensive review of 'exercise as medicine' literature suggests that exercise can be beneficial in the prevention and treatment of cardiovascular, pulmonary, metabolic, neurological and psychiatric diseases, musculoskeletal disorders and cancers (Pedersen and Saltin, 2015), of which many are associated with ageing. Resistance training has been shown to improve older adults' (65 – 72 years old) sense of strength, endurance, balance and coordination, which positively affected their physical and mental functioning (Dionigi, 2007). This highlights the importance of increasing or maintaining levels of PA, in line with the Government guidance, for physical health outcomes in older adults.

1.3.3. Physical activity and cognitive and mental health

PA has beneficial effects on cognitive function in older adults, particularly relating to motor function, cognitive speed, auditory and visual attention (Angevaren, et al., 2008). Higher levels of PA have been associated with a decreased risk of cognitive decline and dementia in adults ≥ 65 years old (Blondell, Hammersley-Mather and Veerman, 2014). These positive effects of PA on cognition are also found in older adults (≥ 55 years) with mild cognitive impairment (Olanrewaju, et al., 2016), suggesting these benefits are not just for cognitively healthy older adults. In addition to the cognitive benefits, regular engagement in PA has been associated with significant improvements in psychological well-being and reduced depression and anxiety symptoms (Chodzko-Zajko, et al., 2009). Older adults (≥ 50 years) who are more physically active tend to have higher levels of psychological well-being (Chad, et al., 2005). Resistance training has been shown to increase older adults' psychological well-being as the physical changes that occur are often linked with increased self-worth and self-esteem (Dionigi and Cannon, 2009). This highlights further the complex interaction of physical, cognitive and mental health, and that PA can provide beneficial effects across them all, whether directly or indirectly.

1.3.4. Physical activity prevalence

Regular and sustained engagement in PA has the potential to improve physical health, mental and cognitive health, quality of life (QoL) and independence in older adults (Smith, et al., 2015, Daskalopoulou, et al., 2017, Chad, et al., 2005, Tak, et al., 2013). Despite these benefits, ageing is associated with lower levels of aerobic PA and strength training (Wilcox, 2016, Chad, et al., 2005), and many older adults fail to meet guidelines for PA. People who fail to meet these guidelines can be described as physically inactive (Sedentary Behaviour Research Network, 2012). The Active Lives survey 2019/20 found that only 55% older adults (aged ≥ 55 years) met the government recommendations of at least 150 minutes of moderate PA per week, with 12.5% completed between 30-149 minutes per week and 32.5% completed < 30 minutes PA per week (Sport England, 2020). A trend in decline of overall PA and functional fitness levels has been shown in the natural ageing process (Milanović, et al., 2013); however, there is also a change in intensities of physical activities associated with ageing (Chodzko-Zajko, et al., 2009). Light PA and inactivity have been shown to increase while levels of moderate and vigorous PA decrease with ageing (Smith, et al., 2015). Social isolation has also been associated with decreased PA in older adults (Engberg, et al., 2012). Therefore, targeting older adult populations, particularly those who are socially isolated, for PA intervention is important.

1.4. Sedentary behaviour and health in older adults

Whilst being physically active can attenuate health risks associated with ageing and with social isolation and loneliness in older adults, reducing sedentary behaviour (SB) is also important. SB is defined as any waking behaviour characterised by an energy expenditure value of ≤ 1.5 Metabolic Equivalent Tasks (METs) whilst in a sitting or reclining posture (Sedentary Behaviour Research Network, 2012, Tremblay, et al., 2017). Guidelines on SB for adults and older adults suggest minimising time spent being sedentary, and when possible, long periods of inactivity should be broken up with light intensity PA or at least standing up (Department for Health and Social Care, 2019). It has been estimated that in the UK during 2016, prolonged SB cost the NHS £677 million and contributed to 69,276 deaths that may have been avoided if prolonged SB had been eliminated (Heron, et al., 2019).

1.4.1. Sedentary behaviour and physical health

Greater time spent in SB is associated with an increased risk of mortality in older adults (≥60 years) (de Rezende, et al., 2014). Increased total sitting time (≥10 hours/day total sitting time) is associated with a 65% higher risk of all-cause mortality and a 115% increased risk of cardiometabolic disease mortality risk than those who sit for less than 4 hours/day (Chau, et al., 2015). In old age, SB has been positively associated with Body Mass Index (BMI), fat mass, total cholesterol (TC), low-density lipoproteins (LDL) and insulin levels and negatively associated with high-density lipoprotein (HDL) (Wirth, et al., 2017). Self-reported SB and time spent watching television (TV) were associated with waist circumference, BMI and cholesterol ratio (TC:HDL) (Stamatakis, et al., 2012a). These biomarkers are risk factors for many NCD's suggesting that excessive SB is associated with such conditions in older adults (Wirth, et al., 2017).

Repeated bouts of prolonged SB, measured objectively using an Actigraph accelerometer, were shown to be adversely associated with bone mineral density of the total femur and all hip sub-regions in women, independent of their moderate-to-vigorous physical activity (MVPA); no association was found in men (Chastin, et al., 2014b). This suggests that reducing SB in older women is particularly important for maintaining bone health. During long periods of sedentary time, a lack of movement can result in increased joint stiffness and pain, potentially making it more challenging and discouraging for older adults to stand or break up their sedentary time; however, sometimes stiffness can act as motivation to move (Hirvensalo, Rantanen and Heikkinen, 2000, Seguin, et al., 2012, Gennuso, et al., 2013, Chastin, et al., 2014a). Older adults (≥ 65 years) who self-rated their health as very good/good spent proportionally less time of their day engaged in SB than those who rated their health fair (-3.56%) and bad/very bad (-5.66%) (Wilson, et al., 2019). From this study it is unclear whether the older adults' poor health results in greater SB, or whether greater SB leads to poorer health. However, objectively measured SB has been found to be negatively associated with physical function, both measured using the Short Physical Performance Battery (SPPB) and self-reported physical function, and increased fear of falling in older adults living in retirement communities (Rosenberg, et al., 2016). This suggests that prolonged SB has negative physical health outcomes for older adults, and that poor health has the potential to increase the likelihood of prolonged SB.

1.4.2. Sedentary behaviour and cognitive and mental health

As with PA, SB can affect older adults' cognitive and mental health. A systematic review of adults (aged ≥40 years) suggested that SB was associated with lower cognitive performance (N = 8; n = 13,873) (Falck, Davis and Liu-Ambrose, 2017); however, a recent review found varied and inconclusive evidence of the relationship between SB and cognitive function in older adults (mean age ≥ 65 years) (Olanrewaju, et al., 2020). Older adults (≥ 65 years) with depression spend an increased amount of time – 36 min/day – in SB than their non-depressed peers (Stubbs, et al., 2018). This suggests that a reduction in SB may positively impact depressive symptoms in older adults. Indeed, in older adults (aged 65-85), replacing 30min of SB per day with light PA has favourable effects on depression scores (Yasunaga, et al., 2018).

1.4.3. Sedentary behaviour prevalence

Older adults (≥ 65 years) spend an average of 14.2 hours/day engaging in SB (Leask, et al., 2015), and research has shown that older adults aged ≥65 years old spend between 62%-86% of their waking day in SB (Gorman, et al., 2014). Older adults (≥ 65 years) also spend a larger proportion of their total sedentary time in bouts ≥30 min (women 33%, men 39%), compared to adolescents and adults (Santos, et al., 2018). Therefore, interventions targeting SB, specifically prolonged SB, and replacing it with PA may be beneficial for older adults.

When objectively measured, approximately 65-80% of an older adults (aged ≥ 60 years old) waking day (9.4 hours/day) is spent in SB; however according to self-reported data the average amount of time is 5.3 hours/day (Harvey, Chastin and Skelton, 2015). This disparity between individuals' perceptions of and their actual SB may impact intervention design and could be utilised within an intervention itself. Older adults (aged ≥ 65 years old) spend 22.9% of non-screen time in social or cognitively demanding sedentary activities such as reading (Leask, et al., 2015), which have been found to be positively associated with mental health benefits (Stamatakis, et al., 2012a, Chastin, et al., 2014a). TV viewing has been found to correlate with negative health outcomes but is also associated with other unhealthy habits such as consumption of unhealthy food and drinks; these behaviours could compound the negative health effects associated with watching TV (Stamatakis, et al., 2012b). Therefore, targeting passive SB particularly of long-bout duration, such as TV watching, may be beneficial for health and well-being of older adults.

1.5. Socially isolated older adults' physical activity and sedentary behaviours

The health risks associated with social isolation are numerous and diverse and may also be due to having a negative effect on health behaviours, such as PA and SB (Lauder, et al., 2006). For instance, people who are socially isolated are less likely to consistently engage in MVPA at least once a week and are more likely to be overweight or obese and to smoke (Kobayashi and Steptoe, 2018). Older adults aged ≥ 50 years who are socially isolated are less likely to be physically active than those who are not socially isolated, independent of gender, age, socioeconomic status, marital status, smoking, alcohol consumption, self-rated health, limiting longstanding illness, mobility limitations, depressive symptoms and loneliness (Schrempft, et al., 2019). In addition, sedentary time during the day and in the evenings has been found to be greater in older adults who were socially isolated (Schrempft, et al., 2019). A systematic review (N = 27; n = 56,245) found moderate support that older adults who have greater social support for PA, especially from family members, are more likely to engage in PA; and support from friends is important for leisure-time PA (Lindsay Smith, et al., 2017). Therefore PA/SB interventions for older adults who are socially isolated are urgently required to help improve the health outcomes in this at-risk population.

Before interventions can be designed, however, it is important to understand why socially isolated older adults do not engage in PA (barriers), and conversely, what motivates them to engage in PA and spend less time in SB (facilitators). Behaviour change interventions that are underpinned by theory, for instance by completing a needs assessment, are likely to be more effective than those without a theory basis (Michie, et al., 2009). The needs assessment enables intervention designers to identify appropriate behaviour change theory for use in the interventions they design (Michie, Atkins and West, 2014). This can involve the identification of the barriers and facilitators the target population experience in relation to the target behaviour.

The barriers and facilitators to PA have been reported extensively in the literature for older adults generally, however not for those who are socially isolated. This gap in the literature is addressed in chapter five and contributes to advancing knowledge in this area of research. This is therefore an important stage within the design of a new behaviour change intervention, but is often overlooked or given inadequate time, meaning there are a plethora of atheoretical PA/SB interventions within the literature (McEwan, et al., 2018). It is important to note, however, that although atheoretical interventions may not be guided explicitly by theory, many are created using a 'common sense' approach to change behaviours and happen to include BCTs, which may help to explain why, in the literature, both theoretical and atheoretical PA interventions have comparable effects on PA (McEwan, et al., 2018, Prestwich, et al., 2014). Therefore, it is worthwhile noting the theoretical underpinnings of PA interventions, and also coding the behaviour change techniques (BCTs) from the intervention description if not explicitly stated by the authors, in the evaluation of PA interventions. A BCT is an 'active ingredient' of a behaviour change intervention that is observable, replicable and irreducible (e.g. feedback, self-monitoring), which can be used alone or in conjunction with other BCTs (Michie, Atkins and West, 2014).

1.6. Physical activity and sedentary behaviour interventions in older adults

Evidence is still limited and inconclusive as to the effectiveness of interventions to reduce SB in older adults. Although some show significant reductions in SB over short periods of time, the number of studies and sample sizes are small and of low methodological quality, therefore, more studies investigating SB interventions in older adults are needed (Aunger, Doody and Greig, 2018). Interventions to promote sustainable PA in older adults have previously achieved limited success, particularly over the long term (Chase, 2013, Daskalopoulou, et al., 2017, van der Bij, Laurant and Wensing, 2002). For example, older adults who took part in a 12-week exercise program (functional task exercise group or resistance strength exercise group) showed no significant difference in “change in PA scores” from the control group at 3, 6 or 9 months (de Vreede, et al., 2007). Similarly, older adults who took part in 16 weeks of flexibility training and 16 weeks of resistance training showed no significant difference in PA compared to the control group at the end of the intervention (p = 0.601) or at the 12-month follow-up (p = 0.447) (Bird, et al., 2011). However, a systematic review of reviews (19 reviews; 413 unique studies) found that PA interventions for older adults aged ≥ 50 years did result in improvements in PA over the study duration, but maintenance beyond this was unclear (Zubala, et al., 2017). This review also highlighted that the included PA interventions were typically face-to-face, with some incorporating remote features (e.g. exercise to be performed at home), in group, individual or a combination of settings (Zubala, et al., 2017).

Traditional face-to-face approaches promoting health behaviours are typically resource intensive, time-limited, require participants to travel to specific locations and lack appropriate techniques for monitoring daily fluctuations in health behaviours (Hekler, et al., 2011). In addition, behaviour change interventions often require professional expertise in delivering BCTs (Lyons, et al., 2014). These limitations mean that often the interventions are inaccessible to many individuals within the target population, such as older adults who are socially isolated. Therefore, there is a need for potentially scalable, low cost and less staff-intensive interventions to help address the low levels of PA and high SB in older adults, particularly those who are socially isolated.

1.7. Digital behaviour change interventions for physical activity and sedentary behaviour

Digital behaviour change interventions (DBCI) use technologies such as mobile applications (apps) and websites to remotely deliver behaviour change interventions (Roberts, et al., 2017). eHealth interventions, which use ICT for health (World Health Organisation, 2020), and mHealth interventions, which use mobile devices (e.g., mobile phones, patient monitoring devices and other wireless devices) for health (World Health Organisation, 2011) are both types of DBCI. DBCI have previously been used in the promotion of PA participation and healthy eating (Flores Mateo, et al., 2015, Rabin, et al., 2011, Middelweerd, et al., 2014). Mobile phones in particular offer the potential for low-cost, accessible, flexible support for behaviour change, reducing the barriers that often emerge with face-to-face interventions, such as travel, finances and access to trained professionals (Crane, et al., 2015). In isolated older adults, digital interventions have the potential to overcome the challenge of equitable access to health service provisions in rural and remote areas, thereby reaching people who may be underserved and traditionally harder to reach (Moore, et al., 2016).

DBCI for PA have been used by older adults and are deemed relevant and acceptable for use in this population (Kim and Glanz, 2013, Lyons, et al., 2017). Two systematic reviews of eHealth interventions for PA in older adults (mean/median age ≥55 years old) independently found eHealth interventions increased PA level in the short term, but evidence for long-term effects were lacking (Muellmann, et al., 2017) (N = 20; n = 6671) (Jonkman, et al., 2018) (N = 12; n = 1208). To date no reviews have been conducted to investigate the efficacy of DBCI for PA and/or SB in older adults exclusively aged ≥50 years old, therefore chapter three contributes to knowledge in this area. Despite the potential advantages of using DBCI in socially isolated older adults, knowledge of the types of technologies this population engage with is lacking. Statistics tend to be reported by age group without reference to social isolation status, making it difficult to design a DBCI for this population. Therefore chapter 4 in this thesis aims to address this gap and contributes to knowledge in this area of research.

1.8. Intervention development

Changing health behaviours, such as PA, requires a complex intervention. A complex intervention involves the interaction of multiple components, for instance: the target behaviour itself; a sensitivity to local context; the practicability of standardising the design and delivery of the intervention; the logistical and organisational factors of implementation; and the consideration of the causal chains linking interventions with outcomes (Craig, et al., 2008, Craig, et al., 2006). Therefore, a systematic process using available evidence and appropriate theory is required to design and evaluate these complex interventions (Craig, et al., 2008, Craig, et al., 2006).

1.8.1. MRC guidance: Developing and evaluating complex interventions

The Medical Research Council (MRC) published guidance in 2006 on developing and evaluating complex interventions (Craig, et al., 2006). This guidance was in the process of being updated whilst the work presented in this thesis was underway, however the final report will not be published until Spring 2021. Figure 2 shows the recommended process through which a complex intervention is developed and implemented. This process is split into four phases: development, feasibility/piloting, evaluation, and implementation. The arrows indicate the main interactions between phases (Craig, et al., 2008). This framework was used to guide the design of the research presented in this thesis, which is concerned with the development phase of the intervention development. Full details of how this framework was used to design the thesis can be seen in chapter two, however the four phases are outlined below.

The guidance proposes that the development phase consists of three steps. The first step is to identify the evidence base, which is usually done through a systematic review, and can be an original review or the use of a recently published one (Craig, et al., 2006). The second step is to identify or develop the relevant theory to underpin the new intervention (Craig, et al., 2006) as theory-based interventions are likely to be more effective than interventions without a theory-base (Michie, et al., 2009). The third step is to model the process and outcomes of the complex intervention before feasibility/piloting or a full-scale trial and evaluation is completed (Craig, et al., 2006). This allows for cost- and time- effective identification of potential weaknesses that can lead to refinements before a full trial is conducted (Craig, et al., 2008).

The aim of the feasibility and piloting phase is to test the intervention on a small scale and it is helpful for identifying potential problems that can be addressed before a larger scale trial (Craig, et al., 2008). This allows for procedures to be piloted, provides information on recruitment and retention rates, which can be used to calculate the required sample size for a full-scale trial. This phase does not need to be a scaled down version of the intended trial, as it may be beneficial to focus on key uncertainties that are identified in the development phase (Craig, et al., 2008). For instance, the development phase may highlight a high drop-out rate for the type of intervention being designed, therefore this phase may focus on attenuating this rather than the efficacy of the intervention itself.

The evaluation phase assesses the effectiveness of the developed intervention and aims to understand the processes of change. First, the effectiveness of the intervention in terms of its primary and secondary outcomes are assessed, and the experimental design chosen should be carefully considered (Craig, et al., 2006). Second, the process of change is evaluated, providing useful information about why an intervention may have failed or produced unexpected outcomes, or why an intervention was successful and how this can be optimised (Craig, et al., 2006). This evaluation of the process of change can include an assessment of the fidelity and quality of implementation, clarification of causal mechanisms and identification of contextual factors that may impact outcomes (Craig, et al., 2008). Third, an evaluation of the cost-effectiveness should be conducted as it is important that the economic cost of the intervention is warranted by its outcomes (Craig, et al., 2006).

The implementation phase involves the dissemination of the research into practice, often via academic publications and dissemination to potential intervention providers in accessible formats (Craig, et al., 2006). The second step is to monitor the intervention as it is used in practice, because it is likely to show different effects in a wider more generalised setting (Craig, et al., 2006). Third, the intervention should be monitored and followed up in the longer term, as it is unlikely that until this point the long-term effects have been evaluated (Craig, et al., 2006).

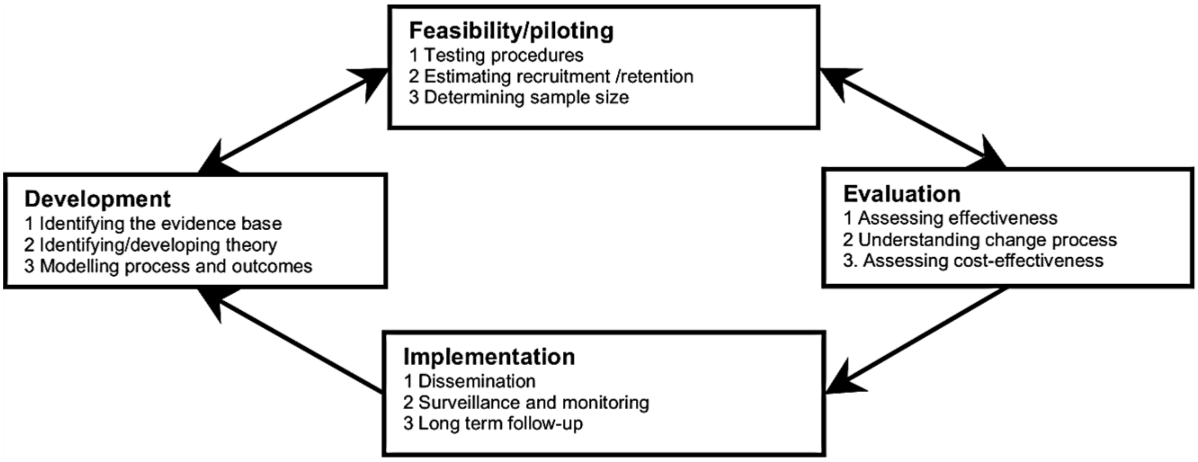


Figure 2. Key elements of the development and evaluation process of complex interventions from Medical Research Council 2006.

1.8.2. The Behaviour Change Wheel

The behaviour change wheel (BCW) (

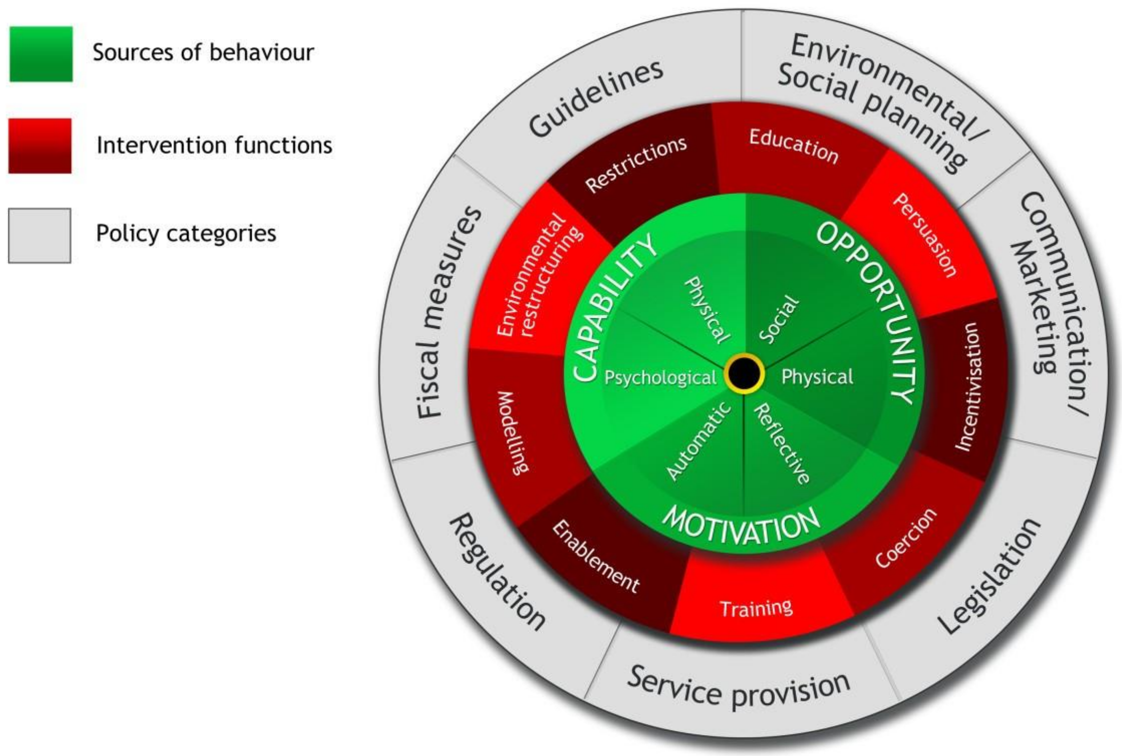


Figure 3) was developed to provide a systematic method for applying theory and evidence to the design and evaluation of behaviour change interventions (Michie, Atkins and West, 2014), and to overcome limitations of 19 previous frameworks (Michie, van Stralen and West, 2011). In this thesis the BCW was chosen as it provides comprehensive and simple to follow guidance to anyone interested in applying theory and evidence to behavioural intervention design and evaluation, with varying levels of expertise, making it highly accessible to those with less experience of intervention design (Michie, Atkins and West, 2014).

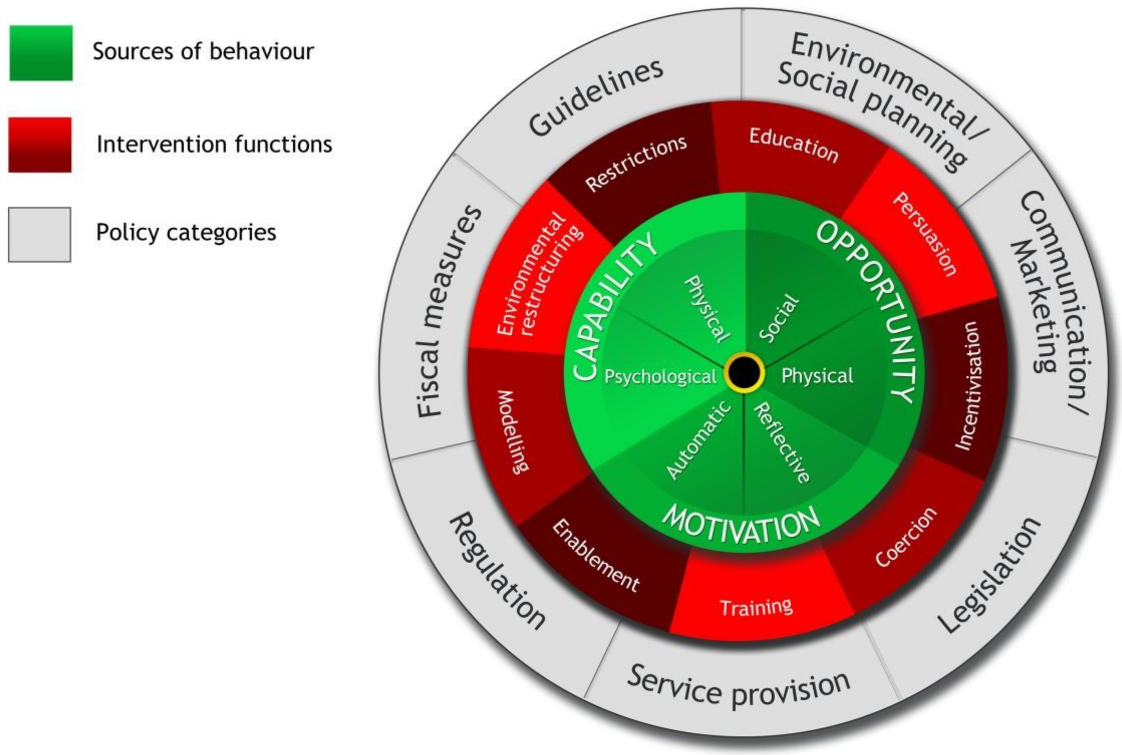


Figure 3. The Behaviour Change Wheel (Michie, van Stralen and West, 2011).

The BCW has 3 levels. At its centre is the ‘COM-B’ system – capability (physical and psychological), opportunity (physical and social) and motivation (reflective and automatic) – which, according to the COM-B model, are the three components that generate behaviour (Michie, van Stralen and West, 2011). The middle layer consists of nine intervention functions – education, persuasion, incentivisation, coercion, training, enablement, modelling, environmental restructuring, and restrictions (Michie, Atkins and West, 2014). Intervention functions can be applied to change the target behaviour, and it is important that the intervention functions chosen are informed by the result of a needs analysis using the COM-B model to increase the efficacy of the intervention (Michie, Atkins and West, 2014). These intervention functions can be linked to specific BCTs identified in the BCT taxonomy v1 (Michie, van Stralen and West, 2011). The BCT taxonomy v1 was developed, in consensus with 55 behaviour change experts across multiple disciplines and countries, by identifying

BCTs that appeared in academic literature or were used in practice; this resulted in 93 clearly defined BCTs grouped into 16 clusters (Michie, et al., 2013). The outer layer of the BCW consists of seven types of policy that can be used to deliver the intervention functions: environmental/social planning, communication/marketing, legislation, service provision, regulation, fiscal measures and guidelines (Michie, Atkins and West, 2014). Both intervention functions and policy options are assessed using the APEASE criteria – affordability, practicability, effectiveness/cost-effectiveness, acceptability, side effects/safety and equity – and those meeting all APEASE criteria should be considered for use in the design of an intervention (Michie, Atkins and West, 2014).

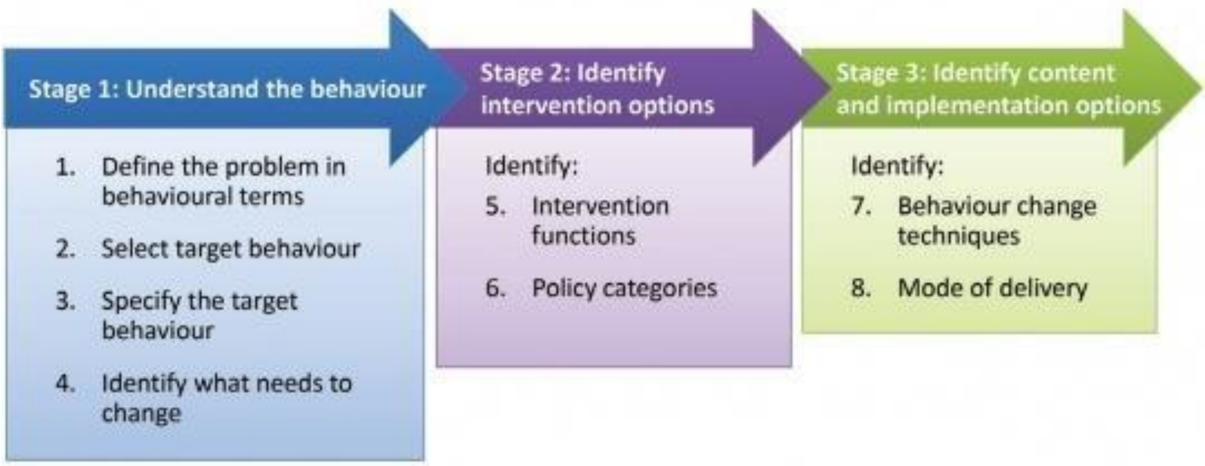


Figure 4. Behaviour change intervention design process (Michie, Atkins and West, 2014).

The BCW has eight steps, categorised into three stages, for the design of a behaviour change intervention (Figure 4). Stage 1: Understand the behaviour is split into four steps: 1) defining the problem in behavioural terms, 2) selecting the target behaviour, 3) specifying the target behaviour, and 4) identifying what needs to change. Stage 2: Identify intervention options is split into two steps: 5) identifying intervention functions, and 6) identifying policy categories. Stage 3: identifying content and implementation options is split into two steps: 7) behaviour change techniques, and 8) mode of delivery. Intervention designers who are limited to a specific policy lever, can move from intervention function selection (stage 2) to BCTs and mode of delivery (stage 3) (Michie, Atkins and West, 2014).

1.9. Summary

Regular and sustained participation in PA, and reduction in SB, have physical, cognitive, and mental health benefits for older adults. Despite this, many older adults remain insufficiently active to achieve these benefits. Older adults who are socially isolated are not only at greater health risk than their non-isolated peers, but they are also less likely to be physically active. Traditional face-to-face PA interventions have achieved limited success, particularly in the long term, and can be resource and cost intensive. There has been a shift towards utilising DBCI to overcome some of the barriers of traditional face-to-face interventions. DBCI have previously been used in older adult populations, so they may have potential for use in harder to reach populations such as socially isolated older adults. However, to date there is no DBCI for PA/SB designed for this population. The MRC guidance and the BCW would provide a helpful framework to design an evidence based DBCI for PA/SB in socially isolated older adults.

1.10. Thesis aim

The aim of the PhD was to use the MRC guidance on developing and evaluating complex interventions, in combination with the BCW, to make recommendations for the design of a DBCI for PA and/or SB in socially isolated older adults.

CHAPTER 2: METHODOLOGY

2.1. Introduction

This chapter presents the methodology used in the design and undertaking of the research carried out as part of this thesis. Utilising the MRC guidance and BCW aligns well with a pragmatic approach to research, therefore first, pragmatism and the assumptions that this approach makes about knowledge are described. Second, how this approach relates to the MRC guidance on intervention development and BCW is explored. Finally, the aims and research questions of each study included in the thesis are presented. Details regarding participants, data collection and data analysis are reported separately in each chapter in their respective methods section.

2.2. Pragmatism

Pragmatism originated from the works of Charles Sanders Peirce (1839-1914) and William James (1842-1910) and was further developed by John Dewey (1859-1952) and later Richard Rorty (1931–2007) (Legg, 2019, Ormerod, 2006, Moore, 2016, Johnson, et al., 2017). Pragmatism has been described as focused on 'what works' in real-world practice (Creswell, 2018, Howe, 1988, Kaushik, Walsh and Lai, 2019), in order to directly improve life conditions and life chances for those in need (Greene and Hall, 2010). It is rooted in human experience rather than metaphysical considerations of the nature of reality or truth (Morgan, 2014), whereby we are all participants in an ever evolving world (Morgan, 2014, Biesta, 2010, Kaushik, Walsh and Lai, 2019). Utilising the MRC guidance for intervention development and the BCW aligns well with a pragmatic approach to research because they both provide a framework centred on 'what-works' in real-world practice to improve the lives of those in need.

Pragmatists reject the metaphysical concepts of epistemology and ontology, and dualisms of objectivism/subjectivism, mind/body, free will/determinism, quantitative/qualitative, suggesting these generate more ‘pseudo-problems’ (Howe, 1988, Burns, 1960, Alexander, 2006, Kaushik, Walsh and Lai, 2019, Creswell, 2018). Pragmatists accept that the broader philosophical arguments on truth and reality can never be solved because one cannot separate meaning from human experience and needs, and they are contingent on context (Dillon, O'Brien and Heilman, 2000, Kaushik, Walsh and Lai, 2019).

Pragmatism favours centring research on addressing the research questions using any methodological tools available, provided they are selected based on their appropriateness to the situation at hand, fostering a cooperative rather than paradigmatic attitude towards research (Tashakkori and Teddlie, 1998, Howe, 1988, Greene and Hall, 2010, Kaushik, Walsh and Lai, 2019, Bryman, 2006). Pragmatism is described as pluralistic, allowing for the use of mixed methods during multi-phase research projects, with the consequences of the research being of greater importance than the methods used (Morgan, 2014, Biesta, 2010, Tashakkori and Teddlie, 1998, Johnson and Onwuegbuzie, 2004, Creswell, 2014, Giacobbi, Poczwardowski and Hunger, 2005, Kaushik, Walsh and Lai, 2019, Creswell, 2018, Bryman, 2006). Within mixed methods research, researchers are often guided to select a ‘typology’ or notion of mixed method design (e.g. explanatory sequential, exploratory sequential and convergent designs) which essentially relate to the order in which quantitative and qualitative stages of research take place (Creswell, 2018). This however, requires the researcher to accept the dualism of quantitative/qualitative in the first instance, which does not fit with the concept of pragmatism (Morgan, 2014). In this thesis, both quantitative and qualitative methods are utilised based upon which are most appropriate for addressing the research questions within each phase of the MRC guidance and using the BCW.

All four phases of the MRC guidance (Craig, et al., 2006) require the intervention users to experience and reflect on their actions and consequences, and indeed those of the intervention providers and researchers, in order to systematically design an effective, practicable and acceptable intervention. For pragmatists, beliefs and action must come before descriptions, theories, explanations and narratives, and research is led by anticipated consequences (Cherryholmes, 1992) because the meaning of human actions and beliefs are found in their consequences (Kaushik, Walsh and Lai, 2019, Morgan, 2017). Theories support practice, but can only be ascribed meaning by the impact that they have on outcomes (Ormerod, 2006). Therefore, knowledge is always based on experience (Kaushik, Walsh and Lai, 2019). Experiences are the continuous interaction of beliefs and actions between a person and their environment; different people will therefore have different experiences that are contextual, temporal, emotional and social (Morgan, 2014, Biesta, 2010, Ormerod, 2006, Kaushik, Walsh and Lai, 2019, Morgan, 2017). Although these experiences are different, they are equally 'real' (Biesta, 2010). Experiences are useful, as warranted beliefs we have from previous experiences can be used in other situations that require action, and the consequences of past actions can aid the prediction of possible future consequences of similar actions (Morgan, 2014, Kaushik, Walsh and Lai, 2019, Johnson, et al., 2017). Experiences alone do not provide knowledge, it is the reflection on actions and their consequences that when put together in a logical way result in knowledge (Biesta, 2010). Pragmatist methodology leads to two forms of reflection: the nature of the problem and its potential solutions, and the nature of the potential solutions and the likely actions (Kaushik, Walsh and Lai, 2019). Indeed stage 1 of the BCW, particularly identifying what needs to change, involves the reflection on past behaviours and identifies potential solutions which can be used to help change future behaviours.

However, pragmatism accepts that knowledge is fallible, as one can never be certain that current knowledge will be appropriate for future problems of inquiry (Greene and Hall, 2010, Hothersall, 2019). It is also not possible to experience an exact situation twice, nor for different people to have identical experiences, so beliefs and knowledge can only be provisional (Morgan, 2013, Kaushik, Walsh and Lai, 2019, Kaufmann, 1959). Dewey avoided the term 'truth' in his writing for this reason, preferring the term 'warranted assertions' to highlight the process of inquiry (Johnson, et al., 2017, Kaufmann, 1959). In a constantly changing world, requirements and experiences change, and thus so will the practical value of one's beliefs; therefore where actions challenge a belief or current knowledge, new facts should be accommodated and new explanations found, which encourages continuous inquiry, openness to change, revision, improvement and advancement of knowledge and practice (Ormerod, 2006, Morgan, 2013, Kaushik, Walsh and Lai, 2019, Leão, Rocha and Laurenti, 2016, Johnson, et al., 2017, Morgan, 2017). The MRC framework shows the cyclical process of intervention development. It assumes that once an intervention is created, implemented, and monitored, it is likely to require development as the world and user beliefs change. Therefore, the work of a pragmatist, and an intervention designer, can never be 'finished'.

Dewey's systematic approach to inquiry has 5 steps; (1) recognising a situation as problematic, (2) reflecting on the nature of the problem using existing beliefs to think about why the situation is problematic, (3) recognising possible actions that would address the problem – suggested solution, (4) reflecting on the effects of the proposed solution using existing beliefs about the likely outcomes of action, (5) action – following through on the suggested solution to the problem (Morgan, 2014, Morgan, 2017, Kaufmann, 1959). It is important that the problems identified are carefully defined before inquiry is undertaken (Dillon, O'Brien and Heilman, 2000), and through the reflective process, the aims of the inquiry may be modified and evolve before progressing to the next steps (Morgan, 2017, Kaufmann, 1959). Scientific research inquiry is similar, but with greater rigour within the research process; step 1 becomes the selection of a research question, step 2 remains the same as Dewey's 2nd step, with reflection on why the situation is problematic (often reported in an introduction/background section in a journal article), step 3 becomes a hypothesis formulation, step 4 become the methods by which results are produced that directly answer the research question, and step 5 becomes collecting and analysing the data in relation to the original aims, or evaluation and testing of the hypothesis (Morgan, 2017, Johnson, et al., 2017). Throughout the process of inquiry, decisions must be made that guide the research. Pragmatists accept that the researcher's decisions are guided by their own beliefs and personal experiences, the shared beliefs of the research community, and what they have learned from the experiences of others (Morgan, 2014). Explanations for the research decisions made in this thesis can be found in their relevant chapters. Each chapter within the thesis maps to stages within the development phase of the MRC guidance (Craig, et al., 2006) and follows the process of research inquiry.

2.3. The application of the Medical Research Council intervention guidelines in the design of the thesis

The MRC intervention development guidance recommends, as a first step, that the evidence base is identified, ideally by carrying out a systematic review before an appropriate behaviour change theory is identified or developed (Craig, et al., 2006). This fits well with pragmatist inquiry, whereby the first task when faced with a problem is to understand it ‘through describing its elements and identifying their relations’ (Legg, 2019). Previous research findings provide a basis for organising future observations and experiences, by highlighting possible practical consequences, so beginning a research project with a systematic review of the literature would be a common starting point for pragmatic researchers (Cherryholmes, 1992). To date there is no literature available on socially isolated older adults’ use of DBCI for PA/SB, therefore, and contributing to knowledge in this area, chapter three presents a systematic review of the literature and meta-analysis of the data from previous studies using DBCI for PA and/or SB in older adults.

Table *1* shows how chapters 3 – 6 relate to the MRC guidance.

The purpose of chapter four was to identify the evidence base of older adults’ current use of technologies, particularly in relation to their social isolation and loneliness. Analysis of descriptive data helped identify demographic characteristics of socially isolated older adults, which was useful for the recruitment of socially isolated older adults in chapters five and six.

This chapter also explored which devices socially isolated older adults already have access to, which online activities they tend to engage in and the frequency of their internet/email use, all of which was needed to inform the selection of the DBCIs employed in chapter six.

Table 1. Studies included in the thesis in relation to the MRC intervention development guidance.

MRC Guidance on intervention development	**Thesis Chapters**
1.1 Identifying the evidence base	Chapter 3 – Digital behaviour change interventions to promote PA and/or reduce SB in older adults: a systematic review and meta-analysis
	Chapter 4 – Internet use, social isolation and loneliness in older adults
1.2 Identifying/developing appropriate theory	Chapter 5 – The barriers and facilitators of socially isolated older adults PA behaviours
1.3 Modelling process and outcomes	Chapter 6 – Socially isolated older adults experiences of using existing DBCI for PA/SB

The focus of chapter five was to develop appropriate theory for the future DBCI, using the BCW to complete a needs assessment for PA in socially isolated older adults. It was hoped that by identifying barriers to and facilitators of PA, these could be accounted for in the development of the new DBCI. This stage was important for clearly identifying what problems socially isolated older adults faced in relation to PA, before developing solutions to these problems. From this information it was then possible to identify appropriate intervention functions and BCTs to include in a novel DBCI for PA/SB for this population.

Chapter six involved socially isolated older adults experiencing two current and publicly available DBCI for PA. It was evident that although many participants from chapter 5 had some experience of technology use, many had limited or no experience of using DBCI for PA. From a pragmatist perspective, it is crucial for participants to experience using DBCI for PA before offering their views about the design of a future DCBI. In addition, previous research with older adults and DBCI suggests they find it difficult to identify their likes and dislikes or understand the realistic capabilities of the technology without first experiencing something like it (Harrington, et al., 2018). Thus, rather than beginning to design a new DBCI based on the knowledge gained from chapters three, four and five, it was decided that an initial evaluation of currently available DBCI, even if they were not theoretically optimal, would produce useful information, be cost and time-effective for the design of a new DBCI. This would allow participants to provide insights informed by experience that would inform the design a new DBCI.

In summary, this thesis follows the MRC guidance for intervention development and, where appropriate, incorporates the BCW, both of which align with pragmatism. Chapters 3 – 6 each have a specific aim and a set of research questions to be addressed, which contribute knowledge to the overall thesis aim: to make recommendations for the design of a DBCI for PA and/or SB in socially isolated older adults. These aims and research questions are outlined below.

2.4. Aims and research questions of each study

2.4.1. Digital behaviour change interventions to promote physical activity and/or reduce sedentary behaviour in older adults: a systematic review and meta-analysis (Chapter 3)

To date, there are no studies investigating DBCI for PA/SB in socially isolated older adults, so it was not possible to conduct a systematic review specifically on this population. Therefore, DBCI for PA/SB used in older adults generally were investigated. The aim of the systematic review and meta-analysis was to gain knowledge and understanding of what DBCI have previously been used in older adults, including psychological underpinnings and BCTs used, their effects on PA and/or SB, and if there were any secondary effects on physical or mental health, or social outcomes. Therefore, the research questions for this study included:

RQ1a: What effect do DBCI have on PA and/or SB in older adults?

RQ1b: What effect do DBCI have on physical health, mental health and social outcomes in older adults?

RQ1c: What are the theoretical underpinnings of the DBCI used to target PA and/or SB in older adults?

2.4.2. Secondary analysis to explore associations between internet/email use in a large sample of older English adults with their perceived social isolation and loneliness. (Chapter 4)

The aim of this study was to explore, in a large sample of older English adults, associations between internet/email use with their social isolation and loneliness.

RQ2a: What are the demographic characteristics of older adults who are socially isolated?

RQ2b: What are the demographic characteristics of older adults (≥50 years) in relation to their frequency of internet/email use?

RQ2c: What are the associations between the frequency of internet use in older adults with their social isolation and loneliness?

RQ2d: What devices do older adults use to access the internet in relation to their frequency of internet/email use, social isolation and loneliness?

RQ2e: What online activities do older adults engage with in relation to their frequency of internet/email use, social isolation and loneliness?

2.4.3. Barriers and facilitators of physical activity in socially isolated older adults (Chapter 5)

The aim of this study was to complete a needs assessment for PA among socially isolated older adults based on COM-B, the model which is at the core of the BCW (Michie, Atkins and West, 2014).

RQ3a: What are the barriers of PA in socially isolated older adults in relation to COM-B?

RQ3b: What are the facilitators of PA in socially isolated older adults in relation to COM-B?

2.4.4. Exploring socially isolated older adults' experiences of using two digital behaviour change interventions for physical activity (Chapter 6)

The aim of this study was to explore and gather socially isolated older adults' experience of using two DBCI for PA, to inform the recommendations for design of a new DBCI for PA specifically for this population.

RQ4a: What are socially isolated older adults' opinions of using DBCI for PA?

RQ4b: What are socially isolated older adults' experiences of using two DBCI for PA?

RQ4c: What features would socially isolated older adults include in the design of a new DBCI for PA?

2.5. Conclusion

This thesis takes a pragmatic approach to achieve the aim of making recommendations for the design of a DBCI for PA and/or SB in socially isolated older adults, utilising the MRC guidance for intervention development and evaluation and the BCW. This thesis comprises four studies which address the development phase of the MRC guidance: chapters three and four identify the evidence base, chapter five identifies and develops appropriate theory and chapter six models the process and outcomes using existing DBCI for PA. From the work in chapters 3 – 6, recommendations for the design of a new DBCI for PA/SB for socially isolated older adults are made and an example is provided (chapter 7).

CHAPTER 3: DIGITAL BEHAVIOUR CHANGE INTERVENTIONS TO PROMOTE PHYSICAL ACTIVITY AND/OR REDUCE SEDENTARY BEHAVIOUR IN OLDER ADULTS: A SYSTEMATIC REVIEW AND META-ANALYSIS

The content of this chapter has been published in the peer-reviewed journal Experimental Gerontology, see publications and conference proceedings (page vii) for details.

3.1. Introduction

Older adults make up a large proportion of the population in the UK, and this proportion is projected to continue to increase (chapter one) (Office for National Statistics, 2017). However, living longer in good health with a high quality of life (QoL) is not guaranteed (Beard, et al., 2016) and many people are living longer with disability (James, et al., 2018). Many older adults find everyday tasks physically demanding and challenging, so physical setbacks or further declines could increase their risk of falling and/or becoming dependent on carers (Rikli, 1999, Deandrea, et al., 2010). As seen in chapter one, low levels of PA and excessive SB are independently associated with multiple negative health outcomes in older adults (Chad, et al., 2005, Wirth, et al., 2017). Therefore, regular and sustained engagement in PA and reduction in SB have the potential to improve health, QoL and independence in older adults (Smith, et al., 2015, Daskalopoulou, et al., 2017, Chad, et al., 2005, Tak, et al., 2013).

Despite the benefits of PA, many older adults, particularly those who are socially isolated, fail to meet government recommendations for PA (see chapter one, section 1.4.1). Previous interventions to promote sustainable PA and reduce SB in older adults have achieved limited success, particularly over the long term (Chase, 2013, Daskalopoulou, et al., 2017, van der Bij, Laurant and Wensing, 2002) (see chapter one). These interventions tended to be face-to-face and so were inconveniently located for participants, time and resource intensive, and lacked appropriate techniques for monitoring daily fluctuations in health behaviours (Hekler, et al., 2011). Thus, there is a need for potentially scalable, low cost and less staff intensive interventions to help address the low levels of PA and high SB in older adults.

Digital behaviour change interventions (DBCI) use technologies such as mobile applications (apps) and websites to remotely deliver behaviour change interventions (Roberts, et al., 2017), for instance promoting PA and healthy eating (Flores Mateo, et al., 2015, Rabin, et al., 2011, Middelweerd, et al., 2014). DBCI may help overcome some of the limitations of the traditional face-to-face interventions, but may be especially useful for older adults who are socially isolated (Moore, et al., 2016). Despite this, the effectiveness of DBCI for PA/SB to improve health outcomes in older adults has yet to be established. This is an important question, since DBCIs present a novel and scalable approach towards providing tailored behaviour change interventions (Forberger, et al., 2017, King, et al., 2013, Roberts, et al., 2017), especially for isolated older adults who have limited contact with traditional person(s) or print-based PA interventions (Norman, et al., 2007), reducing costs and improving patient experience and outcomes (Michie, et al., 2017).

There is currently no literature on the use of DBCI for PA/SB in socially isolated older adults, therefore, to identify the evidence base (see MRC guidelines) for making recommendations for a DBCI for PA/SB in socially isolated older adults (thesis aim), the general population of older adults were used. To date, no systematic review or meta-analysis has assessed the efficacy of DBCI interventions targeting PA and/or SB in older adults (≥ 50 years) from the general population. Therefore, a systematic review and meta-analysis were conducted with the aim of assessing the efficacy of DBCI interventions in older adults (≥ 50 years) on PA and SB. Secondary aims were to explore any effects of DBCI on physical health, mental health and social outcomes, and explore the theoretical underpinning of studies included.

3.2. Methods

The following systematic review followed the PRISMA guidelines (Moher, et al., 2009). Details of the full protocol for this systematic review were registered on PROSPERO (protocol number: CRD42018090359).

3.2.1. Search strategy

Electronic databases were searched via OVID from inception to 2nd March 2018: MEDLINE, PsycINFO and EMBASE. Grey literature was searched manually by entering the same search terms into internet search engines Google and Bing on 2nd March 2018 and the first 10 pages were searched. Searching methodology included terms and synonyms relating to PA, SB, older adults and DBCI (Appendix A). Results of the searches were included in a bibliographic database and duplicates were removed. Titles and abstracts of the studies retrieved using the search strategy were screened for inclusion in the systematic review by two screeners independently. The full text of all potentially eligible papers was reviewed (SS and research assistant) before a final decision on eligibility was made. Any discrepancies were discussed until a decision was reached. A third senior reviewer (LS) acted as an adjudicator if a decision was not reached.

3.2.2. Study inclusion and exclusion

Studies were included if they met the following criteria: (i) randomized controlled trials (RCTs) and pre and post-test studies (ii) in older adults (aged 50+ years) (iii) that use digital interventions (iv) to promote PA and/or reduce SB; and (v) in any setting. In addition, studies had to be published in an electronic journal article and written in English. PA was defined as any bodily movement produced by skeletal muscles that results in energy expenditure (Caspersen, Powell and Christenson, 1985). SB was defined as any waking behaviour characterized by an energy expenditure of ≤ 1.5 Metabolic Equivalents (METs) whilst in a sitting or reclining posture (Tremblay, et al., 2017). DBCI were defined as devices and programs using digital technology to foster or support behaviour change (Yardley, et al., 2016), which include but are not limited to websites, mobile phones, smartphone applications (apps), wearable devices, video games, virtual and augmented reality devices. RCTs that used any control condition (e.g. vs. usual care, treatment as usual or non-digital behaviour change interventions) and pre and post-test studies versus no control group were included. Studies were excluded if they were observational research including cross-sectional and cohort studies, case studies, case series and qualitative research, as were conference abstracts, protocol papers, or N of 1 studies, studies where participants were not exclusively aged ≥50, where participants were not directly involved in using the DBCI, where the intervention did not use a digital intervention, or did not have PA/SB outcomes.

3.2.3. Primary and secondary outcomes

The co-primary outcomes were PA and/or SB, captured via objective measure (e.g. pedometers, accelerometers) or self-report validated tools (e.g. IPAQ (Craig, et al., 2003)), in older adults (age ≥ 50 years old). Secondary outcomes of interest included physical (e.g. blood pressure, body mass, body mass index (BMI), body composition, lipid concentrations, glucose concentrations, cardiometabolic risk (e.g. measure of metabolic syndrome, composite scores of cardiometabolic risk markers), fall risk (e.g. had previous falls, walks with walking aid) and physical functioning (e.g. handgrip strength, RAND-36 physical functioning questionnaire, timed up and go)), mental health (such as depression, anxiety), and social outcomes (such as reduced isolation, perceived loneliness) of PA and/or SB.

3.2.4. Data extraction

Data extracted by two reviewers (SS and research assistant) independently included: first author, year, country, region, setting, population, aims of the study, type of the study (controlled or randomized controlled trial, pre-post-test), number of participants, participant characteristics, details of the DBCI (including duration), inclusion criteria, type of recruitment, type and definition of SB or PA used, type of measurement of PA and SB, measurement of engagements/adherence to the DBCI, effects on PA and SB outcomes, specific BCTs used in DBCI (extracted by a trained coder (SS) using the Behaviour Change Techniques Taxonomy v1 (BCTTv1) – 93 lower-order strategies which cluster into 16 groups of BCTs (Michie, et al., 2013)), psychological or behaviour change theoretical basis to the intervention (if mentioned), physical, mental and social outcomes analysed in the results (if reported), details of control condition, confounding variables, acknowledged limitations by authors and authors conclusions, other/notes. Where information was missing, required clarification or particular variables of interest were not reported in the paper, corresponding authors were contacted to enable inclusion in the meta-analysis.

3.2.5. Quality assessment

Risk of bias was assessed by two independent researchers (SS and research assistant) using the Joanna Briggs Institute (JBI) critical appraisal checklist (Tufanaru, et al., 2017). This tool was chosen as it provided flexibility and methodological appraisal for the study designs included in the review. For RCTs, the JBI checklist contained 13 items that were graded either 'yes', 'no', 'unclear' or 'not applicable' (Appendix B). The checklist for quasi-experimental studies contained nine items and was used for pre-post studies, containing nine items that were graded either 'yes', 'no', 'unclear' or 'not applicable' (Appendix C). Discrepancies between the review authors were resolved by discussion, with involvement of a third review author (LS) where necessary. A greater number of 'yes' items indicated higher quality studies, thus lower risk of bias (Tufanaru, et al., 2017).

3.2.6. Statistical analysis

The meta-analysis aimed to: i) establish the effects of DBCI on PA and SB on older adults, immediately at the end of the intervention and at follow-up, by extracting a pooled effect sizes (described below); ii) establish the effects of DBCI on physiological measures (e.g. weight, heart rate) by extracting a pooled effect size, iii) identify potential modifiers through meta-regression analysis, and iv) assess the influence of publication bias on reported effects.

Random effects meta-analyses calculating standardized mean difference (SMD), mean difference (MD) and 95% CI were conducted for RCT studies for total PA, number of steps per day, MVPA and total SB. For RCT studies meta-analyses investigating total PA and steps, studies were split by when measurement was taken – either immediately at the end of the intervention (EI) or at any later follow up (FU) – to allow differentiation between intervention and potential maintenance effects. Random effects meta-analysis calculating SMD, MD and 95% CI were conducted for pre-post studies for total PA and steps. For pre-post studies meta-analysis investigating total PA and steps, studies were split dichotomously by the number of BCT clusters used in the DBCI – ≥ 3 clusters or 1-2 clusters – as previous research suggests that a threshold of ≥ 3 clusters is required to see significant effects on PA (McEwan, et al., 2018). Where possible, sources of heterogeneity and moderators were investigated with meta-regression analyses including: the number of BCTs used in the DBCI, type of PA measurement, age (years), sex (% males), year of publication, region (North America/non-North America), setting (community-based/ non-community-based) and intervention duration (weeks) were examined. Heterogeneity was assessed with the Cochrane Q and I^2 statistics for each analysis (Higgins, et al., 2003). Values ≥ 50% indicated large heterogeneity and values ≥ 75% very large between studies heterogeneity (Higgins and Thompson, 2002, Ioannidis, Patsopoulos and Evangelou, 2007). Publication bias was assessed through a three-step process. First visual inspection of funnel plots for each analysis were assessed. Second, the Begg-Mazumdar Kendall's tau (Begg and Mazumdar, 1994) and Egger bias test (Egger, et al., 1997) to quantify publication bias were calculated. Since a visual inspection of a funnel plot is somewhat subjective and interpretive, priority was given to quantitative testing of publication bias. Third, I conducted a trim and fill adjusted analysis to remove the most extreme small studies from the positive (or negative) side of the funnel plot, recomputing the effect size at each iteration, until the funnel plot was symmetric about the (new) effect size. All analyses were performed using Comprehensive Meta-Analysis (CMA, version 3) software (Biostat, New Jersey, USA).

3.3. Results

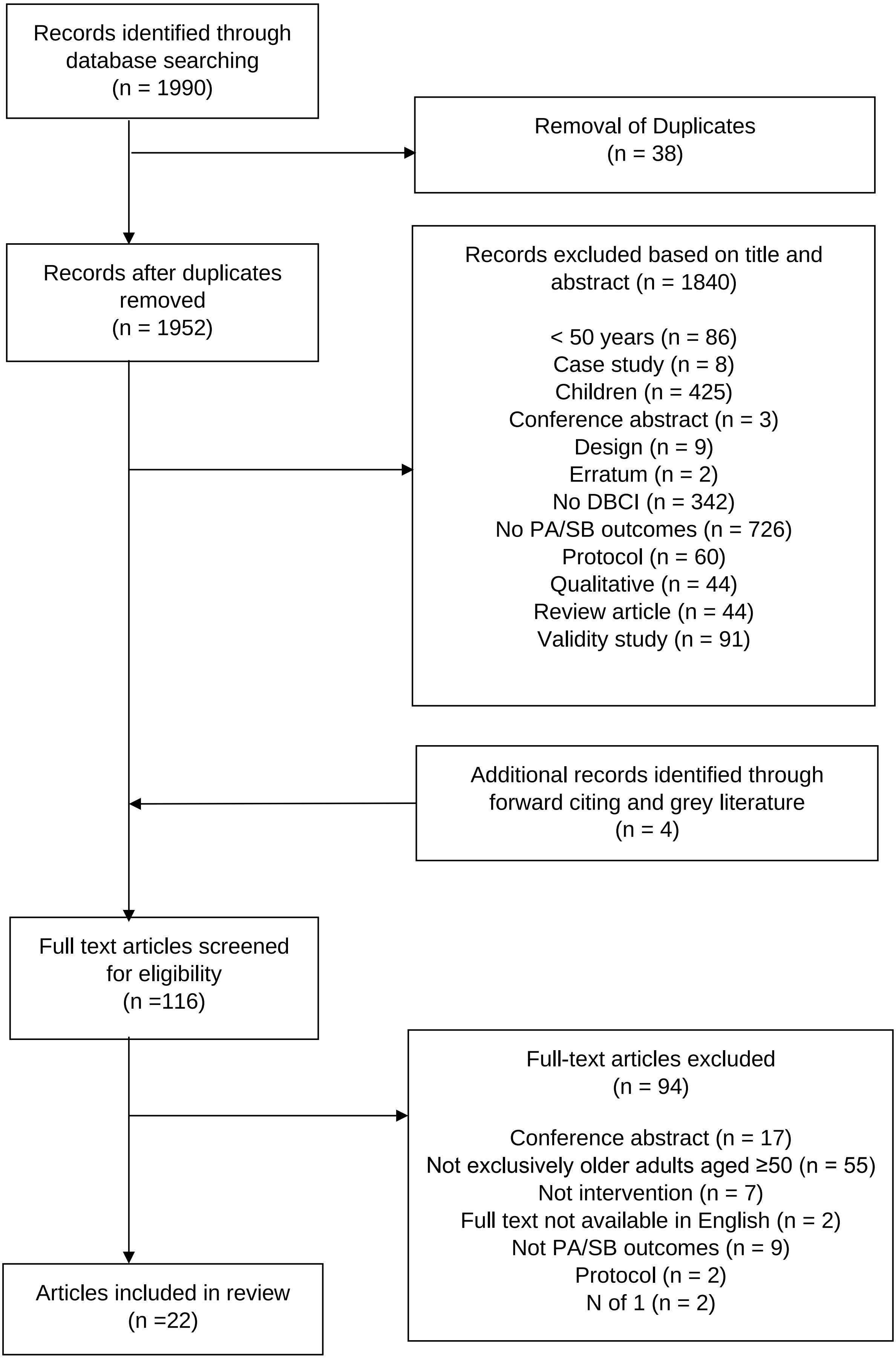
A total of 1990 records were originally identified from the database and four from grey literature searches. After removal of duplicates 1952 studies were title and abstract screened by two independent researchers (97% agreement). 116 studies were selected for full-text review. Ninety-four articles were excluded on full-text review (see figure 1 for a breakdown of reasons for exclusion), leaving 22 articles included in the review. The PRISMA flow diagram of the study selection process can be seen in Figure 5.

Characteristics of the 22 included studies can be found in Table 2 All studies were published between 2007 – 2017. Sample sizes ranged from 17 – 278 participants who completed the studies. Of the 22 studies, 14 were RCT study designs (participants with PA/SB data intervention n = 657, control n = 677) (Ashe, et al., 2015, Bickmore, et al., 2013, Broekhuizen, et al., 2016, Cadmus-Bertram, et al., 2015, Cook, et al., 2015, Frederix, et al., 2015, Kullgren, et al., 2014, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, Ruiz, et al., 2012, King, et al., 2007, Wijsman, et al., 2013, King, et al., 2014), five were pre-post study designs (n = 175) (Knight, Stuckey and Petrella, 2015, Leutwyler, et al., 2015, O'Brien, et al., 2015, Strand, et al., 2014, Tiedemann, Hassett and Sherrington, 2015), one was a randomized crossover study design (n =12 intervention; n = 8 control) (Vidoni, et al., 2016), one was a pre-test post-test quasi-experimental design (n = 24) (Williams, 2016), one was a mixed methods quasi-experimental two group pre-post study design (n = 13 intervention, n = 13 control) (Keogh, et al., 2014). Study durations ranged from 6 – 52 weeks, with a median duration of 12 weeks. Most studies were from the North American region (N = 16), i.e. USA and Canada, two were from Oceania (Australia = 1; New Zealand = 1), one from Asia (Malaysia = 1) and only three were from Europe (Netherlands = 2; Belgium = 1).

Four studies included participants who were community-dwelling older adults (Cook, et al., 2015, Knight, Stuckey and Petrella, 2015, Kullgren, et al., 2014, O'Brien, et al., 2015). Eight studies included community-dwelling older adults who were inactive at baseline (Ashe, et al., 2015, Bickmore, et al., 2013, Broekhuizen, et al., 2016, Wijsman, et al., 2013, King, et al., 2007, King, et al., 2014, Tiedemann, Hassett and Sherrington, 2015, Müller, Khoo and Morris, 2016). Three studies included overweight and obese, inactive older adults (Cadmus-Bertram, et al., 2015, Lyons, et al., 2017, Ruiz, et al., 2012).In two studies, participants lived in residential care settings (Keogh, et al., 2014, Williams, 2016). Participants in two studies had cognitive impairment (Leutwyler, et al., 2015, Vidoni, et al., 2016). One study had participants with COPD (Nguyen, et al., 2009) and one had patients with heart disease (Frederix, et al., 2015). One study included older adults who were eligible to participate in congregate meal sites (Strand, et al., 2014).

The retention rate at follow-up ranged from 48.7% - 100%. Table 3 contains information regarding the DBCI, control treatment, BCTs and engagement/adherence in each study. The approaches to the measurement of engagement and/or adherence were reported in only 14 studies, with some reporting multiple different measures of engagement and others reporting only using one. These varied from group attendance (Ashe, et al., 2015, Leutwyler, et al., 2015, Williams, 2016), completion of full DBCI programme (Wijsman, et al., 2013), the number of times the intervention was interacted with in (e.g. log-ins, posts) (Bickmore, et al., 2013, Cook, et al., 2015, Kullgren, et al., 2014, Lyons, et al., 2017), the percentage of participants that used the website connected to the wearable tracker (Cadmus-Bertram, et al., 2015, Tiedemann, Hassett and Sherrington, 2015) or read the SMS messages (Müller, Khoo and Morris, 2016), the mean number of minutes using the DBCI programme (Cook, et al., 2015, Keogh, et al., 2014), average times/week data were transmitted (Frederix, et al., 2015) or percentage of participants that submitted data (Nguyen, et al., 2009) and the mean number of days the activity monitor was worn by participants (Lyons, et al., 2017). Eight studies did not report on engagement and/or adherence to the DBCI (Broekhuizen, et al., 2016, King, et al., 2007, King, et al., 2014, Knight, Stuckey and Petrella, 2015, O'Brien, et al., 2015, Strand, et al., 2014, Vidoni, et al., 2016).

Figure 5. PRISMA flow diagram illustrating article selection strategy.


Records identified through database searching (n = 1990)
Removal of Duplicates (n = 38)
Records after duplicates removed (n = 1952)
Records excluded based on title and abstract (n = 1840)
< 50 years (n = 86)
Case study (n = 8)
Children (n = 425)
Conference abstract (n = 3)
Design (n = 9)
Erratum (n = 2)
No DBCI (n = 342)
No PA/SB outcomes (n = 726)
Protocol (n = 60)
Qualitative (n = 44)
Review article (n = 44)
Validity study (n = 91)
Additional records identified through forward citing and grey literature (n = 4)
Full text articles screened for eligibility (n =116)
Full-text articles excluded (n = 94)
Conference abstract (n = 17)
Not exclusively older adults aged ≥50 (n = 55)
Not intervention (n = 7)
Full text not available in English (n = 2)
Not PA/SB outcomes (n = 9)
Protocol (n = 2)
N of 1 (n = 2)
Articles included in review (n =22)

The intervention types were diverse, and there appears no clear link between retention rates and the type of intervention used. Fitness trackers were the most commonly used with five using Fitbit (Cadmus-Bertram, et al., 2015, Kullgren, et al., 2014, Vidoni, et al., 2016, Tiedemann, Hassett and Sherrington, 2015, Ashe, et al., 2015), one using the Nike Fuel Band (O'Brien, et al., 2015) and one using the Jawbone Up24 (Lyons, et al., 2017). Three of these also incorporated coaching (Kullgren, et al., 2014, Vidoni, et al., 2016, Tiedemann, Hassett and Sherrington, 2015). Tracking via a smartphone accelerometer was used in one study (Knight, Stuckey and Petrella, 2015) and a tablet app in which pedometer data was manually entered by the participant was used in another (Bickmore, et al., 2013). Six studies used a form of e-coaching or messaging; three just using messaging (King, et al., 2007, King, et al., 2014, Müller, Khoo and Morris, 2016) and three additionally using an activity tracker (Broekhuizen, et al., 2016, Wijsman, et al., 2013, Nguyen, et al., 2009). Exergames were used in four studies: three used the Nintendo Wii (Keogh, et al., 2014, Strand, et al., 2014, Williams, 2016) and one used the Xbox 360 Kinect (Leutwyler, et al., 2015). Websites were used in two studies, one of which was purely educational (Cook, et al., 2015) and another also incorporated messaging (Frederix, et al., 2015). Virtual reality was only used in one study (Ruiz, et al., 2012).

Specific behaviours targeted by the interventions were increasing PA generally (Vidoni, et al., 2016, Bickmore, et al., 2013, Cadmus-Bertram, et al., 2015, Williams, 2016, Leutwyler, et al., 2015, Broekhuizen, et al., 2016, Wijsman, et al., 2013, Keogh, et al., 2014), exercise (Müller, Khoo and Morris, 2016), MVPA (King, et al., 2007, King, et al., 2014), walking (Kullgren, et al., 2014), exercise persistence (Nguyen, et al., 2009), exercise adherence (Ruiz, et al., 2012) and reducing sitting time (Ashe, et al., 2015). One study had three different groups that targeted either exercise, SB or both exercise and SB (Knight, Stuckey and Petrella, 2015). Another study targeted both PA and SB (Lyons, et al., 2017). Two studies targeted PA in addition to another behaviour: prevention of falling (Tiedemann, Hassett and Sherrington, 2015) and diet (O'Brien, et al., 2015). Three studies targeted multiple behaviours: PA, diet and smoking (Frederix, et al., 2015), diet, PA, stress management, smoking (Cook, et al., 2015), holistic health – physical (exercise), emotional, intellectual and social elements (Strand, et al., 2014).

Of all 22 studies, a psychological or behaviour change theoretical basis to the intervention design was mentioned in only 11 studies; The Coventry, Aberdeen and London – Refined (CALO-RE) Taxonomy (Cadmus-Bertram, et al., 2015, Lyons, et al., 2017), social cognitive theory (Ashe, et al., 2015, O'Brien, et al., 2015, Cook, et al., 2015, King, et al., 2007, King, et al., 2014), transtheoretical model (King, et al., 2007, King, et al., 2014, Strand, et al., 2014), whole person wellness model (Strand, et al., 2014), social-ecological model (Ashe, et al., 2015), health promotion model (Williams, 2016), stages of change and I-Change model (Broekhuizen, et al., 2016, Wijsman, et al., 2013).

The most common BCTs were 1.1 goal setting (behaviour) (n = 7) (Ashe, et al., 2015, Broekhuizen, et al., 2016, Kullgren, et al., 2014, Lyons, et al., 2017, Vidoni, et al., 2016, Wijsman, et al., 2013, Williams, 2016), 1.2 problem solving (n = 7) (Ashe, et al., 2015, Bickmore, et al., 2013, King, et al., 2007, Lyons, et al., 2017, Nguyen, et al., 2009, O'Brien, et al., 2015, Vidoni, et al., 2016), 1.3 goal setting (outcome) (n = 5) (Broekhuizen, et al., 2016, Cadmus-Bertram, et al., 2015, King, et al., 2007, Tiedemann, Hassett and Sherrington, 2015, Wijsman, et al., 2013), 2.2 feedback on behaviour (n = 10) (Ashe, et al., 2015, Bickmore, et al., 2013, Broekhuizen, et al., 2016, Frederix, et al., 2015, King, et al., 2007, Kullgren, et al., 2014, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, Wijsman, et al., 2013), 2.3 self-monitoring of behaviour (n = 10) (Ashe, et al., 2015, Bickmore, et al., 2013, Cadmus-Bertram, et al., 2015, King, et al., 2007, Knight, Stuckey and Petrella, 2015, Lyons, et al., 2017, Nguyen, et al., 2009, O'Brien, et al., 2015, Tiedemann, Hassett and Sherrington, 2015, Vidoni, et al., 2016), 3.1 social support (unspecified) (n = 16) (Ashe, et al., 2015, Bickmore, et al., 2013, Broekhuizen, et al., 2016, Cook, et al., 2015, Frederix, et al., 2015, Keogh, et al., 2014, King, et al., 2007, Kullgren, et al., 2014, Leutwyler, et al., 2015, Lyons, et al., 2017, Nguyen, et al., 2009, Strand, et al., 2014, Tiedemann, Hassett and Sherrington, 2015, Vidoni, et al., 2016, Wijsman, et al., 2013, Williams, 2016), 4.1 instruction on how to perform a behaviour (n = 15) (Ashe, et al., 2015, Bickmore, et al., 2013, Broekhuizen, et al., 2016, Cook, et al., 2015, Frederix, et al., 2015, Keogh, et al., 2014, Knight, Stuckey and Petrella, 2015, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, O'Brien, et al., 2015, Ruiz, et al., 2012, Strand, et al., 2014, Wijsman, et al., 2013, Williams, 2016), 6.1 demonstration of the behaviour (n = 7) (Ashe, et al., 2015, Bickmore, et al., 2013, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, Ruiz, et al., 2012, Strand, et al., 2014, Williams, 2016), 7.1 prompts/cues (n = 4) (Ashe, et al., 2015, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009), 8.1 behavioural practice/ rehearsal (n = 9) (Ashe, et al., 2015, Bickmore, et al., 2013, Frederix, et al., 2015, Leutwyler, et al., 2015, Müller, Khoo and Morris, 2016, O'Brien, et al., 2015, Ruiz, et al., 2012, Strand, et al., 2014, Williams, 2016), 9.1 credible source (n = 7) (Ashe, et al., 2015, Broekhuizen, et al., 2016, King, et al., 2007, Lyons, et al., 2017, Nguyen, et al., 2009, Tiedemann, Hassett and Sherrington, 2015, Wijsman, et al., 2013) and 12.5 adding objects to the environment (n = 15) (Ashe, et al., 2015, Bickmore, et al., 2013, Broekhuizen, et al., 2016, Cadmus-Bertram, et al., 2015, King, et al., 2007, Leutwyler, et al., 2015, Lyons, et al., 2017, Nguyen, et al., 2009, O'Brien, et al., 2015, Ruiz, et al., 2012, Strand, et al., 2014, Tiedemann, Hassett and Sherrington, 2015, Vidoni, et al., 2016, Wijsman, et al., 2013, Williams, 2016). The average number of BCTs reported in a study was 6.6 (range 2 – 23; median = 5.5) and the average number of BCT clusters was 5.10 (range 2 – 12; median = 5). Of the studies included in the present review, 91% used ≥3 BCT clusters within the DBCI and the remaining studies used 2 BCT clusters (Keogh, et al., 2014, Knight, Stuckey and Petrella, 2015).

3.3.1. Quality assessment

Of the 22 studies, 15 were evaluated using the RCT appraisal checklist (Ashe, et al., 2015, Bickmore, et al., 2013, Broekhuizen, et al., 2016, Cadmus-Bertram, et al., 2015, Cook, et al., 2015, Frederix, et al., 2015, King, et al., 2007, King, et al., 2014, Kullgren, et al., 2014, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, Ruiz, et al., 2012, Vidoni, et al., 2016, Wijsman, et al., 2013) and seven with the quasi-experimental (non-randomized) checklist (Keogh, et al., 2014, Knight, Stuckey and Petrella, 2015, Leutwyler, et al., 2015, O'Brien, et al., 2015, Strand, et al., 2014, Tiedemann, Hassett and Sherrington, 2015, Williams, 2016). Seven studies were deemed lower risk of bias (Keogh, et al., 2014, Knight, Stuckey and Petrella, 2015, Leutwyler, et al., 2015, O'Brien, et al., 2015, Strand, et al., 2014, Tiedemann, Hassett and Sherrington, 2015, Williams, 2016), 12 were moderate risk of bias (Ashe, et al., 2015, Broekhuizen, et al., 2016, Cadmus-Bertram, et al., 2015, Cook, et al., 2015, Frederix, et al., 2015, King, et al., 2007, King, et al., 2014, Kullgren, et al., 2014, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, Wijsman, et al., 2013) and three were higher risk of bias (Bickmore, et al., 2013, Ruiz, et al., 2012, Vidoni, et al., 2016) (Appendix D).

In RCT studies, true randomization for assignment to groups was present in five studies (Ashe, et al., 2015, Cook, et al., 2015, Frederix, et al., 2015, Kullgren, et al., 2014) (Appendix D). Other studies were randomized but stratified by age (Cadmus-Bertram, et al., 2015),sex (Broekhuizen, et al., 2016, Wijsman, et al., 2013, King, et al., 2007, King, et al., 2014, Nguyen, et al., 2009), BMI (Cadmus-Bertram, et al., 2015), clinic site and health literacy status (Bickmore, et al., 2013) or enrolling with or without their spouse (Müller, Khoo and Morris, 2016). Allocation to groups was concealed in eight studies (Ashe, et al., 2015, Broekhuizen, et al., 2016, Frederix, et al., 2015, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, Vidoni, et al., 2016, Wijsman, et al., 2013), was unclear in four studies (Cadmus-Bertram, et al., 2015, King, et al., 2007, King, et al., 2014, Ruiz, et al., 2012) and was not possible in three studies (Bickmore, et al., 2013, Cook, et al., 2015, Kullgren, et al., 2014). Groups were similar at baseline in 11 studies (Bickmore, et al., 2013, Broekhuizen, et al., 2016, Cadmus-Bertram, et al., 2015, Cook, et al., 2015, Frederix, et al., 2015, King, et al., 2007, King, et al., 2014, Müller, Khoo and Morris, 2016, Lyons, et al., 2017, Ruiz, et al., 2012, Wijsman, et al., 2013), was unclear in one study (Nguyen, et al., 2009), and were not similar in three studies due to weight at baseline (Ashe, et al., 2015), number of steps walked at baseline (Kullgren, et al., 2014), and cognitive impairment (with/without) and average weekly step count at baseline (Vidoni, et al., 2016). A common feature was the inability to blind participants (n = 14) (Ashe, et al., 2015, Bickmore, et al., 2013, Broekhuizen, et al., 2016, Cook, et al., 2015, Frederix, et al., 2015, King, et al., 2007, King, et al., 2014, Kullgren, et al., 2014, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, Ruiz, et al., 2012, Vidoni, et al., 2016, Williams, 2016) and those who delivered the intervention (n = 15) (Ashe, et al., 2015, Bickmore, et al., 2013, Broekhuizen, et al., 2016, Cadmus-Bertram, et al., 2015, Cook, et al., 2015, Frederix, et al., 2015, King, et al., 2007, King, et al., 2014, Kullgren, et al., 2014, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, Ruiz, et al., 2012, Vidoni, et al., 2016, Williams, 2016) to group assignments due to the nature of the interventions. In addition, in seven of the RCT studies (Bickmore, et al., 2013, Broekhuizen, et al., 2016, Cadmus-Bertram, et al., 2015, Cook, et al., 2015, Ruiz, et al., 2012, Vidoni, et al., 2016, Wijsman, et al., 2013) it was unclear whether the outcome assessors were blinded to group assignment and in two it was not possible to blind the outcome assessors to the group assignment (Lyons, et al., 2017, Müller, Khoo and Morris, 2016). Groups were treated identically in 12 studies (Ashe, et al., 2015, Bickmore, et al., 2013, Broekhuizen, et al., 2016, Cadmus-Bertram, et al., 2015, Cook, et al., 2015, King, et al., 2007, King, et al., 2014, Kullgren, et al., 2014, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, Vidoni, et al., 2016, Wijsman, et al., 2013) and was unclear in two studies (Frederix, et al., 2015, Ruiz, et al., 2012). All 15 studies critically appraised using the RCT checklist adequately described and analysed differences in groups at follow up, analysed participants in the groups they were randomized, measured outcomes in the same way for all groups, outcomes were measured in a reliable way, used appropriate statistical analysis and the trial design was appropriate and accounted for any deviations.

Using the quasi-experimental (non-randomized) tool, all seven studies had clear cause and effect variables, participants in comparisons were similar and received similar treatment, multiple measures of outcomes were taken pre and post intervention, completed follow up and, if not adequately described, and analysed differences, measured outcomes in the same and a reliable way, and appropriate statistical analysis was conducted (Keogh, et al., 2014, Knight, Stuckey and Petrella, 2015, Leutwyler, et al., 2015, O'Brien, et al., 2015, Strand, et al., 2014, Tiedemann, Hassett and Sherrington, 2015, Williams, 2016) (Appendix D). Six studies did not have a control group; however, one study did have a control group (Keogh, et al., 2014).

Table 2. Characteristics of included studies.

Author (year)	Country	Study design	Population description	Sample size	Retention rate at follow-up	Men %	Age in years mean (SD)	Age range (yrs)	Conflicts of interest
Ashe (2015)	Canada	RCT	Healthy, community-dwelling, inactive	20 Int. = 12 Con. = 8	80% (20/25)	0	64.95 (4.7)	55-70	None declared
Bickmore (2013)	USA	RCT	Community-dwelling, inactive	113 Int. = 55 Con. = 58	48.7% (128/ 263)	38.8	71.3 (5.4)	65+	None declared
Broekhuizen (2016)	Netherlands	RCT	Community-dwelling, inactive	216 Int. = 107 Cont. = 109	95.7% (225/ 235)	59.1	64.8 (2.9)	60-70	Willem van Mechelen is director-shareholder of VU University Medical Center Amsterdam spin-off company Evalua Nederland B.V. (www.evalua.nl) and non-executive board member of Arbo Unie B.V. (www.arbounie.nl). Both companies operate on the Dutch occupational health care market.
Cadmus-Bertram (2015)	USA	RCT	Overweight, post-menopausal women, inactive	51 Int. = 25 Con. = 26	100% (51/51)	0	60 (7.1)	NR	None declared

Author (year)	Country	Study design	Population description	Sample size	Retention rate at follow-up	Men %	Age in years mean (SD)	Age range (yrs)	Conflicts of interest
Cook (2015)	USA	RCT	Community-dwelling	278 Int. = 138 Con. = 140	100% (278/ 278)	67.3	NR	50-68	The HealthyPast50 program tested in this study is owned by ISA Associates, Inc, a company of which RC and RH are owners.
Frederix (2015)	Belgium	RCT	Heart disease patients	139 Int. = 69 Con. = 70	99.3% (139/ 140)	81.4	61 (8.5)	NR	None declared
Keogh (2014)	New Zealand	Pre – post mixed methods	Living in residential care setting	26 Int. = 13 Con. = 13	100% (34/34)	11.8	83 (8)	NR	NR
King (2007)	Canada	RCT	Community-dwelling, inactive	189 Automated = 61 Human = 66 Con. = 62	78.3% (148/ 189)	NR	60 (5.5)	55+	NR

Author (year)	Country	Study design	Population description	Sample size	Retention rate at follow-up	Men %	Age in years mean (SD)	Age range (yrs)	Conflicts of interest
King (2014)	Canada	RCT	Community-dwelling, inactive	127 Automated = 61 Human = 66	86.7% (189/ 218)	30.7	60 (5.5)	55+	Boston Medical Center (BMC) Inc. has a copyright for the computer-based technology (Telephone-Linked Care [TLC]) that was used in the automated advisor intervention program described. In 1992, BMC gave InfoMedics Inc. the commercial rights in the TLC technology. Dr. Friedman has stock ownership and a consultancy agreement with InfoMedics, and is a member of its Board of Directors.
Knight (2015)	Canada	Pre – post	Generally healthy	45 Exercise = 15 Sedentary = 14 Counselling = 16	100% (45/45)	44.4	63 (5)	55-75	None declared

Author (year)	Country	Study design	Population description	Sample size	Retention rate at follow-up	Men %	Age in years mean (SD)	Age range (yrs)	Conflicts of interest
Kullgren (2014)	Canada	RCT	Healthy	92 Financial = 20 Peer = 22 Combined = 25 Con. = 25	92.4% (85/92)	30	71.9 (5.6)	65+	NR
Leutwyler (2015)	Canada	Pre – post	Diagnosis of schizophrenia or schizoaffective disorder	15	100% (20/20)	80	60.3 (4.4)	55+	None declared
Lyons (2017)	USA	RCT	Overweight and obese, inactive	40 Int. = 20 Con. = 20	100% (40/40)	15	61.5 (5.6)	55-79	MCS's spouse has an equity interest in Apple Inc, a company that may potentially benefit from the research results. In addition, ZHL is employed by Beachbody, a company that may potentially benefit from the research results. ZHL's employment began after data collection and analysis. UTMB's Conflicts of Interest Committee has reviewed these conflicts and a management plan was implemented to prevent any

Author (year)	Country	Study design	Population description	Sample size	Retention rate at follow-up	Men %	Age in years mean (SD)	Age range (yrs)	Conflicts of interest
									appearance of a conflict of interests.
Müller (2016)	Malaysia	RCT	Generally healthy, inactive	39 Int. 18 Con. = 21	90.7% (39/43)	26	63.3 (4.5)	55-70	None declared
Nguyen (2009)	USA	RCT	Stable COPD	17 Int. = 9 Con. = 8	94.4% (17/18)	35.3	68 (10.5)	52-81	None declared
O'Brien (2015)	Canada	Pre – post	Community-dwelling	34	100% (34/34)	35	73.5 (9.4)	60-96	None declared
Ruiz (2012)	Canada	RCT	Overweight and obese Veterans, inactive	21 Self = 7 Other = 7 Con. = 7	93.3% (28/30)	96.4	62 (6)	50+	NR
Strand (2014)	Canada	Pre – post	Eligible to participate in congregate meal sites	46	67.6% (46/68)	13	NR	60+	NR

Author (year)	Country	Study design	Population description	Sample size	Retention rate at follow-up	Men %	Age in years mean (SD)	Age range (yrs)	Conflicts of interest
Tiedemann (2015)	Australia	Pre – post	Community-dwelling, inactive	35	92.1% (35/38)	34.0	67.7 (5.5)	60+	None declared
Vidoni (2016)	Canada	Randomized cross over	(Very) mild cognitive impairment	20 Cog Imp = 12 Con. = 8	69% (20/29)	69.0	71 (5.5.)	60-85	None declared
Wijsman (2013)	Netherlands	RCT	Community-dwelling, inactive	216 Int. = 107 Con. = 109	96.2% (226/ 235)	59.1	64.8 (2.9)	60-70	None declared
Williams (2016)	Canada	Pre – post quasi-experimental	Living in residential care setting	24	100% (24/24)	33.3	79.33 (11.09)	50-99	NR

Int., Intervention; Con., Control; COPD, Chronic Obstructive Pulmonary Disease; NR, not reported

Table 3. Intervention types from included studies

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
Ashe (2015)	Fitbit One	24	Reducing sitting time to encourage PA (n=1)	Group-based education and social support, individualized PA prescription, use of activity monitor (Fitbit One). Phase 1 'ramp up' 4 weekly sessions. Phase 2 'activation' 5 monthly sessions.	Monthly education sessions similar to intervention group. No Fitbit, no information on importance of exercise, no interactions with exercise professionals.	1.1 Goal setting (behaviour), 1.2 Problem solving, 1.4 Action planning, 2.2 Feedback on behaviour, 2.3 Self-monitoring of behaviour, 3.1 Social support (unspecified), 4.1 Instruction on how to perform the behaviour, 5.3 Information about social and environmental consequences, 6.1 Demonstration of the behaviour, 6.2 Social comparison, 7.1 Prompts/cues, 8.1 Behavioural practice/rehearsal, 8.2 Behaviour substitution, 8.4 Habit reversal, 9.1 Credible source, 12.5 Adding objects to the environment (BCT n=16) (Clusters n=10)	Intervention group session attendance range n=6 to n=13 (46-100%); median (IQR) = 10 (3.8) participants/session. Control median (IQR) attendance = 6.5 (1.8).

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
Bickmore (2013)	Tablet, app, pedometers	52	Increasing PA (n=1)	Tablet with embodied conversational agents (ECA) (animated) to motivate participants to do more walking and pedometers	Encouraged to wear pedometers every day and complete monthly logs to track step count	1.2 Problem solving, 2.2 Feedback on behaviour, 2.3 Self-monitoring of behaviour, 3.1 Social support (unspecified), 4.1 Instruction on how to perform the behaviour, 6.1 Demonstration of the behaviour, 8.1 Behavioural practice/rehearsal, 10.3 Non-specific reward, 12.5 Adding objects into the environment (BCT n=9) (Clusters n=8)	Intervention interacted with take-home virtual coach an average of 35.8 ± 19.7 times during first 60-days. Decreased after first week (average of 4.7 per week to 4.0) then to 3.3 sessions/week Used waiting room kiosks 1.0 +/- 2.9 times during 10-month period between 2 and 12 months
Broekhuizen (2016)	Website, e-coach, accelerometer	12	Increasing daily PA (n=1)	Internet based PA program. DirectLife - accelerometer based activity monitor, personal website, and e-coach	3 month waiting list	1.1 Goal setting (behaviour), 1.3 Goal setting (outcome), 1.5 Review behaviour goal(s), 2.2 Feedback on behaviour, 4.1 Instruction on how to perform the behaviour, 9.1 Credible source, 12.5 Adding objects into the environment	Not reported

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
						(BCT n=8) (Clusters n=6)	
Cadmus-Bertram (2015)	Fitbit One and Fitbit website (PA data only)	16	Increasing PA (n=1)	Fitbit One and Fitbit website (PA data only). Asked to perform 150min/week MVPA and walk 10,000 steps/day.	Basic step-counting pedometer, printed materials with tips for increasing steps	1.3 Goal setting (outcome), 1.9 Commitment, 2.3 Self-monitoring of behaviour, 12.5 Adding objects into the environment (BCT n=4) (Clusters n=3)	88% used website, 52% logging in 2-3 day/week. 72% viewed tracker data on device 1 time/day). 80% had no computer issues, 80% had no technical difficulty with tracker, 84% no issues with lost/broken tracker.
Cook (2015)	Web-based education	12	Healthy ageing, - diet, PA, stress management, tobacco use (n=4)	HealthyPast50 - web-based multimedia program with information and guidance on major health promotion topics of healthy ageing, diet, PA, stress management and tobacco use.	Wait-list	3.1 Social support (unspecified), 4.1 Instruction on how to perform the behaviour, 5.1 Information about health consequences, 5.3 Information about social and environmental consequences (BCT n=4) (Clusters n=3)	Mean logins 4.33 (SD=4.28; range 0-28). Mean minutes in program 102.26 minutes (SD=148.32). Mean number of pages viewed 11.04 (SD=20.08; range 0-120)

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
Frederix (2015)	Website, accelerometer, semiautomatic SMS text messages, emails, dietary telecoaching	24	Cardiac rehabilitation core elements – PA, diet, smoking cessation (n=3)	Internet based telerehabilitation program, accelerometer data and website, semiautomatic SMS texts messaging 1x week, pre-defined exercise goals, emails tailored to helpful services, dietary telecoaching, Plus, 12-week conventional centre-based cardiac rehabilitation program, with at least 2 exercise sessions/week, with endurance training, dietitian, psychologist.	Centre-based cardiac rehabilitation program only, at least 2 sessions/week, with including endurance training, dietitian, psychologist.	2.2 Feedback on behaviour, 3.1 Social support (unspecified), 4.1 Instruction on how to perform the behaviour, 5.1 Information about health consequences, 5.3 Information about social and environmental consequences, 8.1 Behavioural practice/ rehearsal (BCT n=6) (Clusters n=5)	Patients transmitted activity data mean 1.0 (SD=0.3) times/week.

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
Keogh (2014)	Nintendo Wii Sports (NWS)	8	Functional ability, PA (n=2)	Nintendo Wii Sports (baseball, boxing, golf, tennis, and 10-pin bowling). Participants selected the frequency, duration, and type of games they wished to play.	No treatment. Underwent normal activities of daily living	3.1 Social support (unspecified), 4.1 Instruction on how to perform the behaviour) (BCT n=2) (Clusters n=2)	Mean 30 ± 24 minutes (range 1-105 min) of NWS/week.
King (2007)	Automated computer controlled interactive phone system	78	Regular MVPA (n=1)	CHAT - homebased moderate intensity PA program delivered by automated computer controlled interactive telephone system or human advice via telephone.	Weekly health education classes	1.2 Problem solving, 1.3 Goal setting (outcome), 1.4 Action planning, 2.2 Feedback on behaviour, 2.3 Self-monitoring of behaviour, 3.1 Social support (unspecified), 9.1 Credible source, 12.5 Adding objects into the environment (BCT n=8) (Clusters n=5)	NR
King (2014)	Automated computer controlled interactive phone system	26	Regular MVPA (n=1)	CHAT - homebased moderate intensity PA program delivered by automated	Weekly health education classes	Follow-up study to King 2007	NR

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
				computer controlled interactive telephone system or human advice via telephone.			
Knight (2015)	Smartphone app (health anywhere), Blackberry Curve 8530, Bluetooth enabled blood pressure monitor, glucometer with polymap wireless adaptor, pedometer	12	Exercise, OR sedentary behaviour, OR Both exercise and sedentary behaviour (n= 1 or 2)	All groups had access to smartphone, app, Bluetooth blood pressure monitor, glucometer with wireless adaptor and pedometer. Exercise group: PA prescription targeting increases in high-intensity activity (i.e. exercise). Sedentary behaviour group: PA prescription targeting reductions and interruptions in low-	n/a	2.3 Self-monitoring of behaviour, 2.4 Self-monitoring of outcome(s) of behaviour(s), 4.1 Instruction on how to perform the behaviour (BCT n=3) (Clusters n=2)	NR

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
				intensity daily activity. Comprehensive counselling group: Activity prescription targeting both Exercise and Sedentary behaviours (see above).			

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
Kullgren (2014)	Fitbit pedometer, automated email/text feedback	24	Walking (n=1)	Financial incentive group: Wore pedometers, automated email/text feedback about how often they met goal. Entry into lottery to win money if met goal Peer network group: wore pedometers, automated email/text feedback about how often met goal. Access to online message board where they could communicate with 4 other participants. Combined group: Used both financial and peer network intervention simultaneously	Fitbit pedometer. Goal to increase daily steps by 50%. No specific instructions but provided links to National Institutes of Health information on exercise and walking.	1.1 Goal setting (behaviour), 2.2 Feedback on behaviour, 3.1 Social support (unspecified) (peer only), 10.1 Material incentive (behaviour) (financial only) (BCT n=4) (Clusters n=4)	Posts in Peer network and combined group by individual (median =1 post, range 0-27), and peer group (median 5 posts, range 0-71). 47% never posted a message.

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
Leutwyler (2015)	Xbox 360 Kinect	6	Increasing PA (n=1)	Kinect Xbox 360 for 30min once a week. Most often played games were bowling, dance, carnival games, skiing, tai chi, baseball, darts, golf, river rafting and 20,000 leaks under the sea. Groups of 3-4	n/a	3.1 Social support (unspecified), 8.1 Behavioural practice/ rehearsal, 12.5 Adding objects into the environment (BCT n=3) (Clusters n=3)	Mean number of groups attended 5.6 out of 6 (SD=0.8). Mean total minutes attended 169 out of 180 (SD=23.7) 70% (n=14) perfect attendance.
Lyons (2017)	Jawbone Up24, Jawbone Up app on iPad mini	12	Increasing PA, decreasin g sedentary behaviour (n=2)	Jawbone Up24 and app. Weekly telephone behavioural counselling.	Wait-list	1.1 Goal setting (behaviour), 1.2 Problem solving, 1.4 Action planning, 1.5 Review behaviour goal(s), 1.6 Discrepancy between current behaviour and goal, 1.9 Commitment, 2.2 Feedback on behaviour, 2.3 Self-monitoring of behaviour, 3.1 Social support (unspecified), 3.3 Social support (emotional), 4.1 Instruction on how to perform the behaviour, 4.2 Information about antecedents, 5.1 Information about health consequences, 5.3	Mean of 10.2 (SD=2.4) of 12 counselling calls Wore Up24 monitors mean 81.85 (SD=3.73) of 90 days 5 Up24 monitors reported broken, 1 lost, and replaced.

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
						Information about social and environmental consequences, 5.4 Monitoring of emotional consequences, 5.6 Information about emotional consequences, 6.2 Social comparison, 7.1 Prompts/ cues, 8.2, Behaviour substitution 9.1 Credible source, 10.4 Social reward, 12.5 Adding objects into the environment, 15.3 Focus on past success (BCT n=23) (Clusters n=12)	
Müller (2016)	SMS text messaging	12	Exercise (n=1)	Exercise booklet and SMS text messaging (instructions to exercise, rewards/praise)	Exercise booklet only.	2.2 Feedback on behaviour, 4.1 Instruction on how to perform the behaviour, 6.1 Demonstration of the behaviour, 7.1 Prompts/ cues, 8.1 Behavioural practice/ rehearsal, 10.3 Non-specific incentive (BCT n=6) (Clusters n=6)	50% read all 60 SMS messages 39% ignored SMS messages after some time

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
Nguyen (2009)	Mobile Coaching, pedometer	12	Exercise persistence (n=1)	Information entered on mobile phone and was praised and encouraged by e-coach when desired behaviour performed	Entered information on mobile phone. No e-coach.	1.2 Problem solving, 2.2 Feedback on behaviour, 2.3 Self-monitoring of behaviour, 2.4 Self-monitoring of outcome(s) of behaviour, 3.1 Social support (unspecified), 4.1 Instruction on how to perform the behaviour, 6.1 Demonstration of the behaviour, 7.1 Prompts/ cues, 9.1 Credible source, 12.5 Adding objects into the environment (BCT n=10) (Clusters n=8)	MOBILE-C 87% submitted exercise and symptom data MOBILE-SM 66% submitted exercise and symptom data
O'Brien (2015)	Nike Fuel Band	12	Nutrition, PA (n=2)	Nike Fuel band, document steps and calories on paper diary (no access to computer/smartphone), plus weekly 45min session on strategies to change PA and nutrition, plus 30min group walking session each week led by researcher	n/a	1.2 Problem solving, 2.3 Self-monitoring of behaviour, 2.4 Self-monitoring of outcome(s) of behaviour, 4.1 Instruction on how to perform the behaviour, 8.1 Behavioural practice/ rehearsal, 12.5 Adding objects into the environment (BCT n=6) (Clusters n=5)	NR

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
Ruiz (2012)	Virtual reality	8	Exercise adherence (n=1)	10 min VR session weeks 0, 2 and 4. Virtual representation of the physical self (VRS) exercising condition with an avatar resembling the subjects' heads, or Virtual representation of other (VRO) exercising condition with an avatar featuring an unknown person's head of the same sex, skin colour and approximately same age. Plus, 10min presentation about basic principles of PA and instructions how to perform different types of exercise.	VR without avatar just static graphics depicting the PA routine. Plus, 10min presentation about basic principles of PA and instructions how to perform different types of exercise.	4.1 Instruction on how to perform the behaviour, 6.1 Demonstration of the behaviour, 8.1 Behavioural practice/ rehearsal, 12.5 Adding objects into the environment (BCT n=4) (Clusters n=4)	NR
Strand (2014)	Nintendo Wii Active	24	Holistic health –	LIFE Program - Wii active onsite	n/a	3.1 Social support (unspecified), 4.1 Instruction	NR

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
			physical (exercise), emotional, intellectual , and social (n=unknown)	exergaming (8wks) lead by younger adult trainers (aged 19-26 years) 2x week. Then newsletter intervention for following 16wks		on how to perform the behaviour, 6.1 Demonstration of the behaviour, 8.1 Behavioural practice/ rehearsal, 12.5 Adding objects into the environment (BCT n=5) (Clusters n=5)	
Tiedemann (2015)	Telephone coaching, Fitbit	12	PA promotion and Fall prevention (n=2)	Fall prevention strategies, telephone health-based coaching, Fitbit	n/a	1.3 Goal setting (outcome), 2.3 Self-monitoring of behaviour, 3.1 Social support (unspecified), 9.1 Credible source, 12.5 Adding objects into the environment (BCT n=5) (Clusters n=5)	All participants used the Fitbit enhanced pedometer and synchronized it at least once//week with internet-based software
Vidoni (2016)	Fitbit Zip and coach	16	Increasing PA (n=1)	Fitbit Zip unmasked. Telephone coach biweekly, exercise prescription booklet	Delayed start. Fitbit Zip masked weeks 1-8. Completed intervention in week 9-16.	1.1 Goal setting (behaviour), 1.2 Problem solving, 2.3 Self-monitoring of behaviour, 3.1 Social support (unspecified), 12.5 Adding objects into the environment (BCT n=5) (Clusters n=4)	NR
Wijsman (2013)	Website, e-coach,	12	Increasing daily PA (n=1)	Internet based PA program - DirectLife -	3-month wait-list	1.1 Goal setting (behaviour), 1.3 Goal setting (outcome), 1.5 Review behaviour	Intervention group: 91.2% (104/114)

Author (year)	Intervention type	Study duration (wks)	Target behaviour (n)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
	acceleromete r			accelerometer based activity monitor, personal website, and e-coach		goal(s), 2.2 Feedback on behaviour, 4.1 Instruction on how to perform the behaviour, 9.1 Credible source, 12.5 Adding objects into the environment (BCT n=8) (Clusters n=6)	completed 12-week program
Williams (2016)	Nintendo Wii Sports	6	Increasing PA (n=1)	Nintendo Wii Sports (tennis, bowling, or golf as they allow 4 players to play simultaneously). 45min session including 15min educational component based on Go4Life. Bi-weekly sessions	n/a	Average number sessions attended 9.67. 25% participants (n=6) attended all 12 sessions	

PA, physical activity; MVPA, moderate-to-vigorous physical activity; NR, Not reported.

*In relation to BCT Taxonomy v1 (Michie, et al., 2013)

**Individualized intervention duration. Range provided.

Table 4. Outcome measures for studies included

Author (year)	Physical activity outcome measures	Physical activity measurement	Sedentary behaviour outcome measures	Sedentary behaviour measurement	Other outcomes measured	Confounding Variables	Risk of bias
Ashe (2015)	PA min/day Steps/day	Accelerometer (Actigraph GT3X+)	% time/day	Accelerometer (Actigraph GT3X+)	BMI, weight, SBP, DBP, Behaviour intentions, exercise self-efficacy, self-rated health, social support	Education, employment, baseline measures	Low
Bickmore (2013)	Steps/day	Accelerometer (Omron pedometer HJ-720ITC)	n/a	n/a	None	Sex, literacy category, clinic location, average steps per day during days 1-13 (baseline)	Medium
Broekhuizen (2016)	Change in PA in relation to QoL measures	Accelerometer (GeneActiv – wrist worn)	n/a	n/a	Height, weight, BMI, functioning (physical/ social), role limitations (physical/ emotional) emotional/ mental health, vitality, pain, general health perception, health change, total RAND-36 score	Age, sex, BMI	Medium
Cadmus-Bertram (2015)	PA min/week Steps/day Bouts of MVPA Bouts of Light PA	Accelerometer (Actigraph GT3X+)	n/a	n/a	Technology use, weight, BMI	Age, weartime	Medium

Author (year)	Physical activity outcome measures	Physical activity measurement	Sedentary behaviour outcome measures	Sedentary behaviour measurement	Other outcomes measured	Confounding Variables	Risk of bias
Cook (2015)	Steps/day Change in IPAQ scores	Godin Leisure-time exercise questionnaire	SB min/week	n/a	Diet, BMI, symptoms of distress, coping with stress, ageing beliefs	Gender, age, race, marital status, education, income	Medium
Frederix (2015)	PA min/day	Accelerometer (Yorbody)	n/a	IPAQ	VO2 peak, HR max, Watts, Watts (pred%), first ventilatory threshold (Watts and bpm), oxygen uptake efficiency slope, weight, BMI, DBP, SBP, Heart-QoL	None mentioned	Medium
Keogh (2014)	PA min/day Energy expenditure MVPA days/week	Rapid Assessment of Physical Activity questionnaire (RAPA)	n/a	n/a	Functional performance, QoL	None mentioned	Low
King (2007)	Steps/day	Stanford 7-day physical activity recall (PAR)	n/a	n/a	None	Adjusted for 12-month measures	Medium

Author (year)	Physical activity outcome measures	Physical activity measurement	Sedentary behaviour outcome measures	Sedentary behaviour measurement	Other outcomes measured	Confounding Variables	Risk of bias
King (2014)	Steps/day	Stanford 7-day physical activity recall (PAR)	n/a	n/a	PAR energy expenditure, PAR days/week engaged in 30min or more MVPA, CHAMPS energy expenditure, CHAMPS mins of MVPA, CHAMPS times/week engaged in 30min or more MVPA	Baseline adjusted	Medium
Knight (2015)	Stepping time min/day Steps/day	Accelerometer (Omron pedometer HJ-150)	n/a	n/a	Weight, SBP, DBP, blood glucose	Age, sex, group assignment	Low
Kullgren (2014)	Change in steps/day Number of days walking goals met	Accelerometer (Fitbit)	n/a	n/a	None	Household residents, education, employment status, annual household income, race/ethnicity, health status, motivation to increase walking, relative autonomy index	Medium
Leutwyler (2015)	Change in PA (Number of participants)	Accelerometer (SenseWear Pro Armband)	Change in sedentary hours (Number of participants)	Accelerometer (SenseWear Pro Armband)	None	Smoking status, residence, race	Low
Lyons (2017)	PA min/day Steps/day	Accelerometer (ActivPAL)	SB min/day	Accelerometer (ActivPAL)	Body fat %, weight, fitness	Cohort,	Low

Author (year)	Physical activity outcome measures	Physical activity measurement	Sedentary behaviour outcome measures	Sedentary behaviour measurement	Other outcomes measured	Confounding Variables	Risk of bias
Müller (2016)	PA related energy expenditure (MET-min per week)	IPAQ	SB hours/day (change in)	IPAQ	Exercise self-efficacy score, BMI, grip strength, lower body strength (repetitions in 30sec chair stand test)	None mentioned	Medium
Nguyen (2009)	Steps/day % time in moderate-high activity steps/min	Accelerometer (Stepwatch 3 Activity Monitor)	% time/day	Accelerometer (Stepwatch 3 Activity Monitor)	Incremental cycle test, six-minute walk, peak performance, changes in health-related QoL	None mentioned	Medium
O'Brien (2015)	Steps/day	Accelerometer (Nike Fuel wristband)	n/a	n/a	BMI, WC, SBP, DBP, HR, timed up and go	No confounders adjusted for. Race, Marital status, income, education	Low
Ruiz (2012)	PA related energy expenditure (Kcal/day	Accelerometer (Actigraph GT3X)	n/a	n/a	Self-efficacy	None mentioned	Medium
Strand (2014)	Change in self-report PA (Number of participants)	Cancer Prevention Research Centers Stages of Change PA	n/a	n/a	Perceived physical wellness, program evaluation, successful program site characteristics	None adjusted for. Measured = Ethnicity (white, non-white), general health, marital status, living arrangement, contact with youth in a day PA participation	Low

Author (year)	Physical activity outcome measures	Physical activity measurement	Sedentary behaviour outcome measures	Sedentary behaviour measurement	Other outcomes measured	Confounding Variables	Risk of bias
Tiedemann (2015)	Steps/day	Accelerometer (Pre-Actigraph; Post-Fitbit)	n/a	n/a	None	No confounders adjusted for. Lives alone, English spoken at home, accommodation type, total medications, total co-morbidities, fallen in past year, number of risk factors identified, self-rated balance fair/poor, self-rated fear of falling ≥moderate.	Low
Vidoni (2016)	Steps/week	Accelerometer (Fitbit Zip)	n/a	n/a	Mini physical performance test, 6-min walk (yards), QoL-AD, Self-efficacy	None mentioned	Medium

Author (year)	Physical activity outcome measures	Physical activity measurement	Sedentary behaviour outcome measures	Sedentary behaviour measurement	Other outcomes measured	Confounding Variables	Risk of bias
Wijsman (2013)	Change in PA min/day	Accelerometer (Geneactiv ankle and wrist worn)	n/a	n/a	Weight, BMI, HC, WC, waist/hip ratio, fat %, lean mass, SBP, DBP, HR, grip strength, Framingham 10-year CVD risk %, fasting glucose venous, fasting insulin, HbA1c, HOMA, TC, HDL, Ln triglyceride, LDL, TC:HDL ratio, Ln C-reactive protein	None adjusted for. Measured = degree of self-reported PA, education, smoking, alcohol use, medical history, and medication use	Medium
Williams (2016)	RAPA Scores	RAPA Questionnaire	n/a	n/a	Barriers to exercise, self-efficacy, benefits of exercise	None mentioned	Low

WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure, HR, heart rate; HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol; QoL, quality of life; TC, total cholesterol; HC, hip circumference; HOMA, homeostatic model assessment.

3.3.2. Main results

3.3.2.1. Physical activity measurement

Outcome measures and confounding variables for each study can be found in Table 4. All studies included in the review reported on PA outcomes. PA was measured objectively in 17 studies – four used Actigraph GT3X+ accelerometers (Ashe, et al., 2015, Cadmus-Bertram, et al., 2015, Ruiz, et al., 2012, Tiedemann, Hassett and Sherrington, 2015), two used Omron pedometers (Bickmore, et al., 2013, Knight, Stuckey and Petrella, 2015), two used GeneActiv accelerometers (Broekhuizen, et al., 2016, Wijsman, et al., 2013), one used an ActivPAL inclinometer (Lyons, et al., 2017), one used Yorbody accelerometer (Frederix, et al., 2015), three used a Fitbit (Kullgren, et al., 2014, Tiedemann, Hassett and Sherrington, 2015, Vidoni, et al., 2016), one used a Nike Fuel wristband (O'Brien, et al., 2015), one used a SenseWear Pro Armband (Leutwyler, et al., 2015), one used a Stepwatch 3 (Nguyen, et al., 2009) – and using self-report questionnaires in seven studies – one used the Godin Leisure-Time Exercise Questionnaire (Cook, et al., 2015), one used the International Physical Activity Questionnaire (IPAQ) (Müller, Khoo and Morris, 2016), two used the Rapid Assessment of Physical Activity questionnaire (RAPA) (Keogh, et al., 2014, Williams, 2016), two used the Stanford 7-day physical activity recall (PAR) (King, et al., 2007, King, et al., 2014), one used the Cancer Prevention Research Centers Stages of Change Physical Activity (Strand, et al., 2014).

3.3.2.2. Total physical activity narrative results

Overall 15 studies, including 10 RCTs (Ashe, et al., 2015, Bickmore, et al., 2013, Cadmus-Bertram, et al., 2015, Kullgren, et al., 2014, Lyons, et al., 2017, Nguyen, et al., 2009, Vidoni, et al., 2016, Ruiz, et al., 2012, Frederix, et al., 2015, Müller, Khoo and Morris, 2016) and five pre-post-test studies (Knight, Stuckey and Petrella, 2015, O'Brien, et al., 2015, Tiedemann, Hassett and Sherrington, 2015, Williams, 2016, Keogh, et al., 2014) measured total PA. Objectively measured steps were used in the total PA meta-analysis where available (Ashe, et al., 2015, Bickmore, et al., 2013, Cadmus-Bertram, et al., 2015, Kullgren, et al., 2014, Lyons, et al., 2017, Nguyen, et al., 2009, Knight, Stuckey and Petrella, 2015, O'Brien, et al., 2015, Vidoni, et al., 2016, Tiedemann, Hassett and Sherrington, 2015), and questionnaire data on PA was also used (Keogh, et al., 2014, Williams, 2016, Müller, Khoo and Morris, 2016, Ruiz, et al., 2012). PA measured by step count was reported as median and interquartile range in Frederix, et al. (2015) so was not entered into the meta-analysis model. PA in Strand, et al. (2014) was reported as the number of people who had a change in self-reported PA – by week 8 five inactive people became active and by week 25, 6 more became active – so was not entered into the meta-analysis model. No score of total PA was available or calculable for Broekhuizen, et al. (2016), King, et al. (2007), King, et al. (2014), Leutwyler, et al. (2015) or Wijsman, et al. (2013).

3.3.2.3. Total physical activity meta-analysis results

For the meta-analysis on total PA, Vidoni, et al. (2016) was entered as a pre-post study rather than an RCT using only participants without cognitive impairment for more appropriate comparisons between studies. Among RCT (EI), DBCI significantly increased total PA (N = 8, n = 450, SMD = 0.28; 95% CI 0.01, 0.56; p = 0.04; I^2 = 47%) (Table 5 and Table 6) (Ashe, et al., 2015, Bickmore, et al., 2013, Cadmus-Bertram, et al., 2015, Kullgren, et al., 2014, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, Ruiz, et al., 2012). A pooled analysis of two RCT (FU) studies (Bickmore, et al., 2013, Kullgren, et al., 2014) showed no increase in total PA (n = 255, SMD = 0.11; 95% CI -0.14, 0.36; p = 0.39; I^2 = 0%). Between-groups difference in total PA was found between RCT (EI) and RCT (FU) study designs (SMD = 0.19; 95% CI 0.004, 0.37; p = 0.05). DBCI significantly increased total PA in pre-post studies (N = 6, n = 159, SMD = 0.25; 95% CI 0.09, 0.41; p = 0.002; I^2 = 37%) (Knight, Stuckey and Petrella, 2015, O'Brien, et al., 2015, Tiedemann, Hassett and Sherrington, 2015, Vidoni, et al., 2016, Williams, 2016, Keogh, et al., 2014).

Among RCT (EI) with objectively measured PA, DBCI had no effect on total PA (N = 7, n = 411, SMD = 0.28; 95% CI -0.02, 0.06; p = 0.07; I2 = 52%) (Ashe, et al., 2015, Bickmore, et al., 2013, Cadmus-Bertram, et al., 2015, Kullgren, et al., 2014, Lyons, et al., 2017, Nguyen, et al., 2009, Ruiz, et al., 2012). One RCT (EI) study subjectively measured total PA and found no increase in total PA (SMD = 0.36, 95%CI -0.27, 1.00, p = 0.27; I^2 = 0%) (Müller, Khoo and Morris, 2016). A between-groups difference in total PA was found between objectively and subjectively measured PA in RCT (EI) (SMD = 0.30; 95% CI 0.02, 0.57; p = 0.03). Two RCT (FU) studies objectively measured total PA, thus results were the same as above and not reported again. DBCI significantly increased total PA in pre-post studies with objectively measured PA (N = 4, n = 122, SMD = 0.24; 95% CI 0.02, 0.45; p = 0.03; I^2 = 51%) (Knight, Stuckey and Petrella, 2015, O'Brien, et al., 2015, Tiedemann, Hassett and Sherrington, 2015, Vidoni, et al., 2016). Among subjectively measured PA pre-post studies, DBCI significantly increased total PA (N = 2, n = 37, SMD = 0.27; 95% CI 0.02, 0.53; p = 0.04; I^2 = 0%) (Keogh, et al., 2014, Williams, 2016). Between-groups difference in total PA was found between pre-post studies measuring PA objectively and subjectively (SMD = 0.25; 95% CI 0.09, 0.41; p = 0.003).

Among pre-post studies, DBCI with ≥3 BCT clusters significantly increased total PA (N = 4, n = 101, SMD = 0.37; 95% CI 0.21, 0.53; p < 0.001; I^2 = 0%) (Table 5 and Table 6) (O'Brien, et al., 2015, Tiedemann, Hassett and Sherrington, 2015, Vidoni, et al., 2016, Williams, 2016). In pre-post studies, DBCI with 1-2 BCT clusters had no effect on total PA (N = 2, n = 21, SMD = 0.09; 95% CI -0.14, 0.32; p = 0.44; I^2 = 21.93%) (Keogh, et al., 2014, Knight, Stuckey and Petrella, 2015). Between-groups difference in total PA was found between DBCI with 1-2 BCT clusters and ≥3 BCT clusters (SMD = 0.28; 95% CI 0.15, 0.24; p < 0.001; I^2 = 36.60%). Meta-analysis on total PA grouped by BCT cluster was not possible for RCT studies as all DBCI included ≥3 clusters.

3.3.2.4. Steps (per day) narrative results

Steps per day were available for 11 studies (RCT = 8, pre-post = 3). Frederix, et al. (2015) reported a pre-intervention daily step count (median = 7748, IRQ = 24) and post intervention at 6 weeks this had increased (median = 7799, IQR 37) and at 24 weeks had further increased (median = 8233, IQR = 32), however these changes were not significant ($p = 0.24$). As steps were reported as medians, likely due to the means being skewed, they were unable to be included in the meta-analysis. One study reported the number of participants that had no change in steps per day (n = 5) and who significantly increased their steps per day (n = 10) (Leutwyler, et al., 2015). In Vidoni, et al. (2016), for participants without cognitive impairment, weekly step count increased by 15530 steps (SD = 18950, $p = 0.05$); however weekly increase was reported – rather than daily – it was deemed inappropriate to assume a 7 day week and estimate standard deviations for daily steps. Therefore, this study was not included in the meta-analysis. Steps were not reported in seven studies (Broekhuizen, et al., 2016, Cook, et al., 2015, King, et al., 2007, King, et al., 2014, Strand, et al., 2014, Wijsman, et al., 2013, Williams, 2016).

3.3.2.5. Steps (per day) meta-analysis results

Among RCT (EI), DBCI showed no significant effect on steps per day (N = 6, n = 383, SMD = 0.18; 95% CI -0.03, 0.38; $p = 0.09$; $I^2 = 0\%$; MD = 401; 95% CI -125, 926; $p = 0.13$) (Table 5 and Table 6) (Ashe, et al., 2015, Bickmore, et al., 2013, Cadmus-Bertram, et al., 2015, Kullgren, et al., 2014, Lyons, et al., 2017, Nguyen, et al., 2009). DBCI also showed no significant effect on daily step count in RCT (FU) studies (N = 2, n = 255, SMD = 0.11; 95% CI -0.14, 0.36; $p = 0.39$; $I^2 = 0\%$; MD = 280 steps; 95% CI -508, 1068; $p = 0.49$) (Bickmore, et al., 2013, Kullgren, et al., 2014). No between-groups difference in steps was found between RCT (EI) and RCT (FU) ($p = 0.06$). Among pre-post studies, DBCI significantly decreased daily step count (N = 3, n = 122, SMD = -0.20; 95% CI -0.42, 0.02; $p = 0.08$; $I^2 = 54\%$; MD = -

737 steps; 95% CI -1361, -113; p = 0.02) (Knight, Stuckey and Petrella, 2015, O'Brien, et al., 2015, Tiedemann, Hassett and Sherrington, 2015).

Among pre-post studies, DBCI with ≥3 BCT clusters showed a significant decrease in steps per day (N = 2, n = 77, SMD = -0.41; 95% CI -0.60, -0.22; p <0.001; I^2 = 0%) (Table 5 and Table 6) (O'Brien, et al., 2015, Tiedemann, Hassett and Sherrington, 2015, Vidoni, et al., 2016). In pre-post studies, DBCI with 1-2 BCT clusters had no significant effect on steps per day (N = 1, n = 45, SMD = 0.12; 95% CI -0.22, 0.24; p = 0.95; I^2 = 0%) (Knight, Stuckey and Petrella, 2015). Between-groups difference in steps per day was found between DBCI 1-2 BCT clusters and ≥3 BCT clusters (SMD = -0.24; 95% CI -0.38, -0.09; p = 0.002; I^2 = 53.55%. Meta-analysis on steps per day grouped by BCT cluster was not possible for RCT studies as all DBCI included ≥3 clusters.

3.3.2.6. Moderate-to-vigorous physical activity (min/week) narrative results

In total, 10 studies measured MVPA, of which eight were RCTs (Ashe, et al., 2015, Cadmus-Bertram, et al., 2015, Cook, et al., 2015, Frederix, et al., 2015, King, et al., 2007, Nguyen, et al., 2009, Wijsman, et al., 2013, Lyons, et al., 2017) and two were pre-post studies (King, et al., 2014, Leutwyler, et al., 2015). MVPA was measured objectively in minutes per day in five studies (Ashe, et al., 2015, King, et al., 2007, King, et al., 2014, Lyons, et al., 2017, Wijsman, et al., 2013), minutes per week in one study (Cadmus-Bertram, et al., 2015). MVPA was measured using questionnaires in two studies; one converted to MET-min/week (Frederix, et al., 2015) and the other as a percentage time at moderate-high PA (Nguyen, et al., 2009). In Cook, et al. (2015), MVPA was measured by Godin questionnaire, however they reported a change in strenuous, moderate and mild exercise separately, compared to the control. Back calculations were not possible therefore it was deemed inappropriate to combine these and enter them into a meta-analysis. In Leutwyler, et al. (2015) only the numbers of participants who demonstrated increases in moderate hours of PA (n =7) and those who did not (n = 8) were reported, no comparable measure of MVPA was reported so was not included in the meta-analysis model.

3.3.2.7. Moderate-to-vigorous physical activity (min/week) meta-analysis results

Among RCTs, DBCI significantly increased MVPA (N = 6, n = 694, SMD = 0.47; 95% CI 0.32, 0.62; $p < 0.001$; $I^2 = 0\%$; MD [N=3] = 51.97; 95% CI 23.91, 80.03; $p < 0.001$) (Ashe, et al., 2015, Cadmus-Bertram, et al., 2015, King, et al., 2007, Frederix, et al., 2015, Nguyen, et al., 2009, Wijsman, et al., 2013). Significant increases in MVPA were shown among RCT (EI) that objectively measured PA (N = 5, n = 443, SMD = 0.53; 95% CI 0.34, 0.72; $p < 0.001$; $I^2 = 0\%$; MD = 10.14; 95% CI -2.33, 22.61; $p = 0.11$). RCT (EI) that subjectively measured PA also showed increases in MVPA (N = 1, n = 251, SMD = 0.38; 95% CI 0.13, 0.63; $p < 0.001$; $I^2 = 0\%$; MD = 49.71; 95% CI 17.17, 82.26; $p = 0.003$). Between-groups difference in MVPA was found between objectively and subjectively measured RCT (EI) studies (SMD = 15.20; 95% CI 3.56, 26.84; $p < 0.001$). Due to an insufficient number of studies available, meta-analysis on MVPA was not possible for pre-post studies.

3.3.2.8 Sedentary behaviour (min/day) narrative results

In total 7 studies measured SB which was measured objectively in five studies – one used Actigraph GT3X+ (Ashe, et al., 2015), one used ActivPAL (Lyons, et al., 2017), one used SenseWear Pro Armband (Leutwyler, et al., 2015), one used a Stepwatch 3 (Nguyen, et al., 2009) – and two using the IPAQ self-report questionnaire (Frederix, et al., 2015, Müller, Khoo and Morris, 2016). Sedentary minutes per day were reported in three studies (Ashe, et al., 2015, Lyons, et al., 2017, Müller, Khoo and Morris, 2016), minutes per week in one study (Frederix, et al., 2015), sedentary time as a percentage of the day in one study (Nguyen, et al., 2009) and the number of participants that changed sedentary time (increase/decrease) in one study (Leutwyler, et al., 2015).

3.3.2.9. Sedentary behaviour (min/day) meta-analysis results

Across RCTs, DBCI significantly reduced SB (N = 5, n = 255, SMD = -0.44; 95% CI -0.69, -0.19; $p < 0.001$; $I^2 = 0\%$; MD [N = 3] = 58.49; 95% CI -100.34, -16.64; $p < 0.001$) (Table 5 and Table 6) (Ashe, et al., 2015, Frederix, et al., 2015, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009). Among RCT (EI) studies that measured SB objectively, DBCI significantly reduced SB (N = 4, n = 216, SMD = -0.45; 95% CI -0.72, -0.17; $p = 0.001$; $I^2 = 0\%$; MD = -33.47; 95% CI -90.63, 23.70; $p = 0.25$) (Ashe, et al., 2015, Frederix, et al., 2015, Lyons, et al., 2017, Nguyen, et al., 2009). No significant change in SB was found in RCT (EI) that measured SB subjectively (N = 1, n = 39, SMD = -0.40; 95% CI -1.04, 0.23; $p = 0.22$; $I^2 = 0\%$; MD = -0.76, 95% CI -1.95, 0.43; $p = 0.21$) (Müller, Khoo and Morris, 2016). Between-groups difference was found between objectively and subjectively measured SB in RCT (EI) (SMD = -0.44; 95% CI -0.69, -0.19; $p < 0.001$). Due to an insufficient number of studies available, meta-analysis on SB was not possible for pre-post studies.

Table 5. Meta-analysis of effects of DBCIs on physical activity and total sedentary time.

Analysis	No. studies	No. participants	Meta-analysis								
			SMD	**95% CI**		**P value**	**Between group P value**	**No. studies**	**MD**	**95% CI**		**P value**
Total PA												
Study Design												
RCTs (EI)	8	450	**0.28**	**0.01**	**0.56**	**0.04**	**0.05**	n/a	n/a	n/a	n/a	n/a
RCTs (FU)	2	255	0.11	-0.14	0.36	0.39		n/a	n/a	n/a	n/a	n/a
Pre-post	6	159	**0.25**	**0.09**	**0.41**	**0.002**	n/a	n/a	n/a	n/a	n/a	n/a
PA Measure												
Objective RCT (EI)	7	476	0.28	-0.02	0.06	0.07	**0.03**	n/a	n/a	n/a	n/a	n/a
Subjective RCT (EI)	1	39	0.36	-0.27	1.00	0.27		n/a	n/a	n/a	n/a	n/a
Objective Pre-post	4	122	**0.24**	**0.02**	**0.45**	**0.03**	**0.003**	n/a	n/a	n/a	n/a	n/a
Subjective Pre-post	2	37	**0.27**	**0.02**	**0.53**	**0.04**		n/a	n/a	n/a	n/a	n/a
BCT Clusters												
≥ 3 Pre-post	4	101	**0.37**	**0.21**	**0.53**	**<0.001**	**<0.001**	n/a	n/a	n/a	n/a	n/a
1-2 Pre-post	2	21	0.09	-0.14	0.32	0.44		n/a	n/a	n/a	n/a	n/a

Analysis	No. studies	No. participants	Meta-analysis									
			SMD	95% CI		P value	Between group P value	No. studies	MD	95% CI		P value
Steps												
Study Design												
RCTs (EI)	6	383	0.18	-0.03	0.38	0.09	0.06	6	401	-125	926	0.13
RCTs (FU)	2	255	0.11	-0.14	0.36	0.39		2	280	-508	1068	0.49
Pre-post	3	122	-0.20	-0.42	0.02	0.08	n/a	3	**-737**	**-1361**	**-113**	**0.02**
BCT Clusters												
≥ 3 Pre-post	2	77	**-0.41**	**-0.60**	**-0.22**	**<0.001**	**0.002**	2	**-1194**	**-1727**	**-662**	**<0.001**
1-2 Pre-post	1	45	0.12	-0.22	0.24	0.95		1	25	-862	911	0.96
MVPA												
Study Design												
RCT (EI)	6	694	**0.47**	**0.32**	**0.62**	**<0.001**	n/a	3	**51.97**	**23.91**	**80.03**	**<0.001**
PA Measure												
Objective RCT (EI)	5	443	**0.53**	**0.34**	**0.72**	**<0.001**	**<0.001**	5	10.14	-2.33	22.61	0.11
Subjective RCT (EI)	1	251	**0.38**	**0.13**	**0.63**	**<0.001**		**1**	**49.71**	**17.17**	**82.26**	**0.003**

Analysis	No. studies	No. participants	Meta-analysis									
			SMD	95% CI		P value	Between group P value	No. studies	MD	95% CI		P value
Total SB												
Study Design												
RCT (EI)	5	255	**-0.44**	**-0.69**	**-0.19**	**<0.001**	n/a	3	**-58.49**	**-100.34**	**-16.64**	**<0.001**
SB Measure												
Objective RCT (EI)	4	216	**-0.45**	**-0.72**	**-0.17**	**0.001**	**<0.001**	4	-33.47	-90.63	23.70	0.25
Subjective RCT (EI)	1	39	-0.40	-1.04	0.23	0.22		1	-0.76	-1.95	0.43	0.21

SMD, standardized mean differences; MD, mean differences; PA, physical activity; (EI) End Intervention; (FU) Follow Up; MVPA, moderate-vigorous physical activity; Total SED, total sedentary time; RCT, randomized control trial.

p ≤ 0.05 in bold

Table 6. Heterogeneity and Publication bias for the meta-analysis of effects of DBCIs on physical activity and total sedentary time.

Analysis	**No. Studies**	**Heterogeneity**			**Publication Bias**				
		Q	**P value**	**I^2**	**Kendall's Tau**	**P value**	**Egger intercept**	**P Value**	**Trim and fill analysis Effect size (95% CI) [Number studies trimmed]**
Total PA									
Study Design									
RCTs (EI)	8	18.86	0.04	46.98	0.33	0.16	1.99	0.11	0.25 (0.07, 0.44) [1]
RCTs (FU)	2	0.51	0.92	0.00	0.17	0.73	1.65	0.04	0.05 (-0.16, 0.26) [2]
Pre-post	6	11.04	0.14	36.60	0.04	0.90	-0.70	0.75	Unchanged
PA Measure									
Objective RCT (EI)	7	18.69	0.03	51.83	0.31	0.21	1.98	0.15	0.24 (0.05, 0.42) [1]
Subjective RCT (EI)	1	0.00	1	0.00	n/a	n/a	n/a	n/a	n/a
Objective Pre-post	4	10.28	0.07	51.36	0.00	1.00	-1.37	0.62	Unchanged
Subjective Pre-post	2	0.75	0.39	0.00	n/a	n/a	n/a	n/a	n/a
BCT Clusters									
≥ 3 Pre-post	4	2.48	0.48	0.00	0.17	0.73	1.27	0.58	0.35 (0.20, 0.50) [1]
1-2 Pre-post	2	3.84	0.28	21.93	0.83	0.09	18.34	<0.01	Unchanged

Analysis	No. Studies	Heterogeneity			Publication Bias				
		Q	P value	I^2	Kendall's Tau	P value	Egger intercept	P Value	Trim and fill analysis Effect size (95% CI) [Number studies trimmed]
Steps									
Study Design									
RCTs (EI)	6	0.17	0.68	0.00	0.29	0.19	1.24	0.13	0.19 (-0.005, 0.39) [1]
RCTs (FU)	2	6.03	0.87	0.00	n/a	n/a	n/a	n/a	n/a
Pre-post	3	8.61	0.07	53.55	0.10	0.81	6.09	0.51	-0.34 (-0.59, -0.10) [2]
BCT Clusters									
≥ 3 Pre-post	2	0.34	0.56	0.00	n/a	n/a	n/a	n/a	n/a
1-2 Pre-post	1	0.82	0.66	0.00	-0.67	0.30	-19.05	0.02	Unchanged
MVPA									
Study Design									
RCT (EI)	6	3.10	0.80	0	-0.43	0.23	-0.39	0.63	Unchanged
PA Measure									
Objective RCT (EI)	5	0.93	0.33	0	0.00	1	2.48	0.01	Unchanged
Subjective RCT (EI)	1	3.10	0.80	0	n/a	n/a	n/a	n/a	n/a

Analysis	No. Studies	Heterogeneity			Publication Bias				
		Q	**P value**	**I^2**	**Kendall's Tau**	**P value**	**Egger intercept**	**P Value**	**Trim and fill analysis Effect size (95% CI) [Number studies trimmed]**
Total SB									
Study Design									
RCT (EI)	5	1.54	0.82	0	0.10	0.81	0.53	0.54	-0.47 (-0.72, -0.23) [1]
SB Measure									
Objective RCT (EI)	4	0.02	0.90	0	0.10	0.81	0.53	0.54	-0.49 (-0.75, -0.23) [1]
Subjective RCT (EI)	1	1.54	0.82	0	n/a	n/a	n/a	n/a	n/a

PA, physical activity; (EI) End Intervention; (FU) Follow Up; MVPA, moderate-vigorous physical activity; Total SED, total sedentary time; RCT, randomized control trial.

Heterogeneity and publication bias scores based on standardized mean differences

p ≤ 0.05 in bold

3.3.3 Secondary outcomes

Common secondary outcomes that were measured in at least five or more papers have been reported on separately, including weight, blood pressure, physical functioning, and quality of life. For all secondary outcomes of each study see Table 7 and for heterogeneity and publication bias see Table 8. Due to the number of studies available measuring the respective comparators, meta-analysis was only possible for RCT studies.

3.3.3.1. Weight meta-analysis

Seven studies measured the impact of DBCI on body weight; five RCTs (Ashe, et al., 2015, Cadmus-Bertram, et al., 2015, Frederix, et al., 2015, Lyons, et al., 2017, Wijsman, et al., 2013) and two pre-post studies (Knight, Stuckey and Petrella, 2015, Broekhuizen, et al., 2016). Among RCTs, DBCI had no significant effect on weight (N = 5, n = 466, SMD = -0.15; 95% CI -0.33, 0.03; p = 0.10; I^2 = 0%; MD = -0.68kg; -3.45, 2.09; p = 0.63) (Table 7 and Table 8).

3.3.3.2. Blood pressure meta-analysis

Five studies measured the impact of DBCI on blood pressure; three RCTs (Ashe, et al., 2015, Frederix, et al., 2015, Wijsman, et al., 2013) and two pre-post studies (Knight, Stuckey and Petrella, 2015, O'Brien, et al., 2015). It is important to note that Wijsman, et al. (2013) was automatically removed from the model when analysing mean differences due to blood pressure being measured as 'a change in', resulting in only 81 in the intervention and 78 in the control mean difference analysis. DBCI significantly decreased systolic blood pressure (SBP) among RCTs (N = 3, n = 375, SMD = -0.14; 95% CI -0.35, 0.07; p = 0.18; I^2 = 4%; MD = -11bpm; 95% CI -21.96, -0.71, p = 0.04) (Table 7 and Table 8). DBCI showed no significant effect on diastolic blood pressure (DBP) (SMD = 0.10; 95% CI -0.30, 0.09; p = 0.30; I^2 = 0%; MD = -3bpm; 95% CI -9.00, 2.93; p = 0.32).

3.3.3.3. Physical functioning meta-analysis

Nine studies measured physical functioning; seven RCT (Broekhuizen, et al., 2016, Frederix, et al., 2015, Lyons, et al., 2017, Müller, Khoo and Morris, 2016, Nguyen, et al., 2009, Vidoni, et al., 2016, Wijsman, et al., 2013) and two pre-post studies (Keogh, et al., 2014, O'Brien, et al., 2015). Similar to total PA, Vidoni, et al. (2016) was considered a pre-post study rather than an RCT using only participants without cognitive impairment for more appropriate comparisons between studies. Broekhuizen, et al. (2016) and Wijsman, et al. (2013) reported different measures of physical functioning of the same intervention with the same participants. It was deemed inappropriate to include both in a meta-analysis, and as Wijsman, et al. (2013) reported outcomes that were able to be used in other meta-analyses, it was decided that for continuity that physical functioning data from Wijsman, et al. (2013) only would be included. Many different methods were used to measure physical functioning across studies; using the physical functioning score from the RAND-36 questionnaire (Broekhuizen, et al., 2016), VO2 peak (Frederix, et al., 2015), bicep curls in 30 seconds through full range of motion (Keogh, et al., 2014), 6-minute walking test (Lyons, et al., 2017, Nguyen, et al., 2009, Vidoni, et al., 2016), timed up and go (TUG) (O'Brien, et al., 2015) and grip strength (Müller, Khoo and Morris, 2016, Wijsman, et al., 2013). Among RCTs, DBCI significantly improved physical functioning in older adults (N = 5, n = 451, SMD = 0.21; 95% CI 0.03, 0.40; p = 0.03; I^2 = 0%) (Table 7 and Table 8).

3.3.3.4. Quality of life meta-analysis

Five studies measured the impact of DBCI on QoL; three RCTs (Broekhuizen, et al., 2016, Frederix, et al., 2015, Nguyen, et al., 2009) and two pre-post studies (Keogh, et al., 2014, Vidoni, et al., 2016). Among RCT studies, DBCI had no significant effect on QoL scores in older adults (N = 3, n = 372, SMD = 0.27; 95% CI -0.2, 0.57; p = 0.07; I2 = 37.92%) (Table 7 and Table 8).

Table 7. Meta-analysis of effects of DBCIs on weight, blood pressure and physical functioning in RCT studies.

Analysis	No. Studies	No. participants	Meta-analysis SMD	95% CI		P value	No. Studies	Meta-analysis MD	95% CI		P value
Weight	5	466	-0.15	-0.33	0.03	0.10	5	-0.68	-3.45	2.09	0.63
SBP	3	375	-0.14	-0.35	0.07	0.18	2	**-11.33**	**-21.96**	**-0.71**	**0.04**
DBP	3	375	-0.10	-0.30	0.09	0.30	2	-3.04	-9.00	2.93	0.32
Physical functioning	5	451	**0.21**	**0.03**	**0.40**	**0.03**	n/a	n/a	n/a	n/a	n/a
QoL	3	372	0.27	-0.02	0.57	0.07	n/a	n/a	n/a	n/a	n/a

SMD, standardized mean difference; MD, mean difference; RCT, randomized control trial; kg, kilograms; SBP, systolic blood pressure; DBP, diastolic blood pressure; QoL, quality of life.

Mean differences for SBP and DBP based on 2 studies (159 participants) as Wijsman, et al. (2013) automatically removed from model.

p ≤ 0.05 in bold

Table 8. Heterogeneity and publication bias for the meta-analysis of effects of DBCIs on weight, blood pressure and physical functioning in RCT studies.

Analysis	**No. Studies**	**Heterogeneity**			**Publication bias**				
		Q	**P value**	**I^2**	**Kendall's Tau**	**P value**	**Egger intercept**	**P value**	**Trim and fill analysis Effect size (95% CI) [Number studies trimmed]**
Weight	5	1.71	0.79	0	-0.10	0.81	0.47	0.59	-0.26 (-0.40, -0.11) [3]
SBP	3	2.09	0.35	4.19	0.00	1	-1.70	0.39	-0.03 (-0.27, 0.21) [2]
DBP	3	1.80	0.40	0	0.00	1	-1.55	0.40	-0.07 (-0.30, 0.16) [1]
Physical functioning	5	3.69	0.45	0.00	0.30	0.46	0.78	0.47	0.19 (0.005, 0.37) [1]
QoL	3	3.22	0.20	37.92	0.00	1	1.91	0.46	0.09 (-0.08, 0.26) [2]

Heterogeneity and publication bias scores based on standardized mean differences

p ≤ 0.05 in bold

3.3.3.5. Mental health outcomes

One study (Cook, et al., 2015) investigated the effect on symptoms of distress (measured by a 15-item scale developed by (Orioli, Jaffe and Scott, 1991)) and coping with stress (measured by a 12-item scale (Orioli, Jaffe and Scott, 1991)) and found no significant difference between the control and intervention groups. The authors speculate that this may be due to a ceiling effect as both groups had relatively low stress and high coping skills at baseline. Despite the intervention in Strand, et al. (2014) targeting holistic health including emotional, intellectual and social elements, there was no measure of these reported.

3.3.3.6. Social outcomes

None of the included studies reported the effects of the DBCI on social outcomes.

3.3.4. Meta-regression

Meta-regression analysis was only possible for total PA RCT (EI) studies as other meta-analyses presented above contained too few studies ($n < 10$). Independently, the number of BCTs used in an intervention, the type of PA measurement (objective/subjective), the mean age of participants, the percentage of males, the publication year, the region (North America/ non-North America), the setting of the intervention (i.e. community based / non-community based), or the duration (weeks) of the intervention did not impact total PA ($p > 0.05$). The variance between studies could be partially accounted for in the number of BCTs used ($r^2 = 0.24$), mean age of participants ($r^2 = 0.06$) and the year of publication ($r^2 = 0.07$), accounting for approximately 37% of the variance seen between studies (Table 9).

Table 9. Meta-regression analysis for moderators in RCT (EI) studies on total physical activity.

Moderator	**Coefficient**	**95% Confidence Interval**		**P value**	**r^2**
		Lower	Upper		
Number BCTs	0.04	-0.43	0.08	0.08	0.24
PA measurement	0.08	-0.89	1.04	0.88	0.00
Mean age	-0.04	-0.09	0.02	0.20	0.06
% males	-0.005	-0.16	0.007	0.43	0.00
Publication year	0.10	-0.56	0.26	0.21	0.07
Region	0.08	-0.90	1.04	0.88	0.00
Setting	-0.21	-1.07	0.66	0.64	0.00
Duration	0.06	-0.02	0.13	0.12	0.00

BCT, behaviour change technique; PA, physical activity. PA measurement (objective/ subjective); Region (North America/ non-North America); Setting (community based/ non-community based).

$p \leq 0.05$ in bold

3.4. Discussion

This is the first systematic review and meta-analysis to assess the effects of using DBCI to target PA and/or SB in older adults (≥ 50 years old). The current meta-analyses suggest that among RCT (EI) studies, DBCI increased total PA (SMD = 0.28, $p = 0.04$), increased MVPA (SMD = 0.47, $p < 0.001$; MD = 52, $p < 0.001$) and reduced sedentary time (SMD = -0.44, $p < 0.001$; MD = -58, $p <0.001$) when compared with control conditions. Similar increases in total PA were also shown in pre-post studies (SMD = 0.25, $p = 0.002$). Reductions in systolic blood pressure and improvements in physical functioning were identified among RCTs.

DBCI increased total PA in both RCT and pre-post study designs when measured immediately at the end of the intervention, however from the two follow-up RCT studies it appears this was not maintained long-term. Similarly, in a systematic review of reviews, Zubala, et al. (2017) found non-digital PA interventions often resulted in increased in PA in older adults (≥ 50 years), but effective maintenance beyond one year was unclear. It appeared that DBCI have the potential to increase total PA in older adults but may face similar problems to traditional methods regarding maintenance, although this is still unknown. Between-groups differences were seen between objectively and subjectively measured total PA in both RCT (End Intervention) and pre-post studies, however, these results must be interpreted with caution due to very low numbers of studies in subgroups. Self-reported PA often overestimated actual PA levels (Prince, et al., 2008, Colbert, et al., 2011) and this was evident in the meta-analysis, with the subjectively measured study reporting a larger increase in total PA than objectively measured.

Increases in MVPA were shown in the present meta-analysis, equivalent to 52 min/week. This is important as it represents 35% of the 150 min/week recommendation for older adults (Public Health England, 2014). Similar increases were shown in a meta-analysis conducted by Roberts, et al. (2017), who found MVPA increased by approximately 40 min/week in cancer survivors when they engaged with a DBCI to promote PA. Additionally, a multilevel PA intervention in older adults (≥ 65 years), including group walks, individual counselling and self-monitoring with pedometers, increased MVPA by 56 minutes per week (Kerr, et al., 2018). The present study found between-groups differences in MVPA in RCT (EI) studies when measured objectively vs. subjectively; however, it must be noted that only one study measured MVPA subjectively, thus statistical significance should be interpreted with caution. Similarly, a previous random effects meta-analysis of RCT studies using wearable and smartphone apps in adults (≥ 18 years) showed improvements in objectively measured MVPA but not in subjectively measured MVPA (Gal, et al., 2018). This suggests that objective PA measurement is required to accurately assess the efficacy of such interventions.

No effect was found on daily step count in either RCT or pre-post designs, although non-significant, greater increases were shown in the short term and attenuated at follow up. Unexpectedly, a reduction in the number of steps taken per day equivalent to 737 steps per day was found in the MD of pre-post studies, despite indications of increases in total PA and MVPA. An explanation for this could be due to low numbers of studies and participants in the calculations, or that total PA and MVPA increased due to non-ambulatory activities such as cycling or swimming. Conversely, a previous meta-analysis of non-digital PA interventions in older adults (≥ 65 years) showed an increase of 620 more steps/day in the intervention group compared with the control group (Chase, 2015). Previous random-effects meta-analysis of RCT studies showed that smartphone apps and wearable interventions significantly increased daily step counts in adults (≥ 18 years) (Gal, et al., 2018). DBCI may have potential to increase daily step counts in older adults, particularly in the short term, but more research is required.

It is important to note that included studies which did not stipulate a baseline level of PA for participant inclusion/exclusion did not show significant differences in PA, although there were encouraging non-significant increases. Most of the studies that showed significant increases in PA included participants who were inactive at baseline and the PA was usually only sustained during the intervention itself or for a short time after the intervention had finished. It is possible that DCBI were only effective in inactive older adults, or that this population just had a greater potential to increase their PA than already active peers. Participants who lived in residential care facilities or who had cognitive impairments showed no significant change in their PA when using the DBCI, although the direction of change was encouraging. Increases in steps were seen in COPD patients (Nguyen, et al., 2009) but were not in heart disease patients, although there were significant increases in total leisure time PA (a summary of vigorous, moderate, and walking activity) were found (Frederix, et al., 2015). This suggests that special populations require more specialist DBCI tailoring that requires further research.

The present meta-analyses showed DBCI were associated with a significant reduction in SB, equivalent to 58 min/day. Similarly, a goal-setting-based non-digital intervention to reduce SB in older adults (≥ 60 years) showed significant reductions in total sitting time of 51.5 minutes per day (Lewis, et al., 2016). Reduction in SB was seen in the present study when SB was measured objectively but not subjectively, although only one study measured SB subjectively so effect sizes must be interpreted with caution. Subjective measurement had previously been shown to significantly underestimate SB in older adults (Van Cauwenberg, et al., 2014, Copeland, et al., 2017), therefore future studies should aim to measure SB objectively when possible.

The present review highlights the diverse range of DBCI for PA that have been used in older adults. There is no conclusive evidence from the review that suggests a link between the type of DBCI used and retention rates, nor the effectiveness of the intervention. Three of the four studies using Exergames and one VR showed no significant difference in PA and the fourth only showed increases during the intervention itself. This may suggest that Exergaming is not effective in promoting PA in older adults, however the populations in the present review included those living in residential care facilities, those who were eligible for congregate meal sites and those who had cognitive impairments. Therefore, these findings cannot be extrapolated to generally healthy, community-dwelling older adults. A previous systematic review indicated that exergames show promise for targeting physical function, cognition and psychosocial outcomes (N = 22; n = 536) (Chao, Scherer and Montgomery, 2015), however evidence that exergames are effective at increasing PA in community-dwelling older adults is still lacking (Kappen, Mirza-Babaei and Nacke, 2019). In the present study, three of the four studies using exergame DBCI measured PA using self-report questionnaires, and only one measured PA objectively. Future research exploring the use of exergames in older adults in relation to PA should consider objectively measuring PA to further understanding of the effects of exergames on community-dwelling older adults on their PA outcomes.

There is no clear evidence that the type of DBCI has any impact on the number of BCTs present in an intervention, however, the meta-regression for total PA RCT (EI) studies highlighted a potential reason for variance within these studies was due to the number of BCTs used in the interventions. One of the most common BCTs in the present review was social support. Evidence suggests older adults are more likely to engage in PA if meaningful motivators such as social and environmental support and enjoyment are present, rather than purely cognitive strategies or BCTs (Zubala, et al., 2017). Socially isolated older adults may not have a social network to encourage them to engage in PA, meaning this BCT may be vital in the development of a DBCI in this population. However, further research is required to investigate the needs of older adults who are socially isolated in relation to their PA behaviours, and this is addressed in chapter five. In the present review, goal setting and feedback on behaviour were also commonly present. Similarly, goal setting, feedback and self-monitoring behaviours were common in DBCI in cancer survivors (Roberts, et al., 2017) and in eHealth interventions – using information and communication technologies for health – in older adults (≥ 55 years) (Muellmann, et al., 2017). These BCTs were common among apps and wearables showing the most significant improvements in behavioural and health outcomes (Schoeppe, et al., 2016). Therefore, the BCTs goal setting, feedback, self-monitoring, and social support should be considered when designing future DBCI for older adults.

A recent meta-analysis of 224 PA interventions found no linear associations between PA and the number of BCT clusters; however, the authors suggest a minimum of three BCT clusters are needed to produce significant effects on PA (McEwan, et al., 2018). The present meta-analyses in pre-post studies supports previous findings of a ≥3 BCT cluster threshold for significant effects on total PA and steps per day to be found. In addition, all RCT studies used DBCI with ≥3 BCT clusters and had significant effects on total PA, MVPA and also SB. Future DBCI should therefore consider utilizing BCTs from three or more different clusters in order to significantly effect changes in behaviour.

The target behaviours of the interventions in this review were generally poorly reported, requiring the researcher to dissect the details of the intervention to ascertain the target behaviour. Many merely reported PA without a direction of change, although it was assumed using the context of the study that this was to increase PA. Providing a more detailed description of the target behaviour – e.g. type of PA, PA intensity, frequency, duration – and context would be beneficial for evaluating the effectiveness of the intervention but also for the design of future interventions (Michie, Atkins and West, 2014). In the present study no clear link was found between the targeted behaviours, or the number of behaviours targeted, and the effectiveness of the intervention. Further research is required to explore connections between the defined target behaviours, intervention components and effectiveness of the interventions. This would be aided by studies reporting a clear and specific definition the target behaviour(s) and BCTs used in the intervention, in addition to the effectiveness findings.

Secondary outcome meta-analysis showed no change in weight, DBP or QoL. Explanations for this could be due to the limited number of studies measuring these outcomes, the DBCI were too short-term to influence these factors, or extraneous factors (such as diet or mental health) impacted these outcomes. Nevertheless, engaging in DBCI reduced SBP by approximately 11bpm, but did not affect DBP. Similarly, a multilevel non-digital PA program in older adults (≥ 65 years) showed significant reductions in SBP (6.8 bpm; SD = 3.2) and DBP

(2.5 bpm; SD = 1.9) at 6 months into the intervention (Kerr, et al., 2018). Increases in PA may induce post-exercise hypotension (MacDonald, 2002), thus may be important for helping to manage blood pressure in older adults. Physical functioning was significantly increased by DBCI in the present meta-analysis, which may be due to improvements in stamina, strength, balance, coordination or increased movement confidence associated with increased PA, and have been documented previously in older adults engaging in exergames (Pope, Zeng and Gao, 2017, Molina, et al., 2014, Skjaeret, et al., 2016, De Queiroz, et al., 2017, Howes, et al., 2017), web-based (Irvine, et al., 2013) and non-digital PA and exercise programs (Taylor, et al., 2004, Chodzko-Zajko, et al., 2009, Barnett, et al., 2003). This suggests that DBCI designed to increase PA and/or reduce SB can also improve physical functioning, even if this is not the targeted outcome. Socially isolated older adults are more likely to live with chronic disease and have a greater NCD risk than those who are not isolated (Elovainio, et al., 2017). In particular, social isolation is associated with increases in systolic and diastolic blood pressure (Shankar, et al., 2011). Therefore, the additional benefits of the DBCI for PA/SB on physical functioning and SBP could be of particular importance to socially isolated older adults. Mental health outcomes were only investigated in one study and showed no significant difference between the DBCI group and control group in distress or coping with stress outcomes (Cook, et al., 2015). Further, none of the included studies investigated social outcomes of the DBCI. This suggests more research is required to investigate both mental health and social outcomes, as secondary outcomes, of DBCI PA/SB in older adults.

DBCI have the potential to increase PA and physical functioning and reduce SB and SBP in older adults. This can lead to the prevention and/or maintenance of NCD and greater independence associated with healthy ageing (Smith, et al., 2015, Daskalopoulou, et al., 2017, Chad, et al., 2005, Tak, et al., 2013). As future populations comprise greater proportions of older adults and life expectancies continue to increase, it is important that health, QoL and years lived without disability are maximized, for the individual and for society.

3.4.1. Strengths and limitations

Strengths of this review include that it was the first systematic review and meta-analysis to assess the effectiveness of DBCI on PA and/or SB in older adults aged ≥ 50 years, and was conducted and reported in line with PRISMA guidelines (Moher, et al., 2009). The inclusion of studies using exclusively older adults aged ≥ 50 years ensured the findings were completely relevant to this specific population. Lastly this review highlighted the lack of UK studies investigating DBCI for PA and SB in older adults. One limitation of this review is the relative infancy of the topic area meaning many studies are feasibility focused with small sample sizes, which may impact efficacy estimates. Many studies in this review were short-term interventions with no follow-up, thus surety of the long-term effects of DBCI on PA and SB in older adults. In addition, some meta-analyses reported moderate to high heterogeneity and potential publication bias, although potentially due to variability in the type of DBCI and specific intervention content (Roberts, et al., 2017), so should be interpreted with caution. It was not possible to compare DBCI to a waitlist/no intervention control vs. a non-digital intervention due to the lack of studies, which may statistically impact effect sizes. In addition, BCTs for control conditions were not coded, but may elicit behaviour change or show overlaps with the DBCI, potentially influencing effect sizes. Due to insufficient quantity of studies, it was not possible to conduct meta-regression analysis on most outcomes. Only studies reported in English were reviewed, meaning eligible studies in other languages may have been missed. The terms 'web-based', 'internet' and 'pedometer' were actively excluded from the search methodology, as in pilot searches this elicited unmanageable volumes of results, however, may mean some eligible papers may have been missed. The grey literature search should have helped minimize this.

Future research should continue to investigate the efficacy of DBCI compared with non-digital conditions as well as waitlist/no intervention control conditions and investigate longer-term interventions with follow-ups to investigate the maintenance of PA post-intervention. More information regarding which BCTs make a DBCI more or less effective in promoting PA and/or reducing SB in older adults is also needed. Thus, authors are encouraged to explicitly list the BCTs used in their DBCI, for the intervention and control groups, which may show overlap in BCTs between the groups potentially affecting the magnitude of effects shown. This could also lead to a more comprehensive meta-analysis of studies in the future. Investigators should continue to use objective measures of PA and SB where possible.

3.5 Conclusion

In conclusion, there is evidence that DBCI to promote PA and/or reduce SB result in increases in total PA, MVPA and physical functioning, and reductions in SB and SBP in older adults aged ≥ 50 years, at least in the short term. Further research is required to investigate medium- and long-term interventions, maintenance effects and DBCI compared with no intervention and non-digital interventions control groups. Differences between objective and subjectively measured PA and SB were shown, thus future researchers should aim to objectively measure these where possible. DBCI used with older adults commonly feature the BCTs social support, goal setting and feedback, however further research is needed to identify which BCTs are likely to be effective specifically for socially isolated older adults for the design of a PA/SB DBCI in this population. Additional research is also required to investigate the willingness of socially isolated older adults to engage in DBCI for PA/SB.

CHAPTER 4: INTERNET USE, SOCIAL ISOLATION AND LONELINESS IN OLDER ADULTS

The content of this chapter has been published in the peer-reviewed journal Ageing and Society, see publications and conference proceedings (page vii) for details.

4.1. Introduction

Geographical distance to friends or family, mobility issues and time-consuming roles (e.g. care giver) may impair older adults' ability to engage socially, leaving them vulnerable to social isolation and feelings of loneliness (Leist, 2013). As seen in chapter one, older adults are at greater risk of social isolation and loneliness, which are both independently associated with negative health outcomes, such as NCD risk, cognitive decline, mental health conditions and mortality (Steptoe, et al., 2013b, Cotten, Anderson and McCullough, 2013).

One possible means of reducing social isolation and loneliness in old age is the use of modern technology, in particular the internet. Helping to foster social support and keeping people in contact with one another, the internet can assist in the development of social networks and improve self-confidence among older adults (Chen and Schulz, 2016). Using technology provides a low-cost and accessible means for communication that also has the potential to reduce loneliness and social isolation in older adults (Chipps and Jarvis, 2016). Therefore, it could be speculated that some socially isolated and/or lonely older adults may engage in technology to reduce these.

Social networking sites, general information communication technology (ICT), video games, chat rooms, 3D virtual environments can be useful for reducing social isolation in older adults (≥ 50 years) (Khosravi, Rezvani and Wiewiora, 2016). Video messaging such as Skype, Windows live messenger and telephone, have been shown to increase social support and social connectedness, and reduce social isolation among the elderly (age range 66-83 years) (Chen and Schulz, 2016). It is important to note that the effects rarely lasted more than six months post-intervention, and even with adequate training some ICT interventions were not suitable for every older adult (Chen and Schulz, 2016). Many of the included interventions were only tested at one time point, usually short-term, and used a relatively small number of participants, thus the authors suggest a need for more well-designed studies (Chen and Schulz, 2016). Nonetheless, these studies show that digital interventions have previously been used by older adults who were at risk of social isolation.

To better understand socially isolated older adults' willingness to engage in a DBCI for PA/SB, it may be beneficial to know which technologies and for what purposes they engage in already (MRC guidance: identifying the evidence base). This may also help in the recruitment of socially isolated older adult participants required for chapters five and six. So far, knowledge of older adult's organic use of technology in relation to their social isolation status is lacking. In a cross-sectional study of 11,000 older adults (≥65 years) living in Europe, loneliness was reported less frequently by those who used the internet daily or sometimes compared with never users, and social isolation was less common among those who used the internet every day and sometimes compared with never users (Lelkes, 2013). Of 32 older adults (aged 52-84 years) in Canada with chronic illness (remembering that from chapter one, socially isolated older adults have an increased risk of chronic illness), 88% used a computer daily, 6% used it weekly and only 3% never used a computer; 69% used a mobile phone or tablet daily and 31% never used a mobile phone or tablet (Mercer, et al., 2016). To date there is no evidence for older adults (≥ 50 years) current use of technology, particularly in relation to their social isolation and loneliness. This is important for the design of a novel DBCI for PA/SB specifically for socially isolated older adults. From chapter three, it is evident that older adults generally are willing to use a multitude of technologies for a DBCI for PA/SB, from text messaging to wearables, however, technology use in socially isolated older adults is unknown.

Therefore, the present study used data from English Longitudinal Study of Ageing (ELSA) to explore (i) the demographic characteristics of older adults who are socially isolated and those who are lonely, (ii) the prevalence of internet/email use in older adults, particularly in relation to demographic characteristics, devices used, and online activities engaged in, (iii) the associations between frequency of internet/email use with social isolation and loneliness, and (iv) the devices and online activities older adults engage with in relation to their social isolation and loneliness. It was hypothesised that older adults who more frequently engage with the internet/email would be less likely to be socially isolated or to report feeling lonely, and that associations would be stronger for those who used technology most frequently.

4.2. Methods

4.2.1. Population

ELSA is a longitudinal survey of a representative cohort of adults aged ≥50 years old living in England. The study began in 2002, with data collected via computer-assisted personal interviews and self-completion questionnaires in biennial waves (Steptoe, et al., 2013a). To ensure the most current technology usage possible in a rapidly changing industry, cross-sectional data from the most recent wave, wave 8 (collected 2016/2017), were used. Moreover, longitudinal analysis was considered unfeasible due to attrition reducing the sample size within individual categories of internet/email use even further, leading to problems with statistical power. Complete data on all variables of interest were available for 4492 of the total sample of 8445 participants. Ethical approval was obtained from the NHS Research Ethics Committees under the National Research and Ethics Service (IRAS ID: 185367).

4.2.2. Measures

4.2.2.1. Outcome variables: social isolation and loneliness

Social isolation was computed using a five-item index as used in previous literature (Kobayashi and Steptoe, 2018, Shankar, et al., 2011, Steptoe, et al., 2013b, Jackson, et al., 2019b). One point was assigned to each of the following: if participants reported having less than monthly contact (including face-to-face contact, telephone, and written/email/text messaging contact) with children, other family members and friends, if they did not belong to a social organisation or club, and if they lived alone. Scores ranged from 0 – 5, with higher scores indicating a greater degree of social isolation. As in previous studies, scores were dichotomised at ≥2 versus <2 points to indicate high versus low levels of social isolation (Jackson, et al., 2019b, Steptoe, et al., 2013b).

Loneliness was self-reported using a three-item short form of the Revised University of California Los Angeles (UCLA) Loneliness Scale (Russell, 1996). Questions included: “how often to you feel you lack companionship?”, “how often do you feel left out?”, and “how often do you feel isolated from others?”. Response options were ‘hardly ever or never’ = 1, ‘some of the time’ = 2 or ‘often’ = 3. Total scores ranged from 3 to 9, with higher scores indicating greater loneliness. As in previous papers, these were dichotomised at ≥6 versus <6 to indicate high versus low loneliness (Jackson, et al., 2019a, Steptoe, et al., 2013b).

4.2.2.2. Exposure variable: internet/email use

Frequency of internet/email use was assessed in the self-completion questionnaire, with the question “on average, how often do you use the internet or email?”. Response options were “every day, or almost every day”, “at least once a week (but not every day)”, “at least once a month (but not every week)”, “at least once every 3 months” or “never”.

Those who responded that they accessed the internet/email more than once every 3 months, were asked about the devices they used to access the internet: “On which of the following devices do you access the internet?”. Response options included desktop computer, laptop computer, tablet (e.g. iPad, Samsung Galaxy Tab), smartphone (e.g. iPhone, Android phone), other device, or do not access internet. In addition, participants were asked “for which of the following activities did you use the internet in the last 3 months? Tick all that apply”. Response options included “sending/receiving emails”, “telephoning over the internet/video calls (via webcam) over the internet”, “searching for information for learning, research, fact finding”, “finances (banking, paying bills)”, “shopping/buying goods or services”, “selling goods or services over the internet e.g. via auctions”, “use social networking sites (Facebook, Twitter, Myspace)”, “creating, uploading or sharing content (YouTube, blogging or Flickr)”, “news/newspaper/blog websites”, “streaming/downloading live or on demand TV/radio (BBC iPlayer, 4OD, ITV Player, Demand 5)”, “music (iTunes, Spotify), or eBooks”, “games”, “looking for jobs or sending a job application", "using public services (e.g. obtaining benefits, paying taxes)", "other" or "none of the above".

4.2.2.3. Covariates

Covariates were selected a priori on the basis of previous studies showing associations between these variables and the exposure and outcomes of interest. Covariates assessed in this study were age and sex, as they are both independently associated with differences in internet use (Bol, Helberger and Weert, 2018, Office for National Statistics, 2018a, Quintana, et al., 2018, Berner, Aartsen and Deeg, 2017, Hogeboom, et al., 2010, Choi and Dinitto, 2013), loneliness and social isolation (Kobayashi and Steptoe, 2018). Sex was reported as male or female. Age was input in categories of "50-59y", "60-69y", "70-79y", "80-89y" and "90+ y". Marital status (married/living as married versus single) was also associated with internet use (Berner, Aartsen and Deeg, 2017, Hogeboom, et al., 2010), social isolation and loneliness (Grenade and Boldy, 2008, Steptoe, et al., 2013b, Kobayashi and Steptoe, 2018, Hawkley and Kocherginsky, 2017, Peplau, 1985). Socioeconomic status (SES) was assessed using household non-pension wealth as this has been identified as an appropriate indicator of SES in older adults (Banks, Karlsen and Oldfield, 2004) and used in previous studies utilising the ELSA dataset (Jackson, et al., 2019b, Smith, et al., 2015, Hamer, Lavoie and Bacon, 2014, Quintana, et al., 2018, Jackson, Hackett and Steptoe, 2019). This was entered as a covariate as it has previously been associated with internet use (Hogeboom, et al., 2010, Berry, 2011), social isolation and loneliness (Steptoe, et al., 2013b, Kobayashi and Steptoe, 2018, Choi and Dinitto, 2013).

Living with limiting, long-standing illness(es) have previously been associated with internet use (Hogeboom, et al., 2010, Choi and Dinitto, 2013), social isolation and loneliness (Grenade and Boldy, 2008). Participants were asked if they had any long-standing disability or infirmity.

Long-standing was defined as anything that has troubled them over a period of time, or that is likely to affect them over a period of time. Response options were "yes" or "no". Those answering "yes" were then asked if these illness(es) or disability(ies) limit their activities in any way. Response options were yes or no. Participants responding "yes" to the second question were categorised as having a limiting long-standing illness, otherwise were categorised as not having a limiting long-standing illness.

Depression has been associated with internet use (Cotten, et al., 2012, Cotten, et al., 2014), social isolation and loneliness (Cotten, Anderson and McCullough, 2013, Cornwell and Waite, 2009b, Cacioppo, et al., 2006, Cacioppo, Hawkley and Thisted, 2010, Coyle and Dugan, 2012, Domenech-Abella, et al., 2017, Victor and Yang, 2012, Perlman and Peplau, 1984, Peplau, 1985) in older adults so was included as a covariate. The eight-item Centre for Epidemiologic Studies Depression Scale (CES-D) was used to identify people at risk of depression, although one question was excluded to avoid overlap with loneliness scores meaning a total of seven questions were used; scores were dichotomised as high risk ≥ 3, and low risk < 3 in line with previous literature (Steptoe, et al., 2013b, Kobayashi and Steptoe, 2018, White, et al., 2018, Turvey, Wallace and Herzog, 1999). Questions included: '(much of the time during the past week) you felt depressed, you felt that everything you did was an effort, your sleep was restless, you were happy, you enjoyed life, you felt sad, you could not get going?' to which participants could respond "yes" or "no". The CES-D has acceptable psychometric properties in older adults (Cosco, et al., 2019).

PA was entered as a covariate because individuals who are socially isolated and/or lonely tend to be less physically active (Kobayashi and Steptoe, 2018, Hawkley, Thisted and Cacioppo, 2009, Hawkley and Kocherginsky, 2017, Lauder, et al., 2006). Currently there is no literature on associations of PA and internet use in older adults. In addition, it was important to clarify whether those who were socially isolated were less physically active than those who were not socially isolated, in line with previous literature. This was important to assess the need for a PA intervention in this population Level of PA was assessed at interview with questions on the frequency of mild, moderate and vigorous PA participants engaged in. Responses included “more than once a week”, “once a week”, “one to three times a month”, and “hardly ever or never”. It was not possible to calculate and then dichotomise PA based on the recommended guidelines of 150 min/week MVPA, due to the information available from the ELSA wave 8 dataset. Responses were dichotomised as “active” if moderate and/or vigorous intensity PA ≥ once a week and “inactive” as < once a week, in line with previous literature in this cohort regarding PA and health outcomes (Kobayashi and Steptoe, 2018, Smith, et al., 2015, Demakakos, et al., 2010, Hamer, de Oliveira and Demakakos, 2014, Hamer, Lavoie and Bacon, 2014, Hamer, et al., 2009).

4.2.3. Statistical analysis

Data were weighted to correct for sampling probabilities and non-response to the self-completion questionnaire. Characteristics of the study population, devices used to access the internet and online activities were summarised using descriptive statistics. Differences in covariates, devices and internet activities according to internet/email use were analysed using Pearson’s chi-square analysis. Differences in devices and internet activities according to loneliness and social isolation were also analysed using Pearson’s chi-square analysis. Results were presented as p values with Cramer’s V effect sizes. Binomial logistic regressions were used to analyse associations between internet/email use and social isolation and loneliness, and were adjusted for covariates listed above. Daily use was chosen as the reference group as it was hypothesised that this group would be lowest risk. Results were reported as odds ratios (OR) with 95% confidence intervals (CI). All data were analysed in IBM SPSS Statistics v24. Statistical significance was accepted at $p \leq 0.05$.

4.3. Results

The initial sample comprised 8445 older adults, however the exclusion of older adults with missing data resulted in a final analytical sample of 4492 men and women (mean age 64.3 ± 13.3 years; 51.7% males). Overall, 19.4% of the sample reported high levels of loneliness and 32.9% were classified as social isolated. The majority of older adults reported using the internet/email every day (69.3%). Fewer participants reported using the internet once a week (8.5%), once a month (2.6%), once every three months (0.7%), less than every three months (1.5%) and never (17.4%).

Among lonely older adults, 71.4% used the internet/email at least once a week, with 61.9% using it daily, and 22.5% never using it. The effect size of loneliness on the frequency of internet/email use was small (V = 0.008), and although larger for social isolation, was still considered small (V = 0.20).

Table 10 summarises sample characteristics in relation to frequency of internet/email use. Significant differences were found in all characteristics when comparing internet/email use groups. Compared with less frequent users, older adults who used the internet/email every day were more likely to be younger, male, married/living as married, in richer SES quintiles, have no limiting long-standing illness, exhibiting high levels of depressive symptoms, be physically active, not lonely and not socially isolated. Those never using the internet/email were more likely to be older, female, married/living as married, in the poorest SES quintile, have a limiting long-standing illness, exhibiting high levels of depressive symptoms, be physically active, not lonely but socially isolated. Although both every day and never users were more likely to be married/living as married, have depression and be physically active, never users had a higher proportion of people who were single, had high levels depression and physical inactivity compared with every day users. Compared with other frequencies of internet/email use, those who reported using the internet/email once every three months had the highest prevalence of loneliness and social isolation. The effect sizes for sex, SES, loneliness and social isolation were small (Cramer's V ≤ 0.2), whereas the effect sizes for age, marital status, limiting long-standing illness and depression were moderate (0.2 < Cramer's V ≤ 0.6).

Participants who were socially isolated were more likely to be older, male, unmarried, in the lowest SES quintile and have depression compared with non-isolated participants (Table 11). There was also a higher percentage of participants with longstanding limiting illnesses, higher prevalence of loneliness and physical inactivity among socially isolated participants. Moderate effect sizes were found for marital status (V = 0.36) and SES (V = 0.24), whereas all other variables had small effect sizes. Participants who were lonely were more likely to be younger, unmarried, in the lowest SES quintile and have depression compared with their non-lonely peers. There was also a higher prevalence of longstanding limiting illness, social isolation, and physical inactivity among lonely older adults. Moderate effect sizes were found for marital status (V = 0.24) and depression (V = 0.24), whereas all other variables had small effect sizes.

Approximately 67.6% of socially isolated older adults used the internet/email at least once a week, with 59.6% using it daily, and 26.9% never using it (Table 12). Among lonely older adults, 71.4% used the internet/email at least once a week, with 61.9% using it daily, and 22.5% never using it. The effect size of loneliness on the frequency of internet/email use was small (V = 0.08), and although larger for social isolation was still considered small (V = 0.20).

Table 10. Sample characteristics in relation to internet/email use.

		Frequency of internet/email use						Chi-Square	
	All	**Every day**	**Once a week**	**Once a month**	**Once every 3 months**	**Less than every 3 months**	**Never**	**P value**	**Cramer's V**
	n=4492	n=3113 (69.3%)	n=384 (8.5%)	n=115 (2.6%)	n=32 (0.7%)	n=66 (1.5%)	n=781 (17.4%)		
Age (mean ± SD)	64.3 ± 13.3	62.9 ± 8.8	67.6 ± 11.3	68.5 ± 12.3	66.5 ± 9.5	65.9 ± 13.3	67.5 ± 24.0	<0.001	0.25
50-59	1436 (32.0%)	1265 (40.6%)	73 (19.0%)	12 (10.3%)	11 (36.0%)	18 (26.3%)	57 (7.3%)	<0.001	0.25
60-69	1543 (34.4%)	1176 (37.8%)	139 (36.3%)	48 (42.1%)	10 (30.9%)	23 (35.1%)	146 (18.7%)		
70-79	1003 (22.2%)	550 (17.7%)	115 (30.1%)	34 (29.2%)	6 (20.2%)	16 (24.5%)	281 (36.0%)		
80-89	429 (9.6%)	113 (3.6%)	53 (13.8%)	20 (17.1%)	4 (12.9%)	8 (12.5%)	232 (29.6%)		
90+	80 (1.8%)	10 (0.3%)	3 (0.8%)	1 (1.3%)	0	1 (1.5%)	65 (8.3%)		
Sex									
Men	2322 (51.7%)	1678 (53.9%)	191 (49.9%)	52 (45.7%)	14 (45.2%)	29 (43.1%)	357 (45.6%)	<0.001	0.07
Women	2170 (48.3%)	1435 (46.1%)	192 (50.1%)	62 (54.3%)	17 (54.8%)	38 (56.9%)	425 (54.4%)		

	Frequency of internet/email use							Chi-Square	
	All	Every day	Once a week	Once a month	Once every 3 months	Less than every 3 months	Never	P value	Cramer's V
Marital status									
Unmarried	1274 (28.4%)	702 (22.5%)	113 (29.4%)	51 (44.7%)	9 (27.0%)	22 (33.7%)	376 (48.2%)	<0.001	0.22
Married	3218 (71.6%)	2411 (77.5%)	271 (70.6%)	64 (55.3%)	23 (73.0%)	44 (66.3%)	405 (51.8%)		
SES quintile									
1 (poorest)	782 (17.4%)	400 (12.9%)	54 (14.0%)	32 (27.5%)	5 (16.9%)	24 (36.4%)	266 (34.1%)	<0.001	0.15
2	837 (18.6%)	511 (16.4%)	79 (20.5%)	28 (24.1%)	4 (12.6%)	16 (24.0%)	200 (25.6%)		
3	935 (20.8 %)	636 (20.4%)	87 (22.8%)	25 (21.5%)	14 (44.8%)	9 (13.5%)	164 (21.0%)		
4	961 (21.4%)	712 (22.9%)	105 (27.3%)	21 (18.1%)	4 (11.3%)	12 (18.6%)	108 (13.9%)		
5 (richest)	976 (21.7%)	854 (27.4%)	59 (15.5%)	10 (8.7%)	5 (14.4%)	5 (7.5%)	43 (5.5%)		

		Frequency of internet/email use						Chi-Square	
	All	**Every day**	**Once a week**	**Once a month**	**Once every 3 months**	**Less than every 3 months**	**Never**	**P value**	**Cramer's V**
Limiting Long-standing illness									
No	3046 (67.8%)	2321 (74.6%)	251 (65.4%)	65 (56.6%)	19 (60.3%)	34 (51.7%)	355 (45.4%)	<0.001	0.24
Yes	1446 (32.2%)	792 (25.4%)	113 (34.6%)	50 (43.4%)	13 (39.7%)	32 (48.3%)	426 (54.6%)		
Depression									
Low	2385 (53.1%)	1806 (58.0%)	182 (47.5%)	42 (36.3%)	19 (59.4%)	25 (37.9%)	311 (39.8%)	<0.001	0.16
High	2107 (46.9%)	1308 (42.0%)	201 (52.5%)	73 (63.7%)	13 (40.6%)	41 (62.1%)	471 (60.2%)		
Physical activity									
Inactive	932 (20.8%)	451 (14.5%)	81 (21.2%)	26 (22.4%)	7 (20.7%)	25 (37.2%)	343 (43.9%)	<0.001	0.28
Active	3559 (79.2%)	2663 (85.5%)	302 (78.8%)	89 (77.6%)	25 (79.3%)	42 (62.8%)	438 (56.1%)		
Loneliness									
Low	3619 (80.6%)	2573 (82.6%)	300 (78.3%)	90 (77.9%)	22 (68.4%)	49 (73.4%)	585 (74.9%)	<0.001	0.08
High	873 (19.4%)	540 (17.4%)	83 (21.7%)	25 (22.1%)	10 (31.6%)	18 (26.4%)	196 (25.1%)		

		Frequency of internet/email use						Chi-Square	
	All	**Every day**	**Once a week**	**Once a month**	**Once every 3 months**	**Less than every 3 months**	**Never**	**P value**	**Cramer's V**
Social Isolation									
Not Isolated	3015 (67.1%)	2249 (72.2%)	265 (69.0%)	62 (54.1%)	12 (39.2%)	43 (65.2%)	384 (49.1%)	<0.001	0.20
Isolated	1476 (32.9%)	864 (27.7%)	119 (31.0%)	53 (45.9%)	19 (60.8%)	23 (34.8%)	398 (50.9%)		

Values are number of participants (percentages) within each category of internet/email frequency use unless otherwise stated

SD = standard deviation.

Table 11. Sample characteristics in relation to social isolation status and loneliness.

	All	High Loneliness	Low Loneliness	Chi Square		High social isolation	Low social isolation	Chi Square	
	n=4492	**n = 873**	**n = 3619**	**P value**	**Cramer's V**	**n = 1476**	**n = 3015**	**P value**	**Cramer's V**
Age (mean ± SD)	64.3 ± 13.3	63.0 ± 15.5	64.6 ± 12.70			64.2 ± 15.9	64.4 ± 11.8		
50-59	1436 (32.0%)	306 (35.0%)	1131 (31.2%)	0.003	0.06	426 (28.8%)	1011 (33.5%)	0.00	0.11
60-69	1543 (34.4%)	275 (31.5%)	1269 (35.1%)			490 (33.2%)	1053 (34.9%)		
70-79	1003 (22.2%)	176 (20.2%)	827 (22.8%)			329 (22.3%)	673 (22.3%)		
80-89	429 (9.6%)	91 (10.5%)	338 (9.3%)			186 (12.6%)	244 (8.1%)		
90+	80 (1.8%)	25 (2.9%)	55 (1.5%)			46 (3.1%)	34 (1.1%)		
Sex									
Men	2322 (51.7%)	436 (50.0%)	1886 (52.1%)	0.25	0.02	848 (57.4%)	1474 (48.9%)	0.00	0.08
Women	2170 (48.3%)	437 (50.0%)	1733 (47.9%)			628 (42.6%)	1541 (51.1%)		

	All	High Loneliness	Low Loneliness	Chi Square		High social isolation	Low social isolation	Chi Square	
	n=4492	**n = 873**	**n = 3619**	**P value**	**Cramer's V**	**n = 1476**	**n = 3015**	**P value**	**Cramer's V**
Marital status									
Unmarried	1274 (28.4%)	440 (50.5%)	833 (23.0%)	0.00	0.24	760 (70.5%)	514 (17.0%)	0.00	0.36
Married	3218 (71.6%)	432 (49.5%)	2786 (77.0%)			716 (29.5%)	2502 (83.0%)		
SES quintile									
1 (poorest)	782 (17.4%)	243 (27.8%)	539 (14.9%)	0.00	0.16	428 (29.0%)	354 (11.7%)	0.00	0.24
2	837 (18.6%)	182 (20.8%)	656 (18.1%)			272 (18.4%)	565 (18.7%)		
3	935 (20.8 %)	182 (20.8%)	754 (20.8%)			320 (21.7%)	616 (20.4%)		
4	961 (21.4%)	147 (16.8%)	815 (22.5%)			272 (18.5%)	689 (22.9%)		
5 (richest)	976 (21.7%)	120 (13.7%)	856 (23.6%)			184 (12.5%)	791 (26.2%)		

	All	High Loneliness	Low Loneliness	Chi Square		High social isolation	Low social isolation	Chi Square	
	n=4492	**n = 873**	**n = 3619**	**P value**	**Cramer's V**	**n = 1476**	**n = 3015**	**P value**	**Cramer's V**
Longstanding limiting illness									
No	3046 (67.8%)	488 (55.9%)	2558 (70.7%)	0.00	0.13	609 (41.3%)	836 (27.7%)	0.00	0.14
Yes	1446 (32.2%)	385 (44.1%)	1061 (29.3%)			867 (58.7%)	2179 (72.3%)		
Depression									
Low	2385 (53.1%)	254 (29.1%)	2130 (58.9%)	0.00	0.24	710 (48.1%)	1675 (55.6%)	0.00	0.07
High	2107 (46.9%)	618 (70.9%)	1489 (41.1%)			766 (51.9%)	1340 (44.4%)		
Physical activity									
Inactive	932 (20.8%)	271 (31.0%)	662 (18.3%)	0.00	0.12	435 (29.5%)	497 (16.5%)	0.00	0.15
Active	3559 (79.2%)	608 (69.0%)	2957 (81.7%)			1041 (70.5%)	2518 (83.5%)		
Loneliness									
Low	3619 (80.6%)	n/a	n/a	n/a	n/a	1041 (70.5%)	2578 (85.5%)	0.00	0.18
High	873 (19.4%)	n/a	n/a			435 (29.5%)	437 (14.5%)		

	All	High Loneliness	Low Loneliness	Chi Square		High social isolation	Low social isolation	Chi Square	
	n=4492	**n = 873**	**n = 3619**	**P value**	**Cramer's V**	**n = 1476**	**n = 3015**	**P value**	**Cramer's V**
Social Isolation									
Not Isolated	3015 (67.1%)	437 (50.1%)	2578 (71.2%)	0.00	0.18	n/a	n/a	n/a	n/a
Isolated	1476 (32.9%)	435 (49.9%)	1041 (28.8%)			n/a	n/a		

Values are number of participants (percentages) within each category of internet/email frequency use unless otherwise stated

SD = standard deviation.

Table 12. Frequency of internet/email use by loneliness and social isolation.

Frequency of internet/email use	All	Low Loneliness	High Loneliness	Chi Square		Low social isolation	High social isolation	Chi Square	
	n=4492	n = 3619	n = 873	P value	Cramer's V	n = 3015	n = 1476	P value	Cramer's V
Every day	3133 (69.3%)	2573 (71.1%)	540 (61.9%)	0.00	0.08	2249 (74.6%)	864 (59.6%)	0.00	0.20
Once a week	384 (8.5%)	300 (8.3%)	83 (9.5%)			265 (8.8%)	119 (8.0%)		
Once a month	115 (2.6%)	90 (2.5%)	25 (2.9%)			62 (2.1%)	53 (3.6%)		
Once every 3 months	32 (0.7%)	22 (0.6%)	10 (1.2%)			12 (0.4%)	19 (1.3%)		
Less than every 3 months	66 (1.5%)	49 (1.3%)	18 (2.0%)			43 (1.4%)	23 (1.6%)		
Never	781 (17.4%)	585 (16.2%)	196 (22.5%)			384 (12.7%)	398 (26.9%)		

Values are number of participants (percentages) within each category of internet/email frequency use unless otherwise stated

Unadjusted logistic regressions found once a week users were significantly less likely to experience loneliness than every day users (OR = 0.63, 95% CI = 0.52 - 0.76) and the same was found when only adjusting for social isolation (OR = 0.76, 95% CI = 0.63 - 0.92); however this became non-significant when adjusted for covariates (OR = 1.11, 95% CI = 0.89 - 1.37) (Table 13). Less than once every three month users were significantly more likely to be lonely when adjusting for covariates (OR = 2.49, 95% CI = 1.05 - 5.90), but this became non-significant when additionally adjusting for social isolation. No significant associations were found between other frequencies of internet/email use and loneliness in either the unadjusted or any adjusted regression model.

In the unadjusted and all adjusted models, once a week (adjusted for loneliness and covariates OR = 0.60, 95% CI = 0.49 - 0.72) and once a month users (adjusted for loneliness and covariates OR = 0.60, 95% CI = 0.45 - 0.80) were significantly less likely to be socially isolated than every day users (Table 14). In contrast those using the internet less than once every three months were more likely than every day users to experience high levels of social isolation, but only in the covariate adjusted and loneliness plus covariate adjusted model (adjusted for loneliness and covariates OR = 2.87, 95% CI = 1.28 – 6.40). Never users in the unadjusted and loneliness adjusted models were less likely to be socially isolated than everyday users (unadjusted OR = 0.51, 95% CI = 0.30 - 0.87; loneliness adjusted OR = 0.50, 95% CI = 0.29 - 0.85), however, this became non-significant when covariates were adjusted for. Once every three month users were no more likely than every day users to experience high levels of social isolation in any of the adjusted or unadjusted models (adjusted for loneliness and covariates OR = 0.95, 95% CI 0.61 - 1.45).

Table 13. Older adults' frequency of internet/email use in relation to self-reported loneliness.

High loneliness												
	OR*	**95% CI**	**P value**	**OR****	**95% CI**	**P value**	**OR*****	**95% CI**	**P value**	**OR******	**95% CI**	**P value**
Frequency of internet/email use												
Every day (69.3%)	1.00 (ref)			1.00 (ref)			1.00 (ref)			1.00 (ref)		
Once a week (8.5%)	0.63	0.52-0.76	<0.001	0.76	0.63-0.92	0.01	1.11	0.89-1.37	0.36	1.16	0.94-1.45	0.17
Once a month (2.6%)	0.83	0.62-1.11	0.20	0.98	0.73-1.32	0.91	1.24	0.91-1.71	0.18	1.32	0.96-1.81	0.09
Once every 3 months (0.7%)	0.85	0.53-1.35	0.48	0.88	0.55-1.42	0.59	0.89	0.54-1.46	0.63	0.90	0.54-1.48	0.67
Less than once every 3 months (1.5%)	1.38	0.64-2.95	0.41	1.28	0.59-2.78	0.54	2.49	1.05-5.90	0.04	2.30	0.97-5.45	0.06
Never (17.4%)	1.08	0.61-1.90	0.79	1.25	0.70-2.76	0.45	1.27	0.69-2.33	0.44	1.34	0.73-2.47	0.35

*Unadjusted

*Adjusted for social isolation.

***Adjusted for covariates sex, age, wealth, moderate-to-vigorous physical activity, marital status, limiting long-standing illness, depression

**** Adjusted for social isolation and covariates sex, age, wealth, moderate-to-vigorous physical activity, marital status, limiting long-standing illness, depression.

Table 14. Older adults' frequency of internet/email use in relation to self-reported social isolation.

High social isolation												
	OR*	**95% CI**	**P value**	**OR****	**95% CI**	**P value**	**OR*****	**95% CI**	**P value**	**OR******	**95% CI**	**P value**
Frequency of internet use												
Every day (69.3%)	1.00 (ref)			1.00 (ref)			1.00 (ref)			1.00 (ref)		
Once a week (8.5%)	0.37	0.32-0.44	<0.001	0.39	0.33-0.45	<0.001	0.60	0.50-0.73	<0.001	0.60	0.49-0.72	<0.001
Once a month (2.6%)	0.43	0.33-0.56	<0.001	0.43	0.33-0.56	<0.001	0.60	0.46-0.81	0.001	0.60	0.45-0.80	<0.001
Once every 3 months (0.7%)	0.82	0.55-1.21	0.32	0.84	0.56-1.25	0.38	0.94	0.61-1.44	0.77	0.95	0.61-1.45	0.80
Less than once every 3 months (1.5%)	1.50	0.73-3.09	0.28	1.44	0.69-3.01	0.34	2.96	1.34-6.56	0.007	2.87	1.28-6.40	0.01
Never (17.4%)	0.51	0.30-0.87	0.01	0.50	0.29-0.85	0.01	0.60	0.34-1.07	0.09	0.59	0.33-1.06	0.08

*Unadjusted

*Adjusted for loneliness

***Adjusted for covariates sex, age, wealth, moderate-to-vigorous physical activity, marital status, limiting long-standing illness, depression

**** Adjusted loneliness and covariates sex, age, wealth, moderate-to-vigorous physical activity, marital status, limiting long-standing illness, depression.

Among all older adults, the tablet (47.5%), smartphone (47.4%) and laptop (47.0%) were the most commonly mentioned devices used to access the internet/email (Table 15). Everyday users were most likely to use a smartphone compared to less frequent users, whereas a laptop was most commonly used among less frequent users. Significant differences between internet/email frequency use and the devices used were found among all devices.

Smartphones were most commonly reported device used among those with high loneliness (41.6%) and low social isolation (54.1%); whereas a tablet was most common in those with low loneliness (49.7%) and a laptop amongst those who were socially isolated (41.0%) (Table 16). Weak associations were found between all devices and loneliness. Stronger, but still weak, associations were found for social isolation. Moderate associations were found between smartphone use and social isolation.

Searching for information, sending/receiving emails and shopping/buying were the three most common internet activities in the last three months among all participants, and even when split by internet/email frequency use (Table 17). However, every day users more frequently reported sending/receiving emails than searching for information. Significant differences between the frequency of internet/email use groups were seen among all internet activities and effect sizes for all online activities were strong.

Weak associations were found between loneliness and all types of activities engaged with online (Table 18). All online activities were more strongly, but still weakly associated with social isolation status, except for video calling which showed a moderate association. A larger proportion of those with low loneliness engaged with most of the online activities compared with the proportion of those with high loneliness, excluding creating, uploading and sharing content (high = 11.0%; low = 8.8%), job searching/application (high = 13.6%; low = 7.8%) and other online activities (high = 7.0%; low = 5.7%). The same was true in job searching/application for social isolation status (high = 9.4%; low = 8.7%).

Table 15. Devices used to access the internet in the last three months categorised by internet/email usage.

	Frequency of internet/email use					Chi-Square	
	All	**Every day**	**Once a week**	**Once a month**	**Once every 3 months**	**P value**	**Cramer's V**
	n=3644	**n=3113 (69.3%)**	**n=384 (8.5%)**	**n=115 (2.6%)**	**n=32 (0.7%)**		
Desktop	1745 (47.9%)	1590 (51.1%)	123 (31.9%)	30 (26.3%)	3 (9.8%)	<0.0001	0.72
Laptop	2109 (57.9%)	1865 (59.9%)	185 (48.1%)	44 (38.6%)	16 (49.7%)	<0.0001	0.71
Tablet	2133 (58.5%)	1913 (61.4%)	170 (44.3%)	42 (36.2%)	9 (29.2%)	<0.0001	0.72
Smartphone	2127 (58.4%)	1992 (64.0%)	105 (27.4%)	24 (21.0%)	6 (19.9%)	<0.0001	0.73
Other	110 (3.0%)	101 (3.2%)	3 (0.7%)	5 (4.6%)	1 (4.0%)	<0.0001	0.71

Values are number of participants (percentages) within each category of internet/email frequency use unless otherwise stated

Table 16. Older adults' device use in relation to loneliness and social isolation.

	Loneliness		**Chi-square**		**Social isolation**		**Chi-square**	
	High	**Low**	**P value**	**Cramer's V**	**High**	**Low**	**P value**	**Cramer's V**
	n=873	**n=3619**			**n=1476**	**n=3015**		
Desktop (38.9%)	259 (29.7%)	1487 (41.1%)	<0.001	0.10	498 (33.7%)	1248 (41.4%)	<0.001	0.17
Laptop (47.0%)	355 (40.7%)	1754 (48.5%)	<0.001	0.08	605 (41.0%)	1505 (49.9%)	<0.001	0.17
Tablet (47.5%)	335 (38.4%)	1798 (49.7%)	<0.001	0.10	543 (36.8%)	1591 (50.4%)	<0.001	0.19
Smartphone (47.4%)	363 (41.6%)	1764 (48.7%)	<0.001	0.08	496 (33.6%)	1631 (54.1%)	<0.001	0.22
Other (2.5%)	21 (2.4%)	89 (2.5%)	<0.001	0.07	27 (1.8%)	83 (2.8%)	<0.001	0.17

Values are number of participants (percentages) within each category of loneliness/social isolation unless otherwise stated

Table 17. Internet activities in the last three months categorised by internet/email usage.

	Frequency of internet/email use					Chi-Square	
	All	**Every day**	**Once a week**	**Once a month**	**Once every 3 months**	**P value**	**Cramer's V**
	n=4492	**n=3113 (69.3%)**	**n=384 (8.5%)**	**n=115 (2.6%)**	**n=32 (0.7%)**		
Sending/receiving emails	3307 (73.6%)	2949 (94.7%)	280 (73.0%)	66 (57.8%)	12 (36.6%)	<0.001	0.75
Telephoning/video calls (via webcam)	1184 (26.3%)	1137 (36.5%)	37 (9.5%)	9 (7.5%)	2 (5.8%)	<0.001	0.72
Searching for information	3317 (73.8%)	2915 (93.6%)	309 (80.5%)	76 (66.3%)	17 (54.5%)	<0.001	0.73
Finances	2260 (50.3%)	2131 (68.4%)	113 (29.5%)	15 (13.3%)	1 (1.9%)	<0.001	0.74
Shopping/buying	2831 (63.0%)	2598 (83.4%)	182 (47.5%)	39 (33.9%)	12 (37.8%)	<0.001	0.75
Selling	413 (9.2%)	394 (12.6%)	14 (3.8%)	4 (3.3%)	1 (2.1%)	<0.001	0.71
Social Networking	1742 (38.8%)	1604 (51.5%)	110 (28.7%)	25 (21.5%)	3 (9.9%)	<0.001	0.72
Creating, uploading or sharing content	848 (18.9%)	391 (12.5%)	18 (4.8%)	4 (3.8%)	0	<0.001	0.71
News	1945 (43.3%)	1844 (59.2%)	83 (21.6%)	15 (13.1%)	2 (7.1%)	<0.001	0.74

	Frequency of internet/email use					Chi-Square	
	All	**Every day**	**Once a week**	**Once a month**	**Once every 3 months**	**P value**	**Cramer's V**
	n=4492	**n=3113 (69.3%)**	**n=384 (8.5%)**	**n=115 (2.6%)**	**n=32 (0.7%)**		
Streaming/downloading	1653 (36.8%)	1595 (51.2%)	48 (12.6%)	6 (5.6%)	3 (10.2%)	<0.001	0.74
Games	1089 (24.2%)	982 (31.7%)	86 (22.3%)	14 (11.9%)	2 (6.5%)	<0.001	0.71
Job searching/ application	400 (8.9%)	376 (12.1%)	16 (4.2%)	4 (3.8%)	4 (13.5%)	<0.001	0.71
Using public services	899 (20.0%)	868 (27.9%)	25 (6.5%)	6 (4.8%)	0	<0.001	0.72
Other	267 (5.9%)	235 (7.5%)	20 (5.2%)	11 (9.5%)	1 (4.1%)	<0.001	0.71

Values are number of participants (percentages) within each category of internet/email frequency use unless otherwise stated

Table 18. Older adults' internet activities in the last three months in relation to loneliness and social isolation.

	Loneliness		**Chi-square**		**Social isolation**		**Chi-square**	
	High	**Low**	**P value**	**Cramer's V**	**High**	**Low**	**P value**	**Cramer's V**
	n=873	**n=3619**			**n=1476**	**n=3015**		
Sending/receiving emails (73.6%)	581 (66.6%)	2726 (75.3%)	<0.001	0.08	915 (62.0%)	2391 (79.3%)	<0.001	0.19
Telephoning/video calls (via webcam) (26.3%)	171 (19.6%)	1013 (28.0%)	<0.001	0.09	224 (15.2%)	959 (31.8%)	<0.001	0.22
Searching for information (73.8%)	583 (66.8%)	2734 (75.5%)	<0.001	0.08	919 (62.3%)	2398 (79.5%)	<0.001	0.19
Finances (50.3%)	362 (41.5%)	1897 (52.4%)	<0.001	0.09	616 (41.7%)	1644 (54.5%)	<0.001	0.18
Shopping/buying (63.0%)	486 (55.7%)	2345 (64.8%)	<0.001	0.08	778 (52.7%)	2053 (68.1%)	<0.001	0.18
Selling (9.2%)	55 (6.3%)	358 (9.9%)	<0.001	0.08	92 (6.2%)	321 (10.6%)	<0.001	0.18
Social Networking (38.8%)	323 (37.0%)	1419 (39.2%)	<0.001	0.07	427 (28.9%)	1315 (43.6%)	<0.001	0.19
Creating, uploading or sharing content (18.9%)	96 (11.0%)	317 (8.8%)	<0.001	0.08	90 (6.1%)	323 (10.7%)	<0.001	0.18
News (43.3%)	322 (36.9%)	1622 (44.8%)	<0.001	0.08	475 (32.2%)	1470 (48.8%)	<0.001	0.20
Streaming/downloading (36.8%)	257 (29.4%)	1396 (38.6%)	<0.001	0.09	420 (28.5%)	1233 (40.9%)	<0.001	0.18

	Loneliness		Chi-square		Social isolation		Chi-square	
	High	**Low**	**P value**	**Cramer's V**	**High**	**Low**	**P value**	**Cramer's V**
	n=873	**n=3619**			**n=1476**	**n=3015**		
Games (24.2%)	176 (20.1%)	913 (25.2%)	<0.001	0.08	294 (19.9%)	795 (26.4%)	<0.001	0.17
Job searching/ application (8.9%)	119 (13.6%)	281 (7.8%)	<0.001	0.12	139 (9.4%)	261 (8.7%)	<0.001	0.18
Using public services (20.0%)	174 (19.9%)	725 (20.0%)	<0.001	0.07	217 (14.7%)	682 (22.6%)	<0.001	0.18
Other (5.9%)	61 (7.0%)	206 (5.7%)	<0.001	0.08	77 (5.2%)	190 (6.3%)	<0.001	0.17

Values are number of participants (percentages) within each category of loneliness/social isolation unless otherwise stated

4.4. Discussion

This study identifies the evidence for older adults' current use of technology, particularly in relation to their social isolation status and feelings of loneliness, which is helpful not only for the recruitment of socially isolated older adults, but also aids the development of a DBCI for PA/SB for this population.

In the present study 19% of participants were lonely, almost three times the figure of 6.8% previously reported by Age UK (2018a) using the same data set. One explanation for this could be the different measures used to assess loneliness. In the present study a composite score of three questions was used in line with previous literature, in which there is no mention of the term loneliness, whereas Age UK (2018a) used a single question regarding how often one feels lonely. A single item that directly asks about loneliness can lead to underreporting due to the stigma attached to the experience may mean people are unwilling to admit they are lonely (Victor, et al., 2001, Campaign to end loneliness, 2015). In addition, in the present study participants with missing data on any variable of interest were excluded. If those who are lonely are more likely to spend time completing the survey in its entirety, because being asked by a researcher to help in a study may provide a sense of connection and purpose they desire, there is a greater potential for a higher prevalence of loneliness in this sample than the general population.

The present study has updated knowledge of the prevalence of social isolation among older adults in England, which to the author's knowledge had not been updated since 2001. Approximately 30% were socially isolated, which is congruent with findings from the National Health and Aging Trends Study that found 24% of older adults (≥65 years) were socially isolated and 4% were severely isolated, totalling 28% (Cudjoe, et al., 2020) and the estimation of up to 30% in Europe (Cantarero-Prieto, Pascual-Sáez and Blázquez-Fernández, 2018).

The use of internet/email was highly prevalent in the study population; 69.3% of older adults (≥50 years) use the internet/email every day and 77.8% at least once a week. Among socially isolated participants, 66.6% use the internet/email at least once a week, with 58.8% using it daily. This means that using the internet/email as a method to deliver behaviour change interventions (e.g. PA, dietary, smoking cessation), and/or recruiting participants, has potential in socially isolated older adults, without much additional cost. A larger proportion of socially isolated older adults accessed the internet/email on laptop devices (41.0%), followed by tablet devices (36.8%), desktop computers (33.7%), and smartphones (33.6%). Therefore, the use of laptops, and potentially tablets, should be considered in the design of a future DBCI for socially isolated older adults.

Older adults using the internet/email once a week or once a month were less likely to be socially isolated than every-day users. Conversely, a previous study found that social isolation was reported less frequently in older adults using the internet every day compared with never and sometimes users (Lelkes, 2013). A previous study that gave older adults computers with internet access for three years found that participants were able to stay in touch with their real-world contacts whilst suffering illness (Fokkema and Knipscheer, 2007). Thus, it may be that participants in the present study are unable to reduce their social isolation, however, remain in contact with the outside world through these means (Chen and Schulz, 2016). There is also the possibility that it may encourage isolation due to convenience.

Explanations for the associations between social isolation and frequency of internet/email use may come from specific online activities. Strong associations were found between social isolation and all online activities in the present study. Communicating with family and friends via the internet reduced older adults' (≥ 55 years) social isolation, but when used often, for long durations and to communicate with strangers was associated with greater social isolation (Sum, et al., 2008). Therefore, using internet/email as complementary with, rather than replacement of, face-to-face social meetings may protect against social isolation and potentially loneliness (Lelkes, 2013, Fokkema and Knipscheer, 2007, Cornejo, Tentori and Favela, 2013). Another explanation for the findings in the present study could be that every day users may either be online too frequently and/or for long durations, which may lead to greater social isolation. Once a week and once a month users in the present study may have a better balance, for example are too busy with real-world contacts and activities to spend as much time online, leading to reduced social isolation. Future interventions targeting social isolation in older adults may utilise the internet for cost-effectiveness, however should be in addition to real-world interactions to reduce the increased risk of loneliness. Previous research suggests that sharing content online can enhance conversations and promote real-world interactions that strengthen older adults networks, particularly intergenerationally (Cornejo, Tentori and Favela, 2013). Future research should consider exploring the frequency and duration of internet use, in addition to online activities, when exploring associations with social isolation and loneliness.

Those using internet/email less than once every three months were more likely to be socially isolated than every day user. Explanations for this could be poor access to internet/email services, lack of internet/email education, or even a purposeful decision to live ‘offline’. Older adults aged 65-76 years, of which 72% lived alone, who had no previous experience with using tablet devices were willing to learn this new technology; however many lacked knowledge of and confidence using technology, and were concerned about the lack of guidance and instruction that comes with it (Vaportzis, Clausen and Gow, 2017). Future digital interventions should thus consider the frequency and duration of use and time spent in face-to-face interactions to ensure quality relationships are fostered/maintained to reduce social isolation and feelings of loneliness in older adults. In addition, sufficient support with learning and using the technology should be given to new users, particularly those who are socially isolated so may not have a network to ask for help.

No associations between frequency of internet/email use and loneliness were found in the present study when adjusted for covariates and social isolation; however, previous studies found greater use of the internet was associated with lower loneliness in older adults (Chopik, 2016, Erickson and Johnson, 2011, Heo, et al., 2015, Cotten, Anderson and McCullough, 2013), as measured by the 20-item UCLA loneliness scale (Russell, Peplau and Cutrona, 1980), 3-item UCLA loneliness scale (Russell, 1996) or the 11-item short scale for measuring loneliness in large surveys (Hughes, et al., 2004). One explanation for the null findings in the present study may be that loneliness can be a complex and private matter (Kharicha, et al., 2017), so self-completion questionnaire answers may not reflect true feelings of loneliness. The 3-item UCLA questionnaire to measure loneliness was selected to minimise this in the present study, rather than using the direct questions available in the ELSA data set that explicitly mentions loneliness, as some can find this approach too blunt and can worry about the stigma attached to it so alter their answers (Campaign to end loneliness, 2015). In addition, the UCLA 3-item questionnaire only uses negative wording in the questions which may lead to participants providing the same answer for each question without properly considering what they are being asked (Campaign to end loneliness, 2015). Equally, the use of different measures of loneliness may also provide an explanation for the different findings between previous studies and the present study.

A previous study found older adults' online communities were most heavily used on weekday afternoons, and fewer interactions occurred at weekends or during the Christmas holidays (Nimrod, 2010). This suggests that when face-to-face interactions are available (e.g. with family members who work full-time), older adults choose these over online communities. Therefore, it could be speculated that loneliness in older adults may only be associated with time spent with real-world connections, rather than online connections, hence the null findings in the present study. Loneliness in older adults is related to the quality rather than quantity of relationships (Holt-Lunstad, Smith and Layton, 2010, Russell, et al., 2012, Beneito-Montagut, Cassián-Yde and Begueria, 2018). Relationships among older adults in online communities seem mostly superficial and rarely extend to offline domains (Nimrod, 2010), so there is also potential that the objective measure of frequency of internet/email use in the present study has no bearing on the quality of a relationship for older adults.

The types of activities engaged in whilst online may, however, impact loneliness. In the present study, weak associations were found between most online activities and loneliness status. Loneliness was previously significantly negatively correlated with internet use for communication among older adults, whereas internet use for information, entertainment or total internet use were not correlated with loneliness, measured with the 20-item UCLA loneliness scale (Erickson and Johnson, 2011). In older adults (≥52 years), social media use, specifically Facebook, was not associated with loneliness, measured with the 20-item UCLA loneliness scale (Bell, et al., 2013). Although this could be seen as a communication tool, this suggests older adults use Facebook for other reasons such as entertainment or information. Video calls are a useful tool for overcoming barriers to connect people who cannot meet face-to-face (e.g. geographic distance, time constraints) (Khalaila and Vitman-Schorr, 2018), however they mostly foster established relationships, rather than creating new ones. Elderly residents of a nursing home showed significantly lower loneliness scores, measured using the 20-item UCLA loneliness scale, after three months of video-conferencing with relatives for 5-minutes per week (Tsai, et al., 2010). Previous research showed the number of outgoing telephone calls was not associated with loneliness in older adults, however the number of incoming calls was negatively associated with loneliness (Petersen, et al., 2016b), measured using the 20-item UCLA loneliness scale (Russell, Peplau and Cutrona, 1980). Communicating via the internet with family and friends has been shown to reduce older adults' (≥ 55 years) feelings of loneliness (Sum, et al., 2008), measured using the Social and Emotional Loneliness Scale (SELSA) (DiTommaso, Brannen and Best, 2004), which may suggest the type of online activity and the relationship with whom they are communicating may be an important factor. Future studies should therefore consider investigating the quality of these online and offline relationships when researching loneliness.

One limitation of the present study is the data are self-reported, which is useful for gathering sensitive information such as loneliness and social isolation, however, may include bias and potential under or overestimations of reported behaviours (Lee, et al., 2011, Prince, et al., 2008, Araujo, et al., 2017, Scharkow, 2016). When split by frequency of internet/email use, some groups include low numbers of participants, which may potentially lead to type 1 statistical error for social isolation and type 2 statistical error for loneliness. One purpose of internet use involves communication with others, which was also captured in the social isolation measures including written/email/text messaging contact, therefore there may be some confounding between these variables. In addition, the single item question relating to internet/email use may not provide enough information to gain true insight into the duration of time spent online, via which device and for which activities. Therefore, future studies should aim to elicit more detailed information, including duration of use per day as total time and in bouts of use, in self-report questionnaires on technology use, or utilise event recording to capture real-time use. For instance, many smartphones now have the facility to report on daily and weekly usage, which can be further split into time in specific apps or categories of apps. The present study explores associations, and while speculations can be made, causation regarding internet use, social isolation and loneliness in older adults requires further research. Lastly, as many older adults aged ≥ 50 years may still be in employment, most of which requires the use of the internet/email, there is also potential that results may differ between those who are retired and those who are in employment. This was not investigated in the present study, however future studies in socially isolated older adults and technology use should additionally consider the effects of employment status.

4.5. Conclusion

The present study found that among socially isolated older adults, 66.6% use the internet/email at least once a week, with 58.8% using it daily, and their preferred device to access the internet/email was a laptop. Older adults' social isolation was associated with frequency of internet/email use, but not linearly, whereas their perceived loneliness was not. Those who use the internet/email daily are more likely to be socially isolated than less frequent users. Therefore, the use of a DBCI, particularly the internet/email, for PA/SB would be appropriate for socially isolated older adults as they do engage with technology already. It is suggested that using a laptop device would be most appropriate in this specific sample, although as the data was collected in 2016/17 and technology preferences can change rapidly, there is potential for this to have changed.

CHAPTER 5: IDENTIFYING THE BARRIERS AND FACILITATORS OF PA BEHAVIOURS IN SOCIALLY ISOLATED OLDER ADULTS

5.1. Introduction

Chapter one highlighted that socially isolated older adults require novel interventions to promote PA and reduce SB. Chapter four found that older adults who used the internet/email more frequently were more likely to be socially isolated and that two thirds of socially isolated older adults used the internet/email at least once a week, with 60% using it daily. It also showed that socially isolated older adults were more likely to use a laptop to access the internet/email than any other device. The use of DBCI for PA/SB in older adults were found to be effective at increasing PA and reducing SB (addressed in chapter three). Therefore, creating a DBCI for socially isolated older adults is a viable option to increase PA and reduce SB. However, an understanding of the reasons why this population do not engage in PA, and what motivates them to engage in PA, is still lacking.

Identifying barriers to behaviours ensures that interventions are tailored specifically to the target population (Baker, et al., 2010). The MRC guidance for developing complex interventions (Craig, et al., 2006) suggests that researchers develop a theoretical understanding of the target behaviour. This can be done by drawing on existing evidence and theory, and supplemented by primary research as necessary; for instance, conducting qualitative interviews with stakeholders and/or target populations (Craig, et al., 2006).

The Behaviour Change Wheel (BCW) is a framework synthesized from 19 frameworks of behaviour change found within the research literature (Michie, Atkins and West, 2014). It was designed to guide users through the analysis of the behavioural problem, to then be able to design an appropriate intervention (Michie, van Stralen and West, 2011). At the core of the BCW is the COM-B model, which assumes that behaviours result from the interaction between Capability, Opportunity and Motivation (see (Michie, Atkins and West, 2014). Capability refers to having the physical strength, knowledge, skills and/or stamina to perform the behaviour

(Michie, Atkins and West, 2014). Opportunity refers to the physical and social environment in which the behaviour occurs (Michie, Atkins and West, 2014). Motivation refers to having greater motivation to engage in the behaviour at the relevant time than to not, or to engage in a competing behaviour (Michie, Atkins and West, 2014). Each component of COM-B is further divided into two types; these are defined in Table 19 below.

Table 19. COM-B construct definitions from The Behaviour Change Wheel: A Guide to Designing Interventions by Miche, Atkins and West (2014), p 59-60.

Capability The person or people concerned must have the physical strength, knowledge, skills, stamina etc. to perform the behaviour	*Physical Capability* Physical skill, strength or stamina
	Psychological Capability Knowledge or psychosocial skills, strength or stamina to engage in the necessary mental processes.
Opportunity A conducive physical and social environment for the behaviour to occur e.g. it must be physically accessible, affordable, socially acceptable and there must be sufficient time	*Physical Opportunity* Opportunity afforded by the environment involving time, resources, locations, cues, physical 'affordance'
	Social Opportunity Opportunity afforded by interpersonal influences, social cues and cultural norms that influence the way that we think about things, e.g. the words and concepts that make up our language
Motivation The person or persons must be more highly motivated to do the behaviour at the relevant time than not to do the behaviour, or to engage in a competing behaviour	*Reflective Motivation* Reflective processes involving plans (self-conscious intentions) and evaluations (beliefs about what is good and bad)
	Automatic Motivation Automatic processes involving emotional reactions, desires (wants and needs), impulses, inhibitions, drive states and reflex responses

After identifying what needs to change using the COM-B model, appropriate intervention functions can be selected. Intervention functions are broad categories of means by which an intervention can change behaviour (Michie, Atkins and West, 2014). The BCW shows which COM-B components link with which intervention functions that are most likely to bring about change in the target behaviour, and identified by a group of behaviour change experts (Michie, Atkins and West, 2014). There are nine possible intervention functions that can be chosen:

education; persuasion; incentivisation; coercion; training; restriction; environmental restructuring; modelling; and enablement (Michie, Atkins and West, 2014) (see Table 20).

Table 20. Intervention function definitions from the BCW (pg. 111-112 (Michie, Atkins and West, 2014)).

Intervention function	**Definition**
Education	Increasing knowledge or understanding
Persuasion	Using communication to induce positive or negative feelings or stimulate action
Incentivisation	Creating an expectation of reward
Coercion	Creating an expectation of punishment or cost
Training	Imparting skills
Restriction	Using rules to reduce the opportunity to engage in the target behaviour (or to increase the target behaviour by reducing the opportunity to engage in competing behaviours)
Environmental restructuring	Changing the physical or social context
Modelling	Providing an example for people to aspire to or imitate
Enablement	Increasing means/reducing barriers to increase capability (beyond education and training) or opportunity (beyond environmental restructuring)

Once potential intervention functions have been selected, each must be considered using the APEASE criteria: Affordability, Practicability, Effectiveness/cost-effectiveness, Acceptability, Side-effects/safety, and Equity (Michie, Atkins and West, 2014) The descriptions of each APEASE criterion can be seen below in Table 21. Using the APEASE criteria helps intervention designers make strategic judgements as to what is likely to be most appropriate for the intervention (Michie, Atkins and West, 2014).

Once the intervention functions are decided, appropriate BCTs can be chosen for use in the intervention. The BCW details which BCTs are more or less frequently used in relation to the intervention functions (Michie, Atkins and West, 2014). As mentioned in chapter one, BCTs are an active component of an intervention designed to change behaviour that is observable, replicable and an irreducible component of an intervention designed to change behaviour and make up the BCT taxonomy v1 (Michie, Atkins and West, 2014, Michie, et al., 2013). Each BCT must also be evaluated in terms of the APEASE criteria to ensure the BCTs selected are the most appropriate for the intervention (Michie, Atkins and West, 2014). Identifying the intervention functions and BCTs are crucial for the design of theory- and evidence-based behaviour change interventions.

Table 21. APEASE criterion descriptions.

APEASE Criterion	Description
Affordability	Is it within an acceptable budget to be delivered to, or accessed by, all those for whom it would be relevant or of benefit?
Practicability	Can it be delivered as designed through the means intended to target the population?
Effectiveness/ cost-effectiveness	Is it likely to be effective in a real-world context? What is the ratio of the effectiveness in relation to cost (e.g., financial, time etc.)?
Acceptability	is it likely to be seen as appropriate by relevant stakeholders (e.g., public, professional and political)?
Side-effects/ safety	Are there any potential unwanted side-effects or unintended consequences?
Equity	to what extent may this intervention reduce or increase the disparities in standards of living, wellbeing, or health between different sectors of society?

The COM-B model has previously been shown to be effective for explaining PA behaviours in adults (Howlett, et al., 2017), therefore is likely to be helpful for identifying barriers and facilitators of PA among socially isolated older adults. Within the literature, work has been done to identify barriers and facilitators to PA of older adults generally and are reported below in relation to the COM-B model. However, to date, there is no literature on these barriers and facilitators specifically related to socially isolated older adults.

Factors relating to capability can present barriers or facilitators to older adults' engagement with PA and can be physical or psychological. In the literature, commonly reported barriers to PA among older adults (aged ≥ 50 years) in general, relating to physical capability, include having health concerns, physical limitations, chronic conditions and/or ailments that may be exacerbated by PA or make PA challenging (Sims-Gould, et al., 2012, Bethancourt, et al., 2014, Kelly, et al., 2016, Belza, et al., 2004, Buman, Daphna Yasova and Giacobbi, 2010, Moschny, et al., 2011). Also, having a physically demanding occupation can mean some individuals are less likely to undertake PA outside of work (Berger, et al., 2005). A lack of confidence in ones' physical abilities and fear that PA may therefore be unsafe (Stathi, Mckenna and Fox, 2010), not knowing or understanding what PA is appropriate for them (Bethancourt, et al., 2014) and having depression (Buman, Daphna Yasova and Giacobbi, 2010) are psychological capability barriers to PA commonly experienced by older adults. In contrast, common facilitators of PA in older adults, in relation to capability, include: a 'use it or lose it' attitude to combat the ageing process, with a desire to improve and maintain functional abilities (e.g. balance, coordination, strength, energy, cognition, mood and memory) (Jones and Higgs, 2010, Patel, et al., 2011, Stathi, Mckenna and Fox, 2010); knowing that engaging in PA can help to prevent non-communicable diseases and chronic conditions (Buman, Daphna Yasova and Giacobbi, 2010); knowledge that engaging in PA can help one remain independent (Mehra, et al., 2016, Henwood, et al., 2011); and understanding that PA can help decrease recovery time if a fall event or incident did occur (Bethancourt, et al., 2014). Socially isolated older adults may experience similar barriers and facilitators in relation to capability. However, as highlighted by the demographic profile of the socially isolated older adults in chapter four, particularly in relation to having longstanding limiting illnesses, the extent to which capability is a barrier or facilitator of PA may differ from that of the generic older adult.

The physical and social environment can present both barriers and facilitators to PA for older adults, and these relate to 'opportunity' within the COM-B model. Within the literature the accessibility of appropriate PA, transportation, convenience and cost of PA (Bethancourt, et al., 2014, Kelly, et al., 2016, Sims-Gould, et al., 2012, Belza, et al., 2004, Moschny, et al., 2011), feeling unsafe in neighbourhood environments, adverse weather conditions and uneven walking surfaces (Ball and Crawford, 2005, Bethancourt, et al., 2014, Belza, et al., 2004, Bjornsdottir, Arnadottir and Halldorsdottir, 2012) are common barriers to PA faced by older adults in relation to physical opportunity. In contrast, having entrenched cultural and/or generational attitudes that suggest it may be inappropriate for certain groups to engage in PA (Bethancourt, et al., 2014, Kelly, et al., 2016) and having no social support (Kelly, et al., 2016) are common barriers that relate to social opportunity. Common facilitators relating to opportunity include retirement affording more time to be physically active (Barnett, van Sluijs and Ogilvie, 2012), having social support from family, friends, peers, physicians and staff to be active (Rhodes, et al., 1999, Bethancourt, et al., 2014, Kelly, et al., 2016, Belza, et al., 2004). In addition, PA provides opportunities for social encounters (Mehra, et al., 2016, Fox, et al., 2007, Stathi, Mckenna and Fox, 2010, Hildebrand and Neufeld, 2009, Dionigi, 2007, Beaudreau, 2006, Devereux-Fitzgerald, et al., 2016), and opportunities to feel connected with nature and the environment whilst being active (Buman, Daphna Yasova and Giacobbi, 2010). Socially isolated older adults, as indicated by the findings of chapter four, are likely to have a lower SES than their non-isolated peers. This may mean factors relating to physical opportunity such as finances, transportation and feeling unsafe in their neighbourhoods may present greater barriers to PA than for their non-isolated peers. In addition, the very nature of social isolation may mean factors relating to social opportunity are experienced differently in this population.

Identifying what motivates and demotivates older adults from engaging in PA is important as these can be helpful to use in new interventions. Within the literature common barriers older adults report relating to motivation to engage in PA include having a preference for sedentary activities (Ball, et al., 2006), PA taking low priority in life (Buman, Daphna Yasova and Giacobbi, 2010), cultural expectations of ‘taking it easy’ in retirement (Berger, et al., 2005), feeling bored, intimidated or embarrassed by engaging in PA (Bethancourt, et al., 2014), having low self-efficacy (Bjornsdottir, Arnadottir and Halldorsdottir, 2012), and having previous traumatic experiences of PA (Buman, Daphna Yasova and Giacobbi, 2010). PA is often perceived by older adults as a by-product of other more purposeful activities (McGowan, et al., 2018); for instance not liking doing exercise for the sake of exercise (e.g. going to the gym) but enjoying activities that happen to be physically active (e.g. dancing) (Bethancourt, et al., 2014). Common facilitators of PA in relation to motivation include a desire to compete against others (Cadmus-Bertram, et al., 2019), believing that PA can reduce anxiety and increase confidence (Fox, et al., 2007), or perceiving PA as fun and enjoyable (Fox, et al., 2007, Devereux-Fitzgerald, et al., 2016). Some older adults want to engage in PA balance out other health-harming behaviours, such as smoking, alcohol consumption or unhealthy diet (Phoenix and Orr, 2017). Indeed, experiencing a recent health scare and fearing declines in health can also provide the motivation for some to engage in PA (Sims-Gould, et al., 2012).Many engage in PA for social interaction (Devereux-Fitzgerald, et al., 2016), to provide structure and purpose to their day, a temporary distraction or time for reflection (Phoenix and Orr, 2017). Some do not want to burden their children with sickness (Yang and Yang, 2011), whereas others want to be able to keep up with their grandchildren (Bethancourt, et al., 2014), which both provide motivation to engage in PA.

Whilst the barriers and facilitators of PA in older adults have previously been reported, to date no study has explored the barriers and facilitators to PA specifically experienced by older adults who are socially isolated. As socially isolated older adults differ from their non-isolated peers in terms of demographic characteristics – i.e., they are more likely to be older, male, unmarried, of lower SES, have depression, and have longstanding limiting illnesses (see chapter four) – it is likely that the barriers and facilitators of PA they experience will differ. Understanding these will enable the development of a new PA intervention that is specific to this population. The barriers and facilitators identified can then be mapped to the COM-B model, from which intervention functions and BCTs can be identified (Michie, Atkins and West, 2014), which are important in the design of PA interventions for this target population. Therefore, the present study aims to investigate potential barriers and facilitators of PA in socially isolated older adults (≥50 years), using the BCW and the COM-B model to identify intervention functions and BCTs for use in future PA interventions for socially isolated older adults.

5.2. Methods

5.2.1. Ethical approval

Ethical approval was granted by the department of Psychology and Sport at Anglia Ruskin University on 29th January 2020 (ESPGR-10) (Appendix E). Prospective participants were provided with a participant information sheet outlining the study and what would be required of them (Appendix F). Written informed consent was obtained from participants prior to data collection (Appendix G).

5.2.2. Participant recruitment

A small PPI group of older adults (n = 5) who were not socially isolated were individually provided with version 1 of the participant information sheet, consent form, participant details form, and five different versions of posters advertising the study to provide feedback on (e.g. regarding the wording, font type/size, colours and images used etc.). This feedback was compiled, and final versions of the documents were created using it. Three posters were used, two of which had wording amended to use the phrase 'small social network' as the terms social isolation and loneliness were identified as potentially off putting from the PPI feedback and feedback from organisations through which participants were recruited (Appendix I).

Participants were recruited on a voluntary basis through advertisements and established connections with local councils, ageing and loneliness charities, clubs, and organisations with people over 50 years old across the United Kingdom, and online via social media. Participants included socially isolated older adults (≥50 years) who had no self-reported impairment or comorbidity that meant they could not engage in PA and had access to the internet. No incentives were offered to participants.

Potential participants were provided the participant information sheet and consent form to read and complete. If participants did not provide informed consent, they were exited from the study at this point. If they provided informed consent, participants were asked to complete the participant details form (see section 5.2.3. Materials) which included an assessment of their social isolation status.

Social isolation status was assessed using the 6-item Lubben Social Network Scale (Lubben, et al., 2006) via a Jisc online survey. Questions included 'how many relatives do you see or hear from at least once a month?', 'how many relatives do you feel close to such that you could call on them for help?', 'how many relatives do you feel at ease with that you can talk about private matters?', 'how many friends do you see or hear from at least once a month?', 'how many friends do you feel close to such that you could call on them for help?', and 'how many friends do you feel at ease with that you can talk about private matters?'. Each question was scored out of 5 (answers: zero/none = 0 points, one = 1 point, two = 2 points, three or four = 3 points, five to eight = 4 points, nine or more = 5 points), meaning overall scores ranged between 0 – 30 (Lubben, et al., 2006). The clinical cut-off point of <12 was used to identify those who were socially isolated (Lubben, et al., 2006). Those who had a Lubben score ≥ 12 were contacted via their chosen method using contact information they provided to thank them for their time and interest in the study, and inform them they were not eligible to continue (Appendix J). Those who had a Lubben score < 12 were eligible to take part and were contacted to arrange the next stage.

5.2.3. Materials

A demographic questionnaire gathered data on age, sex, ethnicity, employment status, marital status, education, long-standing limiting illness and home postcode (Appendix H). The postcode was used to derive a score for indices of multiple deprivation (IMD) (Ministry of Housing Communities & Local Government, 2019). As loneliness is independent of social isolation status, and no associations were found between internet/email use and loneliness in older adults (chapter four), it was decided that asking participants about their loneliness was unnecessary to achieve the aims of this part of the project.

Participants’ current levels of PA were assessed using the Rapid Assessment of Physical Activity (RAPA) questionnaire (University of Washington Health Promotion Research Center, 2006). This questionnaire was selected as it was specifically designed for use in populations ≥ 50 years, showed as good or better positive predictive value (77%) and better negative predictive value (75%) than other PA questionnaires designed for use in older adults (e.g. Behavioural Risk Factor Surveillance System (BRFSS) and Patients-centered Assessment and Counselling for Exercise (PACE)) and good discrimination of older adults who did and did not engage in regular moderate PA (Topolski, et al., 2006). There are nine items on the questionnaire, including a range of aerobic PA intensities from sedentary to vigorous, in addition to strength and flexibility, to which participants respond ‘yes’ or ‘no’ regarding whether the statement accurately describes them. Responses to the first seven items are scored 1-7 (1 = sedentary, 2 = under active, 3 = under active [light activities], 4 = under active regular, 5 = active). The strength and flexibility items are scored separately (none = 0, strength = 1, flexibility = 2, both = 3). Scores range between 1-10, with scores <6 regarded as sub-optimal (University of Washington Health Promotion Research Center, 2006).

5.2.4. Procedure

Interviews were conducted by SS via telephone. Interviews lasted on average 28 minutes (range 16 – 47 minutes). All interviews took place between February and June 2020. This included the COVID-19 lockdown period in which nationwide social distancing and limited outdoor activities were enforced, and most of the sport and leisure facilities were closed by the UK Government (Cabinet Office, 2020). Participants were encouraged to discuss their usual PA outside of the pandemic, and any barriers or facilitators mentioned that were specific only to the COVID-19 lockdown were excluded from the analysis.

A semi-structured interview guide (Appendix K) was designed by SS in consultation with JR to identify barriers to and facilitators of PA in socially isolated older adults. It was informed by the COM-B model, using constructs of Capability, Opportunity and Motivation (Michie, Atkins and West, 2014). In addition, participants were asked their views on using DBCI for PA. The interview was piloted with two ineligible older adults (Lubben score >12), and questions and probes were refined.

5.2.5. Data analysis

Demographic data collected via self-report questionnaire were summarised using descriptive statistics. Interviews were audio recorded and transcribed verbatim. Interview data was managed using NVivo qualitative analysis software v12 (QSR International, Melbourne, Australia).

Data were analysed using framework analysis, following the stages of familiarisation, indexing, charting, mapping and interpretation (Ritchie and Spencer, 1994). The COM-B model was selected as the framework a priori due to the use of the BCW throughout the thesis and was confirmed as appropriate during familiarisation with the interview data. The researcher (SS) familiarised themself with the data through the transcription process and by reading and re-reading the transcripts. Data were then indexed under the 6 sub-constructs of the COM-B model: psychological capability, physical capability, social opportunity, physical opportunity, automatic motivation and reflective motivation (Michie, Atkins and West, 2014). In addition, the data was also indexed as a barrier or facilitator of PA. A second researcher (JR) independently coded a sample of 3 interviews to the COM-B framework, barriers and facilitators. The three sample interviews that were independently coded by SS and JR were compared for similarity. Any discrepancies were resolved through discussion and informed the coding of the whole dataset. Data were charted and summarised to create themes under each COM-B subconstruct. From this the data were mapped to link participant typologies, based on the self-report questionnaire, to identify themes. The data were then interpreted and reported in the results section.

5.2.6. Identifying intervention functions and behaviour change techniques

The barriers and facilitators identified and mapped to the COM-B model enabled the identification of appropriate intervention functions and BCTs using the BCW (Michie, Atkins and West, 2014). The BCW provides guidance on which intervention functions are most likely to be effective in bringing about change in the target behaviour (Michie, Atkins and West, 2014). Using the guidance in the BCW, candidate intervention functions appropriate to each barrier were identified. From this list, the intervention functions were then assessed using the APEASE criteria (Michie, Atkins and West, 2014) in the context of the design of a future PA intervention for socially isolated older adults. Based on this, appropriate intervention functions for use in a novel PA/SB intervention in socially isolated older adults were selected.

The BCW provides guidance on the most frequently used BCTs in relation to the intervention functions (Michie, Atkins and West, 2014), and was used to select appropriate BCTs for the selected intervention functions in the present study. Each BCT was evaluated using the APEASE criteria and based on this, appropriate BCTs for use in a novel PA/SB intervention in socially isolated older adults were selected.

5.3. Results

As a result of the recruitment campaign, the online participant information sheet web page was visited 768 times. Of those who either completed the consent form (n = 56) or who made contact via email (n = 17), 41 were not eligible as they had a Lubben score ≥ 12 (mean 19.49 ± 4.46; range 12 – 27). A further nine lost contact, five withdrew due to COVID-19 pressures, and three self-identified as not isolated so decided to not complete the online form. A total of 15 eligible participants were recruited and data from them were included in the analysis.

Demographic information of the included participants can be seen in Table 22. The mean age of the participants was 62.60 years old ± 5.89 (range 52 – 72 years) and participants had a mean Lubben score of 8.40 ± 1.50 (range 7 – 11). Two participants were required to 'shield' by the UK Government during this time (Cabinet Office, 2020), meaning they were unable to leave their homes.

5.3.1. Interview data

Results are presented as barriers and facilitators to PA in relation to the COM-B constructs Capability (Physical and Psychological), Opportunity (Physical and Social), and Motivation (Reflective and Automatic). An overview of the themes identified within each of the six COM-B constructs can be seen in Table 23.

Table 22. Participant demographic information.

Characteristic	N	% Sample
Age (years)		
50 – 59	5	33.33
60 - 69	9	60.00
70+	1	6.67
Sex		
Male	6	40.00
Female	9	60.00
Ethnicity		
White British	10	66.67
White European	3	20.00
White Other/Not specified	2	13.33
Marital status		
Single	2	13.33
Married or co-habiting	9	60.00
Divorced or separated	3	30.00
Widowed	1	6.67
Employment status		
Retired	11	73.33
Employed full-time	4	26.67
Highest level of education		
O-Level/GCSE	1	6.67
A-Level	4	26.67
University degree or higher	10	66.67
*Longstanding Illness**		
Yes – not limiting	5	33.33
Yes – limiting	2	13.33
No	8	53.33
RAPA Score		
Active (score ≥ 6)	6	40.00
Inactive (score < 6)	9	60.00
IMD Decile		
4	1	6.67
5	0	0
6	5	33.33
7	3	20.00
8	3	20.00
9	2	13.33
10	1	6.67

*** Long-standing meaning anything that has troubled you, or is likely to affect you, over a period of time. Does this/do these illnesses(es) limit your activities in any way?*

Table 23. Overview of barriers and facilitators of physical activity in socially isolated older adults.

COM-B Construct	Barriers	Facilitators
Capability		
Physical	• Physical trauma or injuries • Chronic and acute illness • Ageing related physical declines	• PA that is gentler and less strenuous
Psychological	N/A	• Knowledge of 'safe' PA
Opportunity		
Physical	• Lack of convenient facilities • Limited finances • Lack of appropriate equipment/clothing • Bad weather	• Convenient local facilities • Local outdoor spaces • Time • Good weather
Social	• Caring responsibilities • Large group PA settings • Feeling judged by strangers/acquaintances	• Small PA groups • Expertise from Personal trainers/ Medical professionals • Support from spouse or a close friend • Having animals to care for and walk
Motivation		
Reflective	• Lack of planning – life gets in the way • Identity – not being a 'sporty' person • Fear of injury risk	• Having a PA plan and goals • Believing PA has positive health outcomes
Automatic	• Embarrassment, boredom, hate, frustrations, anxiety, fear about PA • Preference for other sedentary activities	• Fun and enjoyment of PA • Guilt if not active

5.3.1.1. Capability

Participants commonly reported physical limitations, which were related to injuries, illnesses and ageing-related declines as barriers to PA. Understanding how to be active safely, and in ways that accommodate a person's physical limitations, were mentioned as facilitators of PA (e.g. gentler and less strenuous PA).

Physical Capability

Physical trauma or injury

The most common barrier faced by socially isolated older adults was a trauma or injury that impacted their physical capability to do PA. This was consistent across sex and employment statuses. However, those who were active either used the incident as a springboard to activity or modified their activity to accommodate their physical capabilities. In contrast, inactive participants tended to focus on what PA they could not do. Accidents and broken bones led participants to be conscious of their injuries, and they cited these as reasons they could no longer do certain PA: *"But then I had a really serious car accident and erm, I ended up having to have operations on my back. And that has kind of, I suppose as well limited the kind of impact that I can do." (P4, female, inactive).*

Some were given specific advice by their healthcare professionals to avoid certain PA to prevent further damage to the injured area: *"I was advised not to run because the shock would not be good to the bone structure which I guess is weaker because they removed pieces of loose bone" (P10, male, inactive, retired).*

Chronic and acute Illnesses

Participants often suffered acute and chronic illnesses which impacted on their ability to engage in PA. Those with chronic illness mentioned it being a major barrier to their PA capability, and despite wanting to be more active and attend PA groups/classes, their unpredictable health made this challenging: *"I'm limited through physical health as to what I* *can actually do... I struggle because I can't tell if I'm going to be alright in a weeks' time" (P5, female, inactive, retired).*

Others mentioned previously having ill health that required major surgery, which had lasting impact on the types of PA they are now able to engage in:

> *"just after I had my transplant, about 6 months later, I had sepsis really bad where I was in hospital. And they did advise me to try and avoid gyms or swimming pools for the risk of erm, infection and whatever… where I've had so many major surgeries, erm, some exercises that I do find really pull on the right side where the surgery site was. So some things I sort of have to be more careful of." (P7, female, inactive, retired).*

However, in some cases these illnesses and injuries facilitated PA, particularly muscle strengthening exercises as part of the recovery process and to help with symptoms of chronic conditions. For those who had liver transplants (n = 2), it was crucial to them that they were active and "*as fit as possible" (P6, male, active, full time employed)* to reduce chances of complications. For those who mentioned they had joint operations (n = 4), they spoke about doing rehabilitation exercises regularly, for instance using *"wobbly cushions which I try to stand on and keep my balance" (P9, male, active, retired).* One female participant started doing Pilates to relieve back pain she felt whilst sitting at work, and continued Pilates post-retirement, as she felt it relieved the pain and increased her flexibility. Two female participants with physical limitations mentioned they do water-based PA as it is not weight bearing so is within their physical capability: *"I used to [BEFORE COVID-19 LOCKDOWN] go twice a week and do aquafit, coz that's obviously non-impact and my knee could cope with it" (P15, female, inactive, retired).*

Ageing-related physical declines

Participants experienced physical issues commonly associated with ageing that prevented them from engaging in certain PA. Having osteoarthritis and/or being in need of a joint replacement soon were commonly mentioned as limiting the duration and the intensity of PA that participants are currently able to engage in:

> *"For example, for me something that now puts a lot of strain on my hands would not be good because I've got arthritis in them. Some of my fingers are, I've also got a trigger finger I need surgery on, but course that has got lost in the current err ongoing thing [COVID-19 LOCKDOWN]. And my knees are not wonderful. So things… the wrong sort of activity, high impact or whatever could be difficult, could damage me" (P14, female, inactive, retired)*

One participant described how the menopause affected her sleeping patterns, which in turn affected her ability to fit in PA before work, because when her alarm goes off "*it's kind of 'ergh' I don't think I can" (P3, female, active, full time employed).* Two males mentioned sensory impairments that have meant they stopped or reduced their PA, although it was unclear if these were ageing related degenerations or not. One stopped playing squash 3-4 years ago because "*double vision that means occasionally I see the ball twice or not at the right time" (P9, male, active, retired).* The other is deaf in his right ear making his preferred PA, road cycling, more challenging because he is "*always concerned about traffic coming up from behind" (P10, male, inactive, retired).*

Psychological Capability

Knowledge of Government physical activity guidelines

When asked if they knew anything about the Government PA guidelines for people aged 50 and older, neither active nor inactive participants were aware of the guidelines existence: *I* *have no idea" (P12, male, active, full time employed); "Er, no. Not a sausage!" (P15, female, inactive, retired).* As this lack of guideline knowledge was consistent in both active and inactive participants, it is unlikely that it poses a major barrier to PA in socially isolated older adults. Some participants were able to *"hazard a guess" (P4, female, inactive, full time employed)* as to the frequency of PA the guidelines, suggesting "*20-30 minutes three times a week is it?" (P5, female, inactive, retired),* although there was some confusion as to the intensity of PA:

> *"I believe that a certain amount of activity is recommended each day or each week, and that activity should be of a certain kind, but if you ask me to quote exact figures and exact… I mean I know there are things like, good physical activity is where you, erm, where you're actually out of breath as opposed to you just going for a casual stroll, and I imagine it was something like 30 minutes a day or something like that?" (P8, male, inactive, retired).*

Knowledge of 'safe' physical activity

Having knowledge of which exercises are possible, and are safe to do within their physical capabilities, was a facilitator of PA. Those who were active and had previous experiences of PA were more likely to mention knowing what PA they could do: *"As I said it's probably 10 or 15 minute [Pilates] session then because I've been doing it for 8-9 years, so I know what the exercises are, and I probably change them every so often." (P13, female, active, retired).*

Those who were inactive were more likely to mention knowing that their PA needed to be "*age appropriate" (P11, female, inactive, retired)* but, with the exception of suggesting walking, they did not elaborate on what 'age appropriate' PA would entail. This suggests that a lack of knowledge of what PA is safe for them could prevent participants engaging in PA, particularly for inactive socially isolated older adults.

5.3.1.2. Opportunity

"Sometimes it's about having the right kind of space or equipment or place to go" (P8, male, inactive, retired). Physical opportunity barriers that were mentioned by participants related to access to local facilities, equipment and clothing, finances, and poor weather conditions. Conversely, good weather conditions, access to outdoor spaces, and having equipment at home were facilitators of PA. For those who were retired, time generally was not a barrier to PA, whereas those in full time employment found their lack of time to be active to be a challenge.

Having caring responsibilities for other people made it harder to be active, however caring for animals such as cats and dogs often means participants must engage in some PA. Having a medical/exercise professional prescribe PA, or a spouse/close friend that provided social support, encouraged participants to be active. Several participants also mentioned joining active groups to do PA, which they found motivating and enjoyable, although finding appropriate beginner level classes that were local and had spaces could make this challenging. Many participants expressed a dislike for larger group activities, either because they found them anxiety inducing or because they preferred the autonomy of doing PA on their own.

Physical opportunity

(In)Convenient Local Facilities

Two female participants mentioned having memberships to local facilities, which they used to engage in PA – *"there's a pool at this gym so that's why I joined that gym" (P5, female, inactive, retired); "I was a member of the local er health club at one of the local hotels and I used to go twice a week and do aquafit" (P15, female, inactive, retired).* Those who had used local facilities felt pressured to use the equipment for very short amounts of time because they were conscious that other people were waiting to use the equipment after them. In addition, some were put off by the lack of cleanliness of the facilities:

> *"The other problem is the changing facilities and that was a little bit of an issue at the place I was going to. The changing facilities have the swimming pool and the gym changing the same place and they are filthy on the whole they just do not get clean enough and the floors are slippery and that lack of cleaning really puts me off" (P11, female, inactive, retired).*

Despite most participants being able to name local facilities (e.g. swimming pool, leisure centre, gym), the most common barrier in relation to facilities was that they required travel by car. Participants found this discouraging, despite most actually having cars they use regularly for other things:

> *"As I say I'm kind of one of those people that I don't really like to get in the car and go to a class. I'd much prefer to do something locally or run locally and the running club is just on the green and you know there's lots of things happening and so, you know… so what I do like to do locally without having to travel with it by car it" (P13, female, active, retired).*

One active male participant mentioned that his gym, swimming pool and local park where he ran and played volleyball, were all within walking distance of his home. Most Participants highlighted a preference for activities that could be done either at home or within walking/cycling distance of home:

> *"Something I can do in the house and from the house I think would work much better for me... because not spending time and indeed money travelling" (P14, female, inactive, retired).*

Limited finances

Having limited income was a common barrier, particularly among retired participants, and was consistent across active/inactive and male/female participants:

> *"It is also a matter of, err, finances. The activities that I like to do, or I would like to do, like Pilates and stuff like that, err, all cost money… if you are a pensioner obviously you are limited by your finances as well. Six or seven pounds for a session somewhere once or twice a week, err, takes a huge chunk of my, my budget. So I couldn't afford it." (P1, female, active, retired).*

Only one person mentioned the financial cost of needing to buy equipment to be able to exercise at home: *"But for me it's all about the equipment that you have to buy too to do things, like the weights or the rowing machine or the whatever." (P4, female, inactive, full time employed).*

Equipment at home

Four participants mentioned that they had fitness equipment at home (e.g. rowing machine, cross-trainer, Pilates mat and equipment, weights set) which they could use to be active. All participants with equipment at home were female; two were active and two were inactive. Those who were active regularly used their indoor rowing machine and Pilates equipment: *"I've got the mat, I've got the ring and the, you know, the bands etc, which I do use" (P14, female, active, retired).* One inactive female mentioned purchasing an exercise bike in anticipation of the COVID-19 lockdown as she was required to shield, however, she confessed that she has barely used it because "*the saddle is so bloody hard" (P7, female, inactive, retired).* The other inactive female said their partner used the cross trainer they have at home, but she never used it. This participant commented that the location of the cross trainer was quite public and that she would be more inclined to use it if she were able to do so privately, somewhere "*that I could close a door and nobody could see me doing it" (P4, female, inactive, full time employed).* The same participant also mentioned that not having appropriate clothing may be another reason she does not use the cross trainer at home, or indeed do PA elsewhere:

> *"I don't actually possess a pair of trousers; this is part of the problem… I would need to buy a pair of trainers because it's not the kind of thing you can do in your slippers. This is going to sound really ridiculous but it's the Gods honest truth, I don't possess a pair of trousers, I don't possess a pair of flat shoes. [laughs] So, just, even that thing of I haven't even got the right stuff to do this in [laughs] seriously, I'd have to go out and buy something to do it with" (P4, female, inactive, full time employed).*

Time

Generally, those still employed found it harder to find time to be active, whereas those who had retired felt they had plenty of time to do PA. One active, full time employed, male participant mentioned he had flexible working hours which meant he could easily make time to do his PA. Two females who were still employed full time said that finding time to be active was difficult whilst working, although one (P3) was extremely active according to their RAPA score:

> *"It's time… it's easier to kind of come home and, and get the laptop out and start doing a bit more work and emails in the evening... When time is tight, time is precious and, you know, I'm kind of doing my work-work at work and thinking oh my evenings are for research and those other things I can't do during the day. So I feel that physical exercise would impinge on, the time that I have… I'm in a fairly senior position at work and I feel that I need to keep on top of work" (P4, female, inactive, full time employed).*

Two inactive male participants that had retired mentioned that they were now busier than before retirement and, as a result they found it hard to find time to be active: *"yeah but when you retire you end up doing even more than you did before." (P10, male, inactive, retired).* However, generally those who were retired reported having plenty of time to be active, regardless of whether they actually were active or not: *"Oh my God I've got – yeah! I've got no excuses time-wise." (P7, female, inactive, retired).*

The outdoors and nature

Being outdoors and/or among nature was important for many participants: *"There's nothing better than being outside and seeing a bit of green. Err, green is good for the soul I think…" (P1, female, active, retired).* Most participants mentioned local Nature Reserves, walking/cycling trails, parks, and beaches in which they could be and were active in:

> *"We've got something called the erm, [says name of local nature reserve]. They're old gravel pits, but erm, they have converted quite nicely into walkways… it's scrubland, there's lots of trees around, but it's, it's interesting. And a bit of wildlife there. There's a lot of fisherman go there. So, yeah, it's a nice walk." (P2, male, inactive, retired).*

Only two participants said they had a limited variety of walking routes available locally: *"it's just the same route, erm, and if you're very unfortunate and you're in an area where you can't vary the route and it's exactly the same route every day, it gets boring as well" (P1, female, active, retired).*

Weather and seasons

Wet and cold weather make it more difficult to be physically active, particularly as this heavily influenced outdoor PA such as walking: *"depending on how much rain we've had as to whether they, the routes are accessible" (P1, female, active, retired)*. Adverse weather also made PA a less enjoyable experience and participants admitted to being less inclined to be active in these conditions: *"if it's raining then I am frankly less likely to go out and stomp round the fields" (P15, female, inactive, retired).* Participants also mentioned disliking being active when it was too hot as they found it *"sapping and uncomfortable" (P12, male, active, full time employed)*. However, warm and dry weather encouraged PA, particularly outdoors: *"In summer I'm extremely, err, active and winter not so much." (P1, female, active, retired)*.

Social Opportunity

Caring responsibilities

A few participants mentioned that they were carers for their spouses and parents, and were also needed to provide occasional care for their children and grandchildren to varying degrees. Caring responsibilities made it difficult for participants to be active, as they had less time, flexibility, and energy:

> *"And my partner unfortunately is um, paralysed 70-90% of the time so I have to get his food ready for him… so I have to be around a lot more than some other people might be… In the Spring my daughter was dumping her children on me because she wasn't well… In my age group having to help look after someone is a pretty common issue." (P11, female, inactive, retired).*

In addition, spending time with the person(s) being cared for often required engagement in activities that were appropriate for the cared for person, and usually involved non-active pastimes (e.g. going for lunch/coffee, playing boardgames or watching television). Caring for a parent was particularly challenging as when the parent wanted to reward or thank their child for their work, they often did so by offering opportunities to relax and be sedentary: *"my mum… she thinks I work hard during the week so at the weekends she tries to keep me from doing* *very much [laughs] 'shall we go out for coffee? Should we go out for lunch together?" (P4, female, inactive, full-time employed).*

Active groups

Several participants mentioned joining walking groups, exercise classes (e.g. tai chi, Pilates, Aquafit) and running clubs, which they found enjoyable and motivating.

> *"I'm a member of a running club so I just sort of got used to running and then just kept, or just tried to keep it up during lockdown so I'm not just sittin' on me bum doin' absolutely nothin'... when the club is running… then there's a whole group of us that meet… and I like the people we meet up with, so… there's sort of the social side of things as well as the exercise, so… makes it easier." (P12, male, active, full-time employed).*

However, some local classes that participants attended had been closed or relocated to less convenient venues, so they stopped doing that PA. Participants also said that group PA sessions were difficult to book due to limited places, that is if they could find one appropriate for their ability in the first place:

> *"but I would, probably part of me would like to have a go at doing sport properly again, but I don't know anybody else who is as useless as I am… when you're somebody who's never had the opportunity to do it, which is loads of us, finding the beginners classes is easier said than done" (P11, female, inactive, retired).*

Several participants mentioned that they preferred smaller groups or being active on their own to do exactly as they wanted when they wanted: *"If there's sort of 20, 30 people, err, as soon as you sort of walk on your own, somebody feels, err, obliged to come and join you and [laughs] and spoil, and spoil the peace" (P1, female, active, retired).*

Influences of strangers or acquaintances

Some participants spoke about feeling anxious when doing PA either in front of, or with, others. One participant said that their social anxiety prevented them from going to the gym/exercise classes they had booked and paid for on several occasions:

> *"I've belonged to different gyms over the years and I used to erm, I joined ones where I would call in on the way home from work because it was, 'well you're going past it so you might as well go in', I thought I'd be more motivated to go. But because I get anxious about walking in where there are going to be people there, I would then just drive home and think oh not tonight. Then that becomes not for a week etc." (P3, female, active, full time employed).*

A couple of participants felt the potential of seeing an acquaintance whilst at the gym, swimming pool or in a group session was "*a big off-putter" (P4, female, inactive, full time employed).* Many participants mentioned anticipating, or even experiencing, feeling judged by other people, usually in relation to their abilities/techniques whilst doing PA, or their body image:

> *"But the weirdest thing for me was my scar. How strange is that? Now, it doesn't bother me, yeah? So basically, I had to wear, you know, dry vests and stuff when I'd get in the pool... And I have a trainer, I have a swimming coach and she said to me, she said 'why, what is your problem?', you know 'what is your problem? You don't need to wear them' and I said 'I do need to wear me vest because people stare at me'." (P6, male, active, full time employed).*

A few participants were wary of being active with others as they were concerned that they might hold the group back, regardless of whether they were active or inactive, and so stopped engaging in that PA with others:

"I used to go running with erm, a couple of female friends of mine but I haven't been running with them because I got a bit slower than them and I just, from my point of view I didn't like to go because I felt I was slowing them down." (P13, female, active, retired).

Support from a key contact - spouse/ close friend/ exercise professional

Having a spouse or close trusted friend who either encouraged participants to be active or were active with them helped PA engagement:

"'coz if I didn't have [SPOUSE] to keep me on the straight and narrow, I would be a very lazy sod and sit on the sofa watchin' TV and weigh about 15 stone more than I do... mean, I'm quite a lot older than her so… I don't wanna stop her bein' able to do something 'coz I'm an old fart and can't keep up." (P12, male, active, full time employed).

Participants who did not have anyone to fulfil this role mentioned that it would be nice to have someone to be active with, and that would make it easier to do regular PA:

"I don't really have erm friends, well friends of my own age around here… so, you know, it's not a matter of doing exercise with somebody else. It's going to be me. It would be easier, obviously, if I had somebody who's, if we had a sort of date to go and do stuff together… Outside of [COVID-19] lockdown, I can go for days at a time without seeing another person [laughs]" (P15, female, inactive, retired).

A couple of participants indicated they had a medical or exercise professional prescribing PA which was beneficial and encouraged them to engage in the recommended PA. Having appointments scheduled with a Personal Trainer not only provided participants with the knowledge they required to achieve certain goals, but also provided accountability: *"I've never let him down… I've gotta keep up the commitment and I've got to do it" (P6, male, active, full time employed).* PA advice or exercise prescription was more commonly mentioned by those with chronic illness, or who required rehabilitation post-injury or illness, and often came from

Doctors or Physiotherapists. In this instance, an expert provided both knowledge of how to engage in PA safely and motivation to engage with PA:

> *"if the man on the, when I go and have this lung function test says ooh, you know 'it's on the move, if you did a bit more exercise it might sort of stem the problem, slow it down a bit', then yes I think that would… if that was ever said I think that would probably jolt me into action" (P2, male, inactive, retired).*

Having animals

Three retired, female participants mentioned having dogs or cats to look after, which required them to go for walks and carry heavy bags of food and litter, and this meant they had to be *"a bit active every day" (P14, female, inactive, retired):*

> *"because I'm living on my own, and because I actually breed cats, I do have to carry quite heavy stuff… I have a cunning plan, and I am getting a couple of puppies at the beginning of next month because I really feel that I need to be pushed to go out, and if you've got a couple of dogs, you've gotta take them out regardless of whether it's raining or not." (P15, female, inactive, retired).*

5.3.1.3. Motivation

Participants who had structure and routine to their PA were more likely to be active, and those who mentioned 'life getting in the way' tended not to have routines and were less likely to be active. Those who set goals or had events planned that they needed to be physically fit for (e.g. 10K races, walking holidays) were also more likely to be active. Participants were wary of getting injured whilst being active, but for the most part, they believed that PA resulted in positive health outcomes and stated this as a motivation to either remain or become more active. Some participants identified themselves as having always been active, whereas others had never done much exercise, suggesting having a PA identity could be viewed as both a barrier and a facilitator for PA. The most prominent factor in facilitating PA among the participants was that the PA was fun and enjoyable. If they found the PA boring, unpleasant or a chore then they were much less likely to participate, and often chose to spend their time engaged in more sedentary activities which they found more interesting.

Reflective Motivation

Planning and goal setting

Participants who did not have explicit plans or goals for PA were less likely to be active. When life events occurred or other tasks needed to be completed, PA was forgotten about or moved down the priority list:

> *"just other life things that need to be done I go to bed and I think 'oh I didn't do any floor exercises today'. So life takes over. I think it requires a certain time of the day when you think 'oh what should I do now?' 'ohh I do some of those exercises for 5-10 minutes'. and that doesn't always happen." (P10, male, inactive, retired).*

Others felt they *'got out of the habit' (P12, male, active, full time employed)* of doing PA and into the habit of filling that time with other, more sedentary, things. However, having a routine and structure of PA were identified as making it easier to engage in PA, for instance walking every morning or attending a class every Wednesday:

> *"That's why the couch to 5K was excellent because it was so structured. And easy to do. Erm, once you started it, it almost hooked you in. I'm the sort of person that I need, I need a bit of structure otherwise I just don't bother or I've only got to miss 1 class or something and that's it. I find myself not going back." (P7, female, inactive, retired).*

In addition, participants mentioned having achievable goals (e.g. running a 10K) or events (e.g. trekking holidays) lined up that helped them regularly engage in PA and helped maintain motivation:

> *"I decided that I wanted to take him [Husband] to see Everest and go in the Himalayas which was obviously a bit more than walking in the Alps sort of thing. So I decided that I needed to make sure I was physically fit, err, lost a bit of weight, so that I could actually enjoy the experience." (P3, female, active, full time employed).*

One participant stated that before she was diagnosed with a chronic health condition that severely reduced her PA capability, she was very competitive, always striving for faster, higher, better outcome scores. She explained that now she sets goals in a different way because her previous goals would now be unrealistic and unachievable. She was also aware that her PA plan may need to change from day to day depending on her chronic condition:

> *"I never really, kind of, if I go swimming I never say I'm gonna do 60 lengths, so I get in a see how my body feels. And then if it's in a good, you know if I'm feeling alright, then I'll swim a lot more than if I'm not. So, I try and do it by time, rather than what accomplishment. So I take the pressure off, that you feel bad because that's all you did. Because I know that I'm getting older and with my health conditions you're only going downwards anyway… so I've always decided that time is a better element, and I say if you do more in that time if your body's feeling good that day." (P5, female, inactive, retired).*

Fear of injury risk

Another barrier identified was *"injury risk… wear and tear on the body" (P4, female, inactive, full time employed)*, which participants perceived to be discouraging, although generally there was a consensus view that this risk should be managed. One participant mentioned she could be "*a bit of a bull in a China shop" (P10, female, inactive, retired)* meaning she could be over enthusiastic about PA and then injure herself in the process. Another commented on requiring physiotherapy when she took up running: *"with running I ended up having a lot of physio as well [laughs] I pulled stuff, which I'm sure is not that healthy" (P7, female, inactive, retired).*

Both active and inactive participants needed to be cautious regarding their PA due to potential adverse effects which could stop them from engaging in or require them to modify their PA: *"I have to pace myself" (P5, female, inactive, retired); "I've got to listen to what my body is saying, I can't risk any sort of internal injury or hernias or anything like that" (P7, female, inactive, retired).* However, once they found PA they believe they were capable of, they continued to do it within a comfortable frequency and intensity: *"because when I swim, because I'm such a good swimmer it doesn't, I'm not out of breath… And that's why I suppose I just go swimming for the moment because I've found something I can do." (P5, female, inactive, retired).*

Beliefs about outcomes of physical activity

All participants believed PA was or would be beneficial to them. A few participants believed PA was good for them but were not able to recall specific benefits at the time of asking: *"I'm sure there are some, but I can't think what they are at the moment" (P8, male, inactive, retired); "there probably are… but I've no idea what" (P12, male, active, full time employed).* Most participants believed PA had mostly positive outcomes on general mental and physical health: *"it makes me feel better... It makes me feel much mentally stronger… I physically feel better" (P6, male, active, full time employed).* Participants also mentioned specific mental health benefits such as having a "*better temperament" (P13, female, active, retired), "increased confidence" (P3, female, active, full time employed), "being able to deal with stuff" (P7, female, inactive, retired), "feeling good" (P9, male, active, retired).* Only three participants, all female, elaborated on what the physical benefits of PA were. One said that it kept their muscles and joints moving which prevented pain because everything was properly supported; another mentioned that it maintained muscle tone. A third spoke from personal experience about increased flexibility and strength:

> *"general sort of, flexibility. So I'm, sort of, able to do certain things that I probably, [laughs] that I haven't done since school. Sort of gymnastic type things… I'm very much able to, it sounds weird, lift heavy things. So in the office, when we've moved offices and I'm lifting a photocopier with somebody or lifting wardrobes, erm, you know, heavy tables, 8 seater tables and things erm, and it's not a problem for me." (P3, female, active, full time employed).*

One participant believed PA would reduce non-communicable disease risk: *"lesser risk of getting debilitating diseases like, you know, stroke, and heart disease and that kind of thing" (P4, female, inactive, full time employed).* Others felt that doing PA would mean they would be fit should they become ill, meaning they would recover more quickly:

> *"I think if anything was to happen health-wise to me, um then being being fairly healthy and fairly active um would sort of help if I, you know, if I had any treatment." (P13, female, active, retired)*

In addition, several mentioned that being active would delay the ageing process and so they would be more likely to live an enjoyable and independent life, in good health for longer:

> *"I'd say it's keeping young, that's ridiculous but… but basically I don't want to get old. [laughs] You know what I mean, I don't wanna end, I do not want to end up in a chair. Unless I have to... and also it's extending the quality of my life as well." (P6, male, active, full time employed).*

Participants who were inactive felt they were more motivated to become active because they were "*getting to the age where I've started to kind of see the priority" (P4, female, inactive, full time employed).* For instance: *"I don't wanna turn around in five years and find that I've* *suddenly got very old very quickly coz I've not done enough activity" (P14, female, inactive, retired).*

Identity

Some participants reported that they would not consider themselves an active person: *"I'm not a sporty person particularly" (P12, male, active, full time employed); "I'm not a gym person" (P1, female, active, retired*); "I never have done a great deal of exercise" (P2, male, inactive, retired). Other participants identified as active people: *"I've always been keen on exercising" (P6, male, active, full time employed)*; *"it's ingrained in me having been a PE teacher" (P5, female, inactive, retired).* Two active, full time employed participants mentioned they became *"obsessive"* (P3, female and P6, male) when doing their PA. One participant believed there was a genetic determinant as to whether some people were active: *"My ancestors were swift, so maybe that [laughs] has something to do with it" (P9, male, active, retired)*. One participant viewed PA identity as a binary, that *"those who are active are very active, and those who are inactive do nothing" (P6, male, active, full time employed)*. This binary was not always accurately reflected in participants' RAPA scores, however, as some that identified as active had RAPA scores suggesting they were inactive, and conversely some who identified as not particularly active as had active RAPA scores. A few participants mentioned being *"too old" (P9, male, active, retired)* to do certain PA: *"I think I've just finished the time for team sports now in life" (P13)*.

Automatic Motivation

Fun and enjoyment

It was crucial that the PA was fun and enjoyable for participants to want and continue to engage in the PA: *"badminton was fun… I like to win [laughs] so it's quite good when that happens" (P9, male, active, retired); "I do aquafit twice a week… because it is fun" (P15,* *female, inactive, retired).* Both active and inactive participants mentioned enjoying being active outdoors (e.g. walking in nature, gardening). Many thought that it could provide distraction from, or added interest in the physical exercise as they were able to admire the landscapes, the flowers and do some bird watching: *"If I go for a walk, sometimes I'll take the camera with me. That's a good way of turning a walk into a dawdle. But if I take the camera, I get some good pictures, I'm really pleased." (P14, female, inactive, retired).*

A few mentioned that they did some PA whilst needing to complete everyday tasks or enjoying other activities, such as walking around museums, housework, gardening, cycling to appointments, walking to the grocery shop or post office: *"I did used to park at the furthest reach of the car park, so when I went to the supermarket I was conscious that this was exercise as well as retail therapy and necessary food purchases" (P14, female, inactive, retired)*

Both active and inactive participants engaged in other, sometimes more enjoyable, sedentary activities, such as crafting, reading, playing cards, playing an instrument, or using the computer. This preference for more sedentary activities was mentioned mostly frequently by inactive participants. Participants recalled becoming *"totally enmeshed" (P14, female, inactive, retired)* in these sedentary activities that they ran out of time to do PA: *"a little task… it's like painting the Forth Bridge, it never ends." (P11, female, inactive, retired).* Some knowingly attempted to justify their avoidance of other less enjoyable activities, such as housework or PA, with these more enjoyable or 'important' tasks: *"Now that [playing piano] is my go to if I wish to avoid doing something else 'coz going and playing scales or whatever is erm, is much more pleasant" (P15, female, inactive, retired).*

Feeling bored whilst doing PA was seen as a barrier that discouraged participants from starting the PA or cut their planned PA short: *"Cause if I'm running on my own, I get bored, I get fed up, I'll cut it short and go home." (P12, male, active, full time employment).* A few participants mentioned they had previously tried to engage in certain PA but that it just did not keep their interest and so they found it hard to sustain: *"I go through phases where I try to do some sort* *of exercises to improve my arms, but I never really carried on because I lack interest." (P9, male, active, retired).*

One participant hated the experience of being *"hot and sweaty… that kind of feeling of eww…" (P4, female, inactive, full time employed)*, yet another reported missing that feeling as they were no longer able to exercise at the intensity they used to due to chronic illness:

> *"I do miss the getting really sweaty, hot and that kind of feeling afterwards… Come home and think 'yeah that was really good'. You know, I was out of breath, I was sweating, and I've had a shower and I feel much better. That adrenaline, serotonin type activities I haven't done for a long, long time. And I kinda miss that really, 'coz you feel as if you've done something." (P5, female, inactive, retired).*

One participant stated, *"I see physical activity as something I have to do rather than something I should enjoy." (P4, female, inactive, full time employed).* Two active female participants, commented that they felt guilty if they did not do their daily PA, so usually did it regardless of other things: *"I feel really guilty if I haven't been on the rower. So, unless I'm going out and doing something, for the day, if I'm just at home, then I get kind of obsessed and twitchy if I haven't done a row and a swim." (P3, female, active, full time employed).*

5.3.2. Identifying intervention functions and behaviour change techniques

Understanding and mapping the barriers and facilitators of PA for socially isolated older adults to COM-B enabled the appropriate intervention functions to be identified using the BCW. Intervention functions suggested in the BCW that are likely to be effective in bringing about behaviour change in relation to the barriers identified by socially isolated older adults can be seen in

Table 24, alongside facilitators identified by participants in the present study that may also help overcome these barriers. These were then appraised using the APEASE criteria and evidence from the literature was drawn upon when needed to make a decision (Table 25). It is suggested that the intervention functions that would be appropriate to use in the context of designing an intervention to promote PA in socially isolated older adults include education, training, environmental restructuring, modelling (with caution) and enablement. From these intervention functions, a possible 19 different BCTs could be considered for use in the design of a new PA intervention for socially isolated older adults. These were also appraised using the APEASE criteria (Table 26) and details of the decision-making process can be found in Appendix L. Designers should particularly consider the following six BCTs as they were common across two or more intervention functions: 2.2 Feedback on behaviour, 2.3 Self-monitoring of behaviour, 2.7 Feedback on outcome(s) of behaviour, 6.1 Demonstration of the behaviour, 7.1 Prompts/cues, and 12.5 Adding objects into the environment.

Table 24. Candidate intervention functions to overcome barriers of physical activity in socially isolated older adults.

COM-B Construct	Barrier identified	Candidate intervention function(s) from the BCW	Associated facilitators identified by participants
Physical Capability	Traumas/Injuries Illness Ageing declines	Training Enablement	Gentle and not too strenuous PA (P2) Positive health outcomes
Psychological Capability	Knowledge of how to do 'age appropriate' PA	Education Training Environmental restructuring Modelling Enablement	N/A
Physical Opportunity	Convenient local facilities	Environmental restructuring Enablement	Preference for PA at home or from home
	Bad weather	Environmental restructuring Enablement	

COM-B Construct	Barrier identified	Candidate intervention function(s) from the BCW	Associated facilitators identified by participants
	Finances	Environmental restructuring Enablement	At home or from home Minimal equipment
	Time	Training Environmental restructuring Enablement Restriction	Planning and goals Preference for PA at home or from home
Social Opportunity	Large PA groups	Environmental restructuring Modelling Enablement	Small active groups A key contact (spouse/friend/doctor/PT)
	Caring responsibilities	Restriction Enablement Environment restructuring Modelling	
	Strangers & acquaintances	Environmental restructuring Modelling Enablement	A key contact (spouse/friend/doctor/PT)
Reflective Motivation	Identity	Education Persuasion Modelling	
	Lack of planning & goal setting	Education Persuasion Incentivisation Coercion Modelling Enablement	
Automatic Motivation	Boring PA or interest in other ‘sedentary’ activities	Persuasion Incentivisation Coercion Training Environmental restructuring Modelling Enablement	Fun and Enjoyment

Table 25. Candidate interventions functions linked with the APEASE criteria.

Candidate intervention functions	**Does the intervention function meet the APEASE criteria in the context of a PA intervention for socially isolated older adults?**
Education	Yes – but unlikely to be effective if used on its own, particularly if only focused on health benefits (Devereux-Fitzgerald, et al., 2016).
Persuasion	Possible – caution should be taken with inducing negative feelings to stimulate action as potential for side-effects relating to self-esteem. In addition, the practicalities of communicating with this hard-to-reach population who are yet to decide to engage in PA could be challenging.
Incentivisation	Possible – Practicability of finding an incentive appropriate for whole target population is challenging. Financial incentives effective to encourage walking among sedentary older adults (Finkelstein, et al., 2008), however are unlikely to sustain PA long-term once incentives removed (Finkelstein, et al., 2016, Harkins, et al., 2017) and would require funding.
Coercion	No – unlikely to be acceptable to socially isolated older adults.
Training	Yes – very appropriate to PA.
Restriction	No – unlikely to be acceptable to socially isolated older adults.
Environmental restructuring	Yes – if there is no/low financial cost to the individual.
Modelling	Yes – but caution should be taken to avoid potential side-effects relating to negative social comparisons.
Enablement	Yes – reducing barriers to capability beyond education and training (e.g. appropriate exercise programming for abilities), and/or opportunity beyond environmental restructuring is possible (e.g. behavioural support). Must not financially impact socially isolated older adults.
Selected intervention functions	• **Education** • **Training** • **Environmental restructuring** • **Modelling (with caution)** • **Enablement**

Table 26. Candidate Behaviour Change Techniques in relation to intervention functions.

Intervention Function	COM-B Component	Potential Behaviour Change Techniques (BCT)	Does the BCT meet APEASE criteria?
Education	Psychological Capability Reflective Motivation	5.3 Information about social and environmental consequences	Yes
		5.1 Information about health consequences	Yes
		2.2 Feedback on behaviour	Yes
		2.7 Feedback on outcome(s) of behaviour	Yes
		7.1 Prompts/cues	Yes
		2.3 Self-monitoring of behaviour	Yes
Training	Physical Capability Psychological Capability	6.1 Demonstration of the behaviour	Yes
		4.1 Instruction on how to perform the behaviour	Yes
		2.2 Feedback on the behaviour	Yes
		2.7 Feedback on the outcome(s) of behaviour	Yes
		2.3 Self-monitoring of the behaviour	Yes
		8.1 Behavioural practice/rehearsal	Yes
Environmental restructuring	Psychological Capability Physical Opportunity Social Opportunity Automatic Motivation	12.5 Adding objects into the environment	Yes
		7.1 Prompts/cues	Yes
		12.1 Restructuring the physical environment	Yes
Modelling (with caution)	Psychological Capability Social Opportunity Reflective Motivation Automatic Motivation	6.1 Demonstration of the behaviour	Yes
Enablement	Physical Capability Psychological Capability Physical Opportunity	3.1 Social support (unspecified)	Yes
		3.2 Social support (practical)	Yes
		1.1 Goal setting (behaviour)	Yes

Intervention Function	COM-B Component	Potential Behaviour Change Techniques (BCT)	Does the BCT meet APEASE criteria?
	Social Opportunity Reflective Motivation Automatic Motivation	1.3 Goal setting (outcome)	Yes
		12.5 Adding objects into the environment	Yes
		1.2 Problem solving	Yes
		1.4 Action planning	Yes
		2.3 Self-monitoring of behaviour	Yes
		12.1 Restructuring the physical environment	Yes
		1.5 Review of behaviour goal(s)	Yes
		1.7 Review of outcome goal(s)	Yes

5.4. Discussion

The present chapter explored the barriers to and facilitators of PA experienced by fifteen socially isolated older adults, of which nine were inactive according to their RAPA score. The three most common barriers mentioned related to physical capabilities (i.e. trauma/injuries, illness and ageing related declines), influences of other people (i.e. caring responsibilities, large active groups and feeling judged by others) and a lack of convenient facilities. The three most common facilitators of PA were enjoyment and fun, beliefs that PA has positive mental and physical health outcomes and influences of other people (i.e. small active groups, support from a key contact).

The most common barriers to PA reported by socially isolated older adults related to physical capability and included trauma/injuries, chronic and acute illness and ageing related degeneration, which is consistent with findings in older adults in general, regardless of their social isolation status. Poor health conditions and ageing related declines in physical capabilities were frequently cited as making certain PA physically difficult, even impossible, for older adults to engage in (Bethancourt, et al., 2014, Buman, Daphna Yasova and Giacobbi, 2010, Moschny, et al., 2011). Similarly, among 2225 Australian older adults (aged ≥ 65 years) who identified themselves to be insufficiently active but would like to be more active, 52% reported ill-health was the main barrier to their PA, even after adjusting for gender, age, BMI, SES and education (Macniven, et al., 2014). Changes in acute or chronic health conditions can hinder older adults' ability to continue with their established exercise routines, often leading to short- or long-term physical limitations that required either stopping or modifying their exercise (Miller and Brown, 2017). Designers of PA interventions for socially isolated older adults should consider potential physical limitations or changes in physical capabilities of the participants, ensuring that the activities are appropriate for individuals highlighting what they can do, rather than what they can no longer do. In some instances it is not the physical capability itself that limits older adults PA, some stop PA to avoid being confronted with their physical ailments or ageing (Buman, Daphna Yasova and Giacobbi, 2010). Indeed, some participants in the present study avoided certain PA and social PA because they did not want to be reminded that their levels of fitness and abilities were not what they once were. Therefore, this disparity should be considered by intervention designers to maintain participants motivation and also for safety.

Belza, et al. (2004) highlighted that although poor health could lead to sedentary lifestyles, it can also provide motivation to become more physically active, thus changes in health status may provide a nudge to engage in healthier behaviours. In the present study nine participants had previously required serious medical intervention (e.g. surgery) for health conditions or a specific trauma. Many of these participants mentioned engaging in PA as part of their rehabilitation or ongoing management of their chronic conditions. This is consistent with findings from previous studies. For example, women aged 65-75 years previously reported health scares (e.g. heart attacks) and being diagnosed with Type 2 diabetes as reasons for instigating an exercise programme (Sims-Gould, et al., 2012). In addition, PA was used by older adults to manage their chronic conditions, and pain associated with them, to prevent regression or acceleration the disease (Bjornsdottir, Arnadottir and Halldorsdottir, 2012, Bethancourt, et al., 2014). Future PA intervention designers for socially isolated older adults should consider that poor health or a traumatic event may provide motivation for participants to engage initially with PA, but individual tailoring is required for individuals, their physical capabilities, motivations, and goal setting.

In terms of psychological capability, most participants were not aware of Government PA guidelines for older adults. This was unsurprising given a cross-sectional study using the Health Survey for England data (n = 561) found only 5.3% of older adults aged 60-64 years were able to accurately state the Government PA guidelines (Chaudhury and Shelton, 2010). However, a recent study also found that knowledge of PA guidelines was not associated with higher PA levels or better physical functioning among older adults aged 65 ± 7 years in the

USA (Cheung, et al., 2019). Indeed, in the present chapter, both active and inactive individuals had no knowledge of the Government PA guidelines. Therefore, informing socially isolated older adults of Government PA guidelines alone is unlikely to be effective in increasing socially isolated older adults PA.

Inactive participants frequently mentioned that they lacked confidence in their knowledge of the types of PA that would be safe for them to engage in. Many commented that they were ‘too old’ for the PA they previously did and wanted something that would be ‘age appropriate’. Not knowing how to carry out PA safely had previously been identified as a barrier to older adults (65-70 years) engaging in PA, with many feeling they required education on this before beginning PA (Spiteri, et al., 2019). Lacking confidence in one’s ageing body can prevent older adults from engaging in certain PA as they are frightened of causing damage to their bodies (McGowan, et al., 2018). Older adults with chronic conditions particularly, such as rheumatoid arthritis, can be fearful of negatively impacting their conditions by engaging in PA, especially if they are unaware of what intensities, durations and frequencies are appropriate for them on different days as their condition fluctuates (Baxter, et al., 2016). Having an appropriately paced PA programme to follow helped older adults build confidence, even if they experienced muscle soreness that often discourages older adults to continue with exercise (Stathi, Mckenna and Fox, 2010). In contrast, active participants in the present study mentioned ‘pacing’ and ‘listening to what my body is saying’ as strategies they used to ensure they kept their PA safely within their physical capabilities. Having this knowledge may help older adults engage in PA more frequently. Therefore, educating socially isolated older adults on how to engage in PA safely, in addition to how to identify and evaluate their internal feedback – for instance aches and pains or mood – before, during and after PA may be beneficial for enhancing self-efficacy and engagement in PA.

The most distinct barriers to PA among socially isolated older adults related to social opportunity. In the literature, it is commonly reported that many older adults enjoy and prefer group exercise as it provides a sense of community, social networking opportunities potentially leading to friendships, motivation to attend, competition, a sense of safety, often meaning adherence to the exercise programme is better (Stathi, Mckenna and Fox, 2010, Mehra, et al., 2016, Devereux-Fitzgerald, et al., 2016, McGowan, et al., 2018, Miller and Brown, 2017, Spiteri, et al., 2019, Franco, et al., 2015). However, in the present study, involved only socially isolated older adults, participants expressed a preference for small group activities and a dislike of larger groups, even to the point of finding them anxiety inducing. Apprehension about group PA has been reported in the literature and is often linked to competitive atmospheres, feeling judged by others, feeling self-conscious, or worried about not being able to keep up with the pace of the group (Bethancourt, et al., 2014, Kelly, et al., 2016). This social discomfort and lack of confidence in social situations can be heightened if participants do not know anyone in the group to begin with, or if the group is made up of people of different ages, genders, physical capabilities or cultures (Franco, et al., 2015, McGowan, et al., 2018). Although some socially isolated older adults mentioned attending group PA, smaller groups were preferred and were reported to be more enjoyable. Those who either did attend or showed interest in group PA felt they would like a balance of group and solo PA. Some older adults, males particularly, have previously reported preferring to exercise alone and enjoying the solitude (Miller and Brown, 2017). Socially isolated older adults sometimes described themselves as “loners” who prefer their own company, being shy or introverted and having less need to socialise, and often did not feel lonely or isolated (Cloutier-Fisher, Kobayashi and Smith, 2011). Therefore, future PA intervention designers should consider socially isolated older adults’ preferences for small group or individual PA.

PA can become a low priority for older adults aged 50-75 with caring responsibilities (Buman, Daphna Yasova and Giacobbi, 2010). Having to care for parents, spouses, children and grandchildren did provide a barrier to PA among several participants in the present study, not only from a time and energy perspective but also because spending time with that person required doing activities they could do together, which were often sedentary (e.g. watching

TV, playing board games). A previous study found older women with spouses who were less physically able than them or who required care were used to doing everything together, so they became less likely to go out on their own for PA; when they did go out, they constantly worried about leaving their spouse on their own in case something happened (Bjornsdottir, Arnadottir and Halldorsdottir, 2012). Many older adults feel that it is more important to help their children, families or communities rather than going to an exercise class (Sims-Gould, et al., 2012, Franco, et al., 2015, McGowan, et al., 2018). However, some older adults used this as motivation to engage in PA as they believed it important to stay active and healthy in order to provide this support and feel valued (Franco, et al., 2015). Maintaining independence was a key motivator for many older adults as they did not want to need to rely on others or burden their family members, particularly their children (Belza, et al., 2004, Henwood, et al., 2011, Mehra, et al., 2016). Highlighting the benefit that PA can help people remain independent for longer may be particularly important for socially isolated older adults as they are more likely to either provide care or require care and have a smaller social circle that could offer help.

Having a supportive spouse or close friend with similar interests in PA was helpful for engaging in PA for participants in the present study. This is consistent with the literature as family and friends can be an important source of support for PA for older adults (McGowan, et al., 2018), not only when beginning to engage in PA but also continuous regular engagement with it (Miller and Brown, 2017). Support can be verbal encouragement, practical help such as transportation, or financial support (Franco, et al., 2015, Bethancourt, et al., 2014). Not having a partner to encourage PA was found to be a barrier in many studies identified in a systematic review of older adults aged 50-64 years (N = 55; n = 5494) (Spiteri, et al., 2019). Some participants in the present study mentioned wanting someone they could be active with as they believed it could help motivate them and make the PA more interesting and enjoyable. Some participants said having a personal trainer or medical professional to advise and help engage them in PA was beneficial. They found it helped motivation as they had a scheduled appointment, but also because professionals were able to provide knowledge about how to exercise safely and effectively for participants to meet their goals. Having an exercise professional tailor exercises to an individual's physical capability or needs is valued by older adults and is reassuring that the exercise is safe (Franco, et al., 2015, Sims-Gould, et al., 2012, Mehra, et al., 2016). This can help older adults build self-efficacy and physical competence, even in a group setting (Stathi, Mckenna and Fox, 2010). A systematic review of qualitative studies (N = 10; n = 261) found a health professional can be an important support for PA in older adults (McGowan, et al., 2018). For instance, having a doctor advise a person to exercise to manage health (e.g. hypertension, diabetes) provided motivation for some sedentary older adults to engage in PA (Buman, Daphna Yasova and Giacobbi, 2010). The use of social support, particularly from a close family member or friend, in a PA intervention is likely to be beneficial to socially isolated older adults. For those without a close family member or friend, support from an exercise or medical professional may help.

One of the most often mentioned barriers to PA in the present study related to physical opportunity. Participants complained that facilities were not local or convenient enough and required travel by car which discouraged their use, despite most having and using their cars for other purposes. Participants clearly preferred being able to walk to facilities or be active at home. The importance of convenience has also been reported in a survey of 52 older adults (aged 66-78 years) in the USA where 86% of respondents reported they preferred doing PA in their own neighbourhood and 28% reported doing PA at home (Bethancourt, et al., 2014). Living in close proximity to their place of exercise is advantageous to older adults, particularly in the case of walking directly outside their home, as the convenience reduced potential friction or barriers to PA (Miller and Brown, 2017). All participants in the present study mentioned having at least one local outdoor space they liked to be active in, such as nature reserves, parks, beaches, fields, and gardens. Easily accessible, local PA facilities, both indoor and outdoor, are important for encouraging older adults to engage in PA, particularly if the weather is bad (Bjornsdottir, Arnadottir and Halldorsdottir, 2012, Chad, et al., 2005, Chastin, et al., 2014a, Crombie, et al., 2004, Justine, et al., 2013). Mehra, et al. (2016) suggests home-based

PA is beneficial for older adults; not only can it be tailored to an individual's physical capabilities and needs, but also overcomes barriers of inconvenient facilities and travel. Thus, a home-based PA intervention for socially isolated older adults may be most appropriate.

Another common barrier for PA in the present study was finances. Participants, particularly those who had retired, were aware that paying for PA would use a considerable amount of their limited income. Affordability of PA is commonly mentioned as a barrier among older adults (Spiteri, et al., 2019), and usually referred to the cost of PA programmes/classes (Sims-Gould, et al., 2012, Belza, et al., 2004, Hildebrand and Neufeld, 2009) and gym/club memberships (Buman, Daphna Yasova and Giacobbi, 2010, Kelly, et al., 2016). Nonetheless, many older adults acknowledged that there are cost-effective or free PA alternatives and so cost was not necessarily a major barrier to PA (Buman, Daphna Yasova and Giacobbi, 2010, Ball, et al., 2006). Some participants in the present study said they would be "loath" (P13) to pay for a gym membership, regardless of whether they were able to afford it. Similarly, a systematic review (N = 132; n = 5987) found that unwillingness to spend money on PA was a barrier to PA among older adults (Franco, et al., 2015). PA that is free to the individual was shown to be a facilitator of PA among older adults (Costello, et al., 2011), and was favourable among participants in the present study. Therefore, ensuring that PA interventions are low-cost or free to the individual is likely to be more enticing for the intervention users, but particularly to socially isolated older adults, regardless of their income.

Time is often reported as a barrier to PA, especially for older people balancing work commitments, family, caring and household responsibilities (Kelly, et al., 2016, Buman, Daphna Yasova and Giacobbi, 2010, Spiteri, et al., 2019). Of the four full time employed participants in the present study, three were highly active and mentioned that they consciously made time for PA, whereas the one inactive, employed participant reported time as their main barrier. Among those who had retired in the present study, most reported they had plenty of time to be active, although only three of eight retired participants had a RAPA score ≥ 6.

Berger, et al. (2005) found older adults (aged 60-64 years) in West Scotland showed a decrease in their total PA once they had retired, yet no change in leisure time PA, meaning their decrease in total PA was due to work-related PA being lost. Some retired participants in the present study mentioned being busier than ever since retiring so finding time to do PA was challenging, especially when incorporating travelling time. Older adults who consider themselves to have busy lives have previously indicated that any daily physical exercises should take no more than 15 minutes a day (Mehra, et al., 2016). Therefore, future PA interventions for socially isolated older adults should consider the impingement on time that travelling takes to and from the PA, in addition to the duration of PA itself. Furthermore, a time-flexible PA intervention, whereby older adults can fit in PA into their busy lives on different days, at different times and for different durations may be helpful.

Extremes of weather are commonly reported as a barrier to PA among older adults (Spiteri, et al., 2019, Belza, et al., 2004, Bird, et al., 2009). This was certainly the case in the present study as participants mentioned that cold and wet, and very hot weather, discouraged them from being active, particularly outdoors. Participants said they found it uninspiring and unpleasant, and potentially hazardous if the ground was slippery. Older women living in retirement homes also said that cold, windy or icy weather presented a barrier to PA as they were afraid they may fall and hurt themselves if they were to go out (Bjornsdottir, Arnadottir and Halldorsdottir, 2012). This highlights the complex interplay between physical opportunity, automatic motivation, psychological and physical capability, as older adults feared hurting themselves in adverse weather conditions, due their lack of confidence in their physical capabilities. Warm and dry weather was reported as a facilitator of PA in the present study. Being a ‘fair weather walker’ was also commonly mentioned by older adults (aged 66-78) (Bethancourt, et al., 2014). At a superficial level, it could be suggested future PA interventions for socially isolated older adults utilise good weather where possible, with indoor alternative activities during adverse weather conditions. However, it may also be important to highlight to these individuals the additional benefits of building competence and confidence in their physical capabilities in a safe environment first, which may mean they are then less fearful of hurting themselves if faced with adverse weather.

All participants in the present study believed that being active had positive outcomes for mental and physical health, which they said motivated them to do PA, although most did not elaborate on the specific physical benefits. Despite this, most wanted to delay the ageing process and prolong the years of independent living, believing that engaging in PA would help this. Older adults aged 65-72 years who participated in a 12-week resistance exercise intervention believed that after only 4 weeks they had improved strength, endurance, balance and coordination, which manifested in improved physical functioning (Dionigi, 2007). Improvements in strength, energy, agility, balance and flexibility were commonly reported as benefits to PA by older adults, with some highlighting these would decrease fall risk, improve mobility and slow the ageing process, increasing the amount of time they would be able to live independently (Franco, et al., 2015, Bethancourt, et al., 2014, Patel, et al., 2011, Spiteri, et al., 2019, Mehra, et al., 2016). Wanting to remain independent and noticing everyday activities being negatively impacted by declining physical capacity provided motivation for older adults (aged 75 ± 3.9 years) to sign up to an exercise programme (Stathi, Mckenna and Fox, 2010). A few inactive females in the present study wanted to become more active as they were concerned about becoming frail. Similarly, older women (age 65-75 years) mentioned concerns of declining health and frailty as reasons for taking up exercise (Sims-Gould, et al., 2012). Healthy ageing was reported as a motivator for PA among older adults, so that they were able to do things they enjoyed such as travel, certain hobbies or caring for their families (Kelly, et al., 2016, Bethancourt, et al., 2014). Therefore, linking the physical benefits of PA to daily physical functioning, including delaying the ageing process and promoting independent living, may be beneficial and motivating for inactive socially isolated older adults. Additionally, linking these benefits to enjoyable activities, such as travel, may provide even stronger motivation to continue to engage in PA longer term.

Participants with chronic health conditions in the present study mentioned engaging in PA to manage their conditions. This finding is common in the literature, with older adults reporting that PA was important in managing their chronic health conditions such as diabetes, hypertension, arthritis and pain (Belza, et al., 2004, Miller and Brown, 2017). This can prompt older adults to join exercise programmes (Mehra, et al., 2016) and provide motivation to continue to engage in PA (Kelly, et al., 2016, Spiteri, et al., 2019). As socially isolated older adults are more likely to live with chronic conditions than their non-isolated peers (Cantarero-Prieto, Pascual-Sáez and Blázquez-Fernández, 2018, Hawkley and Cacioppo, 2010, Kobayashi and Steptoe, 2018), promoting PA as an additional method of chronic disease management may provide motivation to engage in PA, particularly among those who are inactive and/or recently diagnosed with a chronic disease.

Those who were active in the present study mentioned increased strength and flexibility as physical benefits they had experienced due to PA. Consistent with this, older adults (age 75 ± 3.9 years) who had previous exercise experience anticipated that taking part in a new exercise programme would lead to improvements in their fitness, mobility, functional ability, and delay physical deteriorations associated with ageing (Stathi, Mckenna and Fox, 2010). In addition, active older adults aged 52-85 years old (mean 72 years) reported feeling stronger, healthier, and more energetic due to their PA (Belza, et al., 2004). This highlights that those who are already active, or who have been active previously, are more likely to understand the physical benefits afforded by PA, suggesting that those who are inactive may require additional education or provided the experience of being physically active.

Participants also commented on the mental health benefits they experienced from being active, particularly feeling mentally stronger, able to cope, happier and calmer. This is consistent with the literature that suggests engaging in PA helped older adults feel less depressed, anxious and more relaxed and confident (Patel, et al., 2011, Callow, et al., 2020). In addition, a 10-year follow-up study found that PA was associated with the preservation of memory and executive function (Hamer, Muniz Terrera and Demakakos, 2018). These benefits to mood, memory and cognition could provide motivation for older adults to be active (Bethancourt, et al., 2014). As socially isolated older adults have increased mental health risk, such as depressive symptoms (Cacioppo, Hawkley and Thisted, 2010, Kobayashi and Steptoe, 2018) and cognitive declines (Shankar, et al., 2013), highlighting the mental health and cognitive benefits of PA may provide motivation for socially isolated older adults to engage with PA.

Previous studies suggest older adults who were active when they were younger were more likely to mention that they continued to be active as they aged because, to them, living an active lifestyle became part of their identity. In contrast, those who had never engaged in regular PA were reluctant to start, and often struggled to commit to making PA a priority later in life; it appeared to be incongruous with their established lifestyles (McGowan, et al., 2018, Franco, et al., 2015, Bjornsdottir, Arnadottir and Halldorsdottir, 2012, Buman, Daphna Yasova and Giacobbi, 2010). Despite participants in the present study identifying as an 'active' or 'not particularly active' person, this identity was not always consistent with their RAPA score, indicating a disconnect between their beliefs about themselves and behaviours. This suggests a link between participants' identities (COM-B construct reflective motivation) and their knowledge of what constitutes 'active' (COM-B construct psychological capability). Prince, et al. (2008) reported in a systematic review (N = 173; n = 4737) that self-report measures of PA can give both higher and lower estimates of PA compared with objective measures, indicating that people may believe they are more or less active than they actually are. Therefore, interventions that utilise both subjective (e.g. self-report questionnaire) and objective PA measurement (e.g. accelerometer data) may be helpful to highlight potential dissonance and, in combination with education and appropriate goal setting, could be a motivational tool appropriate for use in socially isolated older adults.

Having structured routines, goals or events to aim for encouraged participants in the present study to be active. Active, and some inactive, participants mentioned hiking holidays that required certain levels of fitness, 10K running races and completing certain PA on certain days at certain times, either alone or in a class, as part of their weekly routines. Without these ‘appointments’ ‘life could take over’, and if PA was not a priority, participants found it was easy to run out of time in a day/week. A previous study has found that older adults (aged 75 ± 3.9 years) identified that they required more discipline and structure in their everyday lives, so decided to sign up to an exercise programme to help them reduce their increasingly sedentary lifestyles (Stathi, Mckenna and Fox, 2010). Making PA a priority by planning it into their weekly schedule helped keep older adults accountable to their routine, meaning certain times during the week were protected so that PA was completed (Miller and Brown, 2017). Older adults can find it difficult to make specific exercise goals and plans, so when they find something that works for them in terms of their ability, location and timing, they are likely to continue to do - it’s easy, comfortable and convenient (Stathi, Mckenna and Fox, 2010). Having no particular goals or motivations to carry out PA was identified commonly as a barrier among older adults aged 50-70 in a systematic review (N = 55; n = 5494) (Spiteri, et al., 2019). Similarly, a study in older women found having a commitment to an exercise group made them attend as they did not want to feel guilty by letting the group down if they did not attend (Sims-Gould, et al., 2012). Therefore, accountability and structure are important considerations in future PA interventions in socially isolated older adults. Goal setting may be a useful tool to aid this, however guidance on setting appropriate goals is likely to be required.

Throughout the interviews, participants highlighted the importance of PA being an enjoyable and fun experience, a finding that is evident throughout the literature on facilitators of PA in older adults (Kelly, et al., 2016, Buman, Daphna Yasova and Giacobbi, 2010). PA interventions that are fun, enjoyable and leave older adults feeling good were more likely to engage older adults in PA and were often mentioned as key motivators (Devereux-Fitzgerald, et al., 2016, Kelly, et al., 2016, Spiteri, et al., 2019, Miller and Brown, 2017). Studies have shown home-based PA programmes tended to lack the variation that was found in group classes, which participants could find boring and so were less likely to continue to engage in it (Stathi, Mckenna and Fox, 2010, Mehra, et al., 2016). As home-based interventions were identified above as overcoming barriers related to physical opportunity and physical capability, it is crucial that if a home-based PA intervention is selected for use in socially isolated older adults, that it provides variety, is fun and enjoyable.

In the present study enjoyment and interest were often linked to being physically active outdoors because participants found that walking in nature and looking at the scenery, flora, and fauna distracted from the PA itself. Some older adults were unmotivated by intrinsic benefits of PA; they felt that PA needed purpose (Bethancourt, et al., 2014, McGowan, et al., 2018). In the present study, some participants took photos or bird watched on nature walks; others walked to the shops, did housework and gardening as part of their PA, which they found rewarding as they could see a tangible outcome of their PA. In addition, some participants had animals to care for that required them to be a little active every day, particularly dog walking and moving heavy bags of food and litter. Taking the dog out for a walk has been reported as a common motivation for PA among older adults in the literature (Spiteri, et al., 2019, Bethancourt, et al., 2014). Thus, future intervention designers for socially isolated older adults should consider PA that feels purposeful, or offers potential 'distractions' from the PA itself, to enhance enjoyment and decrease feelings of boredom.

Many older adults enjoyed typically sedentary activities, such as watching TV or sewing and are sometimes more motivated to engage in these pastimes rather than PA (Compernolle, et al., 2019). Participants in the present study mentioned enjoying reading, quilting, playing the piano, and using the computer in which they can be "enmeshed" (P14) for hours each day. A systematic review of qualitative studies (N = 10; n = 261) highlighted that some older adults felt they had earned their relaxed retirement and so were allowed to live a more sedentary lifestyle (McGowan, et al., 2018). It is important to remember this in the design of a future PA intervention for socially isolated older adults in terms of time and enjoyment. This could mean that the PA intervention does not take up much time in the day so that participants have time to become “enmeshed” in their other activities, or indeed that the PA intervention in itself is “enmeshing”. As the use of technology was mentioned as an activity socially isolated older adults already find “enmeshing”, there is potential that its use for PA may be appropriate. Exergames (video games that require bodily movement) have the potential to replace sedentary screen time, reduce sitting time and increase PA (Krause and Benavidez, 2014). Virtual reality can enhance exergaming to immerse – “enmesh” – the user in a virtual environment (Slater and Wilbur, 1997). The use of such technologies and games may also provide alternative motivation or distraction from the PA itself.

Using the barriers and facilitators identified in the present study and mapping them to the COM-B model, the intervention functions that would be appropriate to use in a PA intervention for this population included education, training, environmental restructuring, modelling (with caution) and enablement. In chapter three, from the descriptions of the DBCI, the intervention functions that were used in effective DBCI were education, training, environmental restructuring, incentivisation, enablement, and persuasion. Therefore, the intervention functions selected in the present study are appropriate for use in a novel DBCI for PA/SB in socially isolated older adults. In particular, designers should consider integrating the following six BCTs which were common across two or more intervention functions: 2.2 Feedback on behaviour, 2.3 Self-monitoring of behaviour, 2.7 Feedback on outcome(s) of behaviour, 6.1 Demonstration of the behaviour, 7.1 Prompts/cues, and 12.5 Adding objects into the environment. This is not to say that the use of the other 13 or other BCTs would necessarily be inappropriate. Chapter three highlighted that a minimum of three BCT clusters should be used for a PA intervention to be successful, and also identified BCTs feedback on behaviour and self-monitoring to increase efficacy (Stockwell, et al., 2019). In addition, the demonstration of the behaviour, prompts and cues and adding objects into the environment were commonly used in the DBCI for PA/SB in the review, among others.

5.4.1. Strengths and limitations

This is the first study to investigate the barriers and facilitators of PA specifically in socially isolated older adults (≥50 years). By using interviews in the present study, it was possible to gather a greater depth of data beyond surface level barriers, that may not have been captured in a self-evaluation questionnaire, which was an alternative option suggested in the BCW (Michie, Atkins and West, 2014). For instance, the interviews highlighted the nuance of the social support aspect required by socially isolated older adults to engage in PA (i.e. their dislike of large group PA and preference for small group or individual PA). In addition, by mapping the barriers and facilitators, it was possible to follow a systematic process using the BCW to identify appropriate intervention functions and BCTs for use in future PA/SB interventions for socially isolated older adults. Lastly this study also used a PPI group of older adults aged ≥ 50 years to inform the recruitment and design of the materials used, ensuring the information communicated was clear, understandable and appropriate to this age group.

Despite this, the study also has some limitations. First, though typical of this type of study, the sample size was small, and all participants were of White ethnic background, which may limit the generalisability of these findings to other groups. Representative sampling was not attempted in the present study but should be considered in future studies investigating socially isolated older adults. Secondly, this study began just before the COVID-19 lockdown occurred in the UK in March 2020. This pandemic will have impacted people's work and life patterns, travel, PA, and SB (Hossain, Sultana and Purohit, 2020). It is possible that participants completed the RAPA questionnaire and spoke in the interview in relation to their situation during the lockdown rather than their ‘usual’ routines. The researcher reminded participants to complete their forms and answer the questions as if they were not in lockdown and clarified in the interview whether certain barriers and facilitators mentioned were specific only to the Lockdown situation or not. In addition, due to the Lockdown restrictions, most of the recruitment for this study was moved online, meaning it is likely that the most socially isolated older adults were not reached, and their barriers and facilitators may differ from those in the present sample. Comparison between this sample and the literature is challenging as most studies investigating the barriers and facilitators of older adults PA do not measure social isolation status. It would be beneficial if future studies investigating PA in older adults reported on the social isolation status of the population to facilitate better comparison between studies, furthering the understanding of which features are unique or ubiquitous to socially isolated groups across different age ranges.

5.5. Conclusion

Unique to socially isolated older adults are their preferences for small group PA and support only from key contacts, such as exercise professionals, family and friends, rather than large group PA or places where many people are likely to be at once. It is also important to note that many socially isolated older adults were happy and some even preferred to do PA on their own. Otherwise, socially isolated older adults face many of the same barriers and facilitators reported in the literature generally among older adults. Common barriers included limited or changing physical capabilities and lack of convenient local facilities. In contrast, common facilitators were enjoyment and fun and belief in positive health outcomes. This study mapped these barrier and facilitators to the COM-B model to identify appropriate intervention functions (education, training, environmental restructuring, modelling and enablement) and BCTs that should be considered in the design of future PA interventions for this population: feedback on behaviour (BCT 2.2.), self-monitoring of behaviour (BCT 2.3), feedback on outcome(s) of behaviour (BCT 2.7), demonstration of the behaviour (BCT 6.1), prompts/cues (BCT 7.1), and adding objects into the environment (BCT 12.5). This study provides the theoretical underpinning required for a novel PA/SB intervention specifically for socially isolated older adults.

CHAPTER 6: EXPLORING SOCIALLY ISOLATED OLDER ADULTS' EXPERIENCES OF USING EXISTING COMMERCIALLY AVAILABLE DBCI FOR PA/SB

6.1. Introduction

Socially isolated older adults are less likely to be physically active than their non-isolated peers (Kobayashi and Steptoe, 2018, Schrempft, et al., 2019, Shankar, et al., 2011) and older adults who engaged in PA are less likely to be socially isolated. For instance, previous studies have found that older adults who engaged in higher levels of PA around the home (e.g. cooking, cleaning and tidying) were less likely to be socially isolated (Robins, et al., 2018), and among rural-living older adults (≥ 65 years) those who engaged in sport/exercise were significantly less likely to be to be socially isolated (de Koning, Richards and Stathi, 2019). However, PA interventions with socially isolated older adults have tended to use PA as a vehicle for reducing social isolation, rather than focusing on improving the PA behaviours of socially isolated older adults. A systematic review and meta-analysis showed insufficient evidence that PA interventions were effective at reducing social isolation or loneliness among community-dwelling older adults (range 51-82 years) (N = 38; n = 5288) (Shvedko, et al., 2018). To date there are no published studies that investigate PA interventions for socially isolated older adults aimed at their PA and not their isolation; this warrants further investigation.

Interventions to promote sustainable PA in older adults have previously achieved limited success, particularly over the long term (Chase, 2013, Daskalopoulou, et al., 2017, van der Bij, Laurant and Wensing, 2002). For instance, two systematic reviews independently found that during the intervention period, older adults showed increased PA; however this was not sustained beyond 6-months post-intervention (N = 12; n = 1991) (Sansano Nadal, et al., 2019), and maintenance beyond 12 months was unclear (Reviews = 19; studies = 545) (Zubala, et al., 2017). Another systematic review found there was limited evidence that face-to-face, community-based, low-to-moderate PA increased PA among older adults (≥ 65 years) living in rural or regional areas beyond the intervention period (N = 7; n = 3362) (Moore, et al., 2016). In addition, these traditional PA interventions, delivered face-to-face, were often resource intensive, time-limited and required participants to travel to specific locations (Hekler, et al., 2011). Socially isolated older adults also tended to have limited contact with traditional persons or print based PA interventions (Norman, et al., 2007). Therefore, novel interventions for PA are required for socially isolated older adults that continue to be effective longer term.

Remote delivery of a PA intervention, i.e. where there is no in-person interaction between the participant and intervention provider, may have potential in socially isolated older adults. This concurs with a systematic review found that non-face-to-face PA interventions targeting healthy community-dwelling older adults (≥ 50 years) were effective in increasing PA, and of those studies that conducted a follow-up, 89% found this PA was maintained to follow-up (N = 17; n = 9183) (Müller and Khoo, 2014). In geographically isolated older adults, e-based interventions have the potential to overcome challenges of access to health service provisions in rural and regional areas (Moore, et al., 2016). Indeed, a greater number of older adults are using the internet than ever before, with 93.2% of 55-64 year olds, 83.2% 65-74 year olds and 46.8% 75+ year olds using the internet (Office for National Statistics, 2019). Chapter four highlighted that socially isolated older adults (≥ 50 years) were likely to use the internet more frequently than their non-isolated peers (Stockwell, et al., 2020).Therefore, the use of technology to deliver a non-face-to-face PA intervention to socially isolated older adults may have potential. Mobile phones in particular offer the potential for cheap, accessible, flexible support for behaviour change, reducing the barriers that often emerge during face-to-face interventions (Crane, et al., 2015). A recent survey found that approximately 70% of older adults aged 55-64 in 2020 owned a smartphone, up from 55% in 2019 (Statistica, 2020). Therefore, utilising technology already owned by socially isolated older adults, such as laptops/computers and smartphones, may be useful for a DBCI for PA/SB in this population.

The systematic review and meta-analysis in chapter three found that the use of DBCI for PA/SB in older adults (≥50 years) were effective, at least in the short term. Similarly, other systematic reviews and meta-analyses found mobile interventions (Elavsky, et al., 2019), eHealth interventions (Muellmann, et al., 2017), smartphone apps and wearables (e.g. Fitbit) (Gal, et al., 2018) (Oliveira, et al., 2019) also increase PA and reduce SB in older adults, also at least in the short term. Despite this efficacy, it is important to establish older adults' willingness to engage with these DBCI for PA/SB prior to an intervention. The majority of older women (mean age 74 ± 9 years) who already engaged in a weekly exercise programme were enthusiastic or at least open to using technology for home-based PA and their comments showed curiosity and willingness to learn (Mehra, et al., 2016). A few participants opposed the use of technology for PA, which tended to be underpinned by a lack of confidence and understanding in using the technology (Mehra, et al., 2016). Similarly, eight older adults (aged 61-69 years) with no prior experience of using activity monitoring technology, were positive and excited about using it; however, after using the technology for 2 weeks, only three were excited to continue to use the technology and had purchased their own devices, three were not interested in using it again, and two were ambivalent as although they could see benefits they were not interested enough to pay for it themselves (Fausset, et al., 2013). This suggests that older adults' perceptions of using technology for PA do not always match their experiences, therefore capturing prior beliefs and experiences could provide important insight about the user group to the designer of future interventions.

Engaging older adults with the design process has the potential to mean that the DBCI created better meets the needs of this population (Harrington, et al., 2018). However, with no experience of using activity trackers, older adults (aged ≥ 65 years) were unable to clearly identify features about them they liked (Kononova, et al., 2018). In addition, older adults without experience struggle, when asked, to provide examples of how technology could be used in PA, as responses were limited to showing photos and videos, with only a few participants mentioning video calls to exercise together (Mehra, et al., 2016). Therefore, providing older adults with experiences to draw upon is important in the design of new DBCI for PA as without it, older adults cannot identify their likes and dislikes about a DBCI, and lack understanding of the realistic capabilities of the technology (Harrington, et al., 2018).

To date no work has been undertaken in exploring socially isolated older adults' experiences of using DBCI. Therefore, the aims of this study include: (i) gather information on socially isolated older adults' previous experiences with using DBCI for PA and their beliefs about the advantages and disadvantages of using them; (ii) explore socially isolated older adults' experiences of using two DBCI for PA (iii) explore socially isolated older adults' ideas regarding the design of a DBCI for PA for this population.

6.2. Methods

6.2.1. Participants

The participants in this chapter are the same socially isolated older adult participants as in chapter 5, therefore ethical approval, recruitment, social isolation and PA measures taken for chapter 6 are identical and can be found in chapter 5.

6.2.2. Choice of the digital behaviour change interventions for use in the study

Potential DBCIs were identified in the systematic review and meta-analysis in chapter three. In addition, DBCI were searched for in other academic literature, both android and iOS app stores, using search engines and recommendations from DBCI for PA/SB users of all ages. A digital database of possible DBCI was created to collate information on the following aspects of each DBCI: name, where it was found, type of DBCI, price, description and features, individual BCTs (if previously coded), pros and cons of each DBCI. APEASE criteria (Affordability, Practicability, Effectiveness/Cost-Effectiveness, Acceptability, Side-effects, Equity) was considered in the narrowing down to five DBCI (Michie, Atkins and West, 2014), in addition to their content, typicality, suitability, stability and availability as previously done in the literature (Roberts, et al., 2019). It was speculated that there was a lower likelihood of older adults (≥50 years) owning and using a games console – compared to a smartphone, tablet, or computer – thus exergames were excluded.

A total of 62 DBCI were indexed (Appendix M), of which 5 were presented to a PPI group. DBCI were excluded for the following reasons: they were too expensive (n = 15); it required a monthly subscription (n = 8); the PA was not appropriate for older adults (n = 13); similar DBCIs that were included had more or better features (n = 9); only available on one platform (i.e. android or apple) (n = 5); not designed with UK audience in mind (n = 3); main purpose of DBCI was not PA (n = 2); excessive battery draining (n = 1); DBCI discontinued (n = 1); DBCI company went into liquidation (n = 1).

The PPI target audience was older adults (≥50 years). The researcher approached members of groups with whom they had established connections for time efficiency. PPI participants (n=38; 55.26% female) had a mean age of 64.61 ± 8.21 years (range 52-83 years) and had a mean Lubben Social Network score of 17.66 ± 4.05. Four members of the PPI group were socially isolated (Lubben score <12). The five DBCI options presented to the PPI group included: the ‘10 today’ online videos, Fitbit Inspire HR tracker, Johnson & Johnson 7-minute workout app, Runme Fitness Tracker with the Veryfit Pro app and The Walk app (Appendix N). Feedback from the PPI group helped identify which two DBCI to use in the intervention, with more weight given to responses from those who were socially isolated (score <12; n = 4). To increase the evidence base, feedback from who scored in the bottom half of the Lubben questionnaire were also considered (score ≤15; n = 12). The two DBCI that were chosen for use in the main study were the Runme Tracker and VeryFit Pro app and the Johnson and Johnson 7-minute workout app (Appendix O).

6.2.3. The chosen digital behaviour change interventions

The Runme Fitness Tracker is a commercially available wrist-worn activity tacker that can be paired via Bluetooth to a smartphone or tablet device using the VeryFit Pro app. The device has a screen that displays metrics such as steps taken, calories burned, heart rate, with further functionality to track sleep patterns, set PA goals, record workouts, and monitor PA over time. The tracker costs approximately £15 and the app is free to download and use on both Apple and Android devices. This DBCI encompasses both the device and app and is referred to from this point on as the Runme Tracker. The BCTs included in this DBCI were coded by SS as it had not yet been coded and published in the literature. However, other activities trackers have previously been BCT coded (Lyons, et al., 2014) and this was used to help code the Runme Tracker. The Runme Tracker included 10 different BCTs from 5 different clusters: 1.1 goal setting (behaviour); 1.3. goal setting (outcome); 1.6. discrepancy between current behaviour and goal; 2.2. feedback on behaviour; 2.3. self-monitoring of behaviour; 2.4. self-monitoring of outcome(s) of behaviour; 2.6. biofeedback, 7.1. prompts/cues; 10.3. non-specific reward; and 12.5 adding objects into the environment. See Figure 6, Figure 7 and Figure 8.

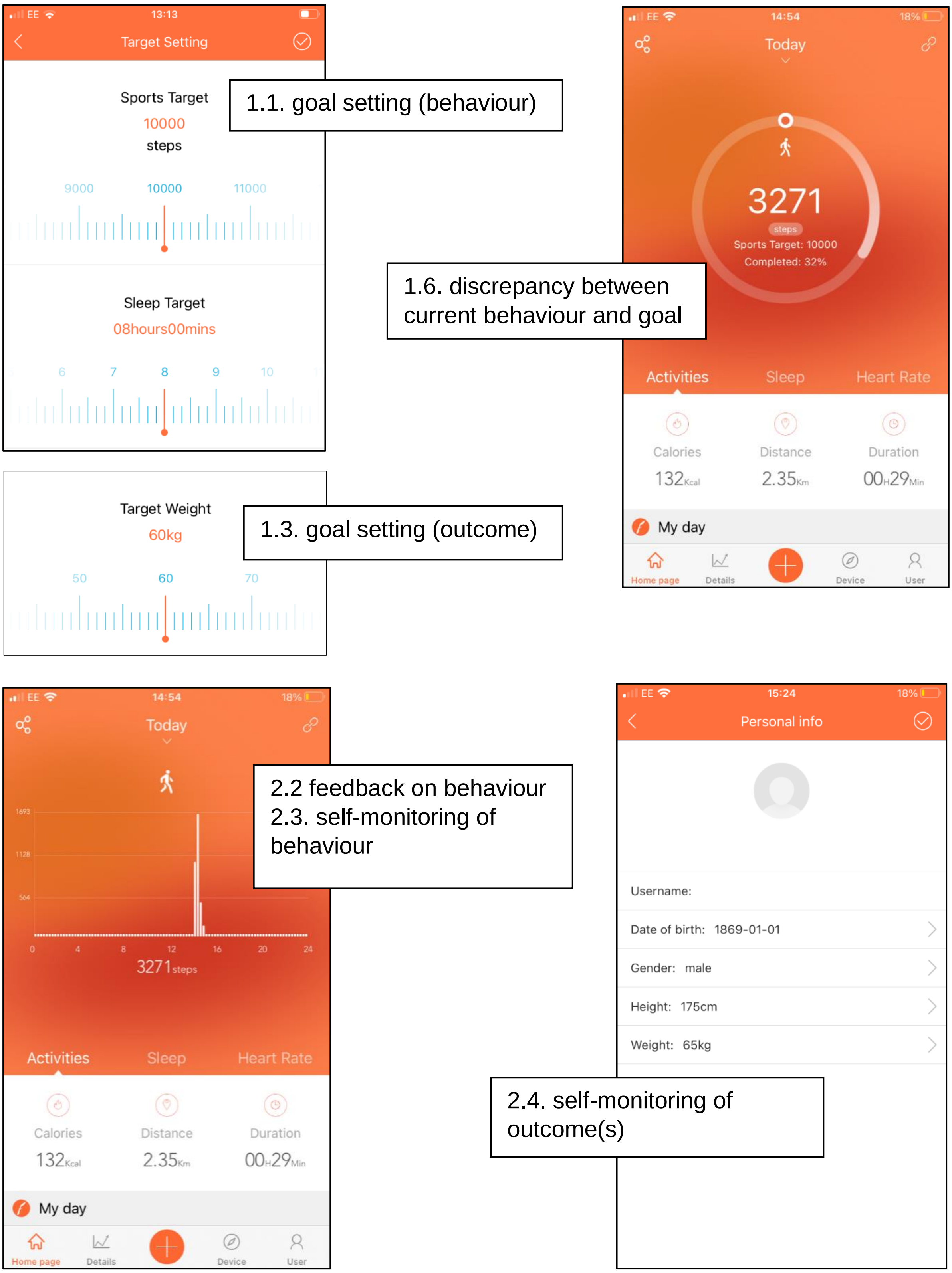


Figure 6. Screenshots of the Veryfit Pro app identifying where BCTs have been coded by SS using the BCT taxonomy v1. BCTs include: 1.1 goal setting (behaviour), 1.3 goal setting (outcome), 1.6 discrepancy between current behaviour and goal, 2.2 feedback on behaviour, 2.3 self-monitoring of behaviour, and 2.4 self-monitoring of outcome(s) of behaviour.

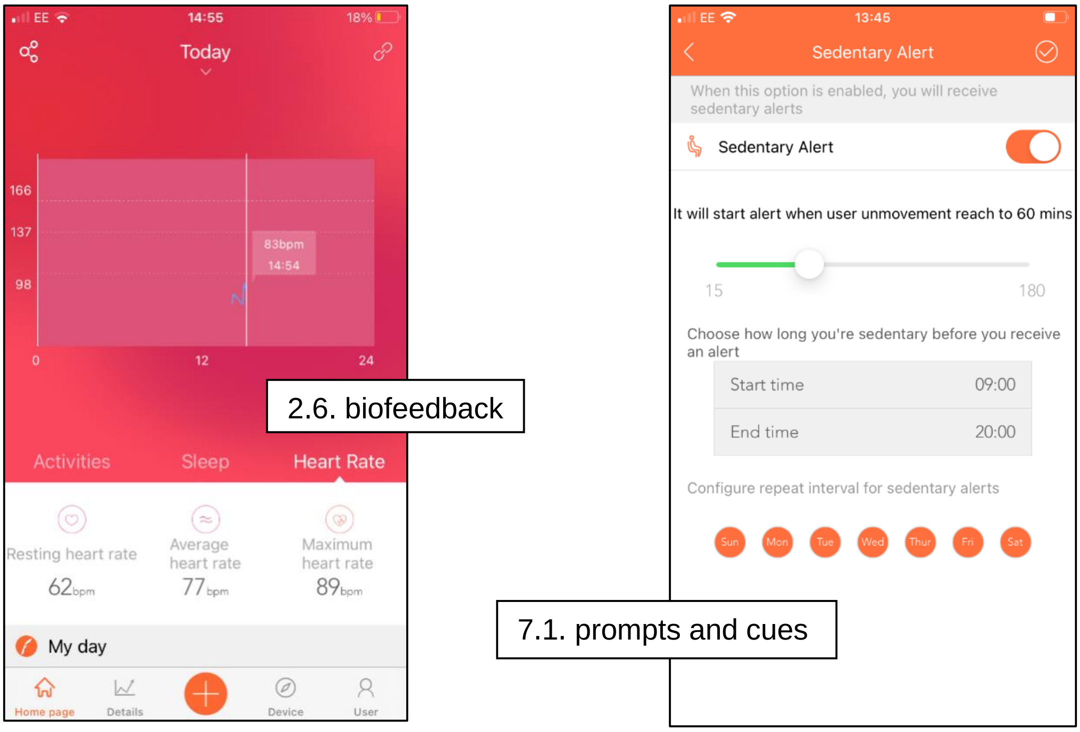


Figure 7. Screenshots of the Veryfit Pro app identifying where BCTs have been coded by SS using the BCT taxonomy v1 continued. BCTs include: 2.6 biofeedback and 7.1 prompts and cues

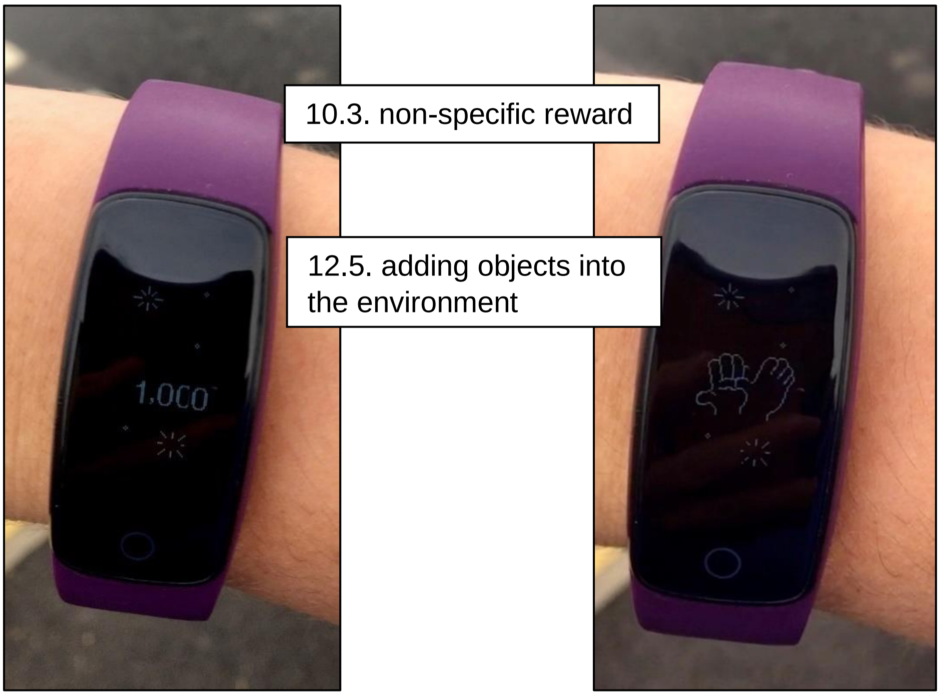


Figure 8. Photograph of the Runme Tracker displaying additional BCTs that were coded by SS using the BCT taxonomy v1. BCTs include: 10.3 non-specific reward and 12.5 adding objects into the environment.

The Johnson & Johnson 7-minute workout (J&J) app can be used on smartphones and tablet Apple or Android devices. There are 22 pre-set workouts, including 72 exercises, that vary in difficulty, intensity, and duration (7-32 mins). The smart workout feature gauges a user's fitness and motivation level to create a variety of workouts specifically for them. The BCTs in this app were previously coded by Roberts, et al. (2019), and were checked by SS. These included 7 different BCTs from 7 different clusters: 1.4. action planning; 2.3. self-monitoring of behaviour; 4.1. instruction on how to perform the behaviour; 6.1. demonstration of the behaviour; 7.1. prompts/cues; 8.7. graded tasks; and, 9.1. credible source. See Figure 9 and Figure 10 for screenshots of the J&J app with the BCTs coded.

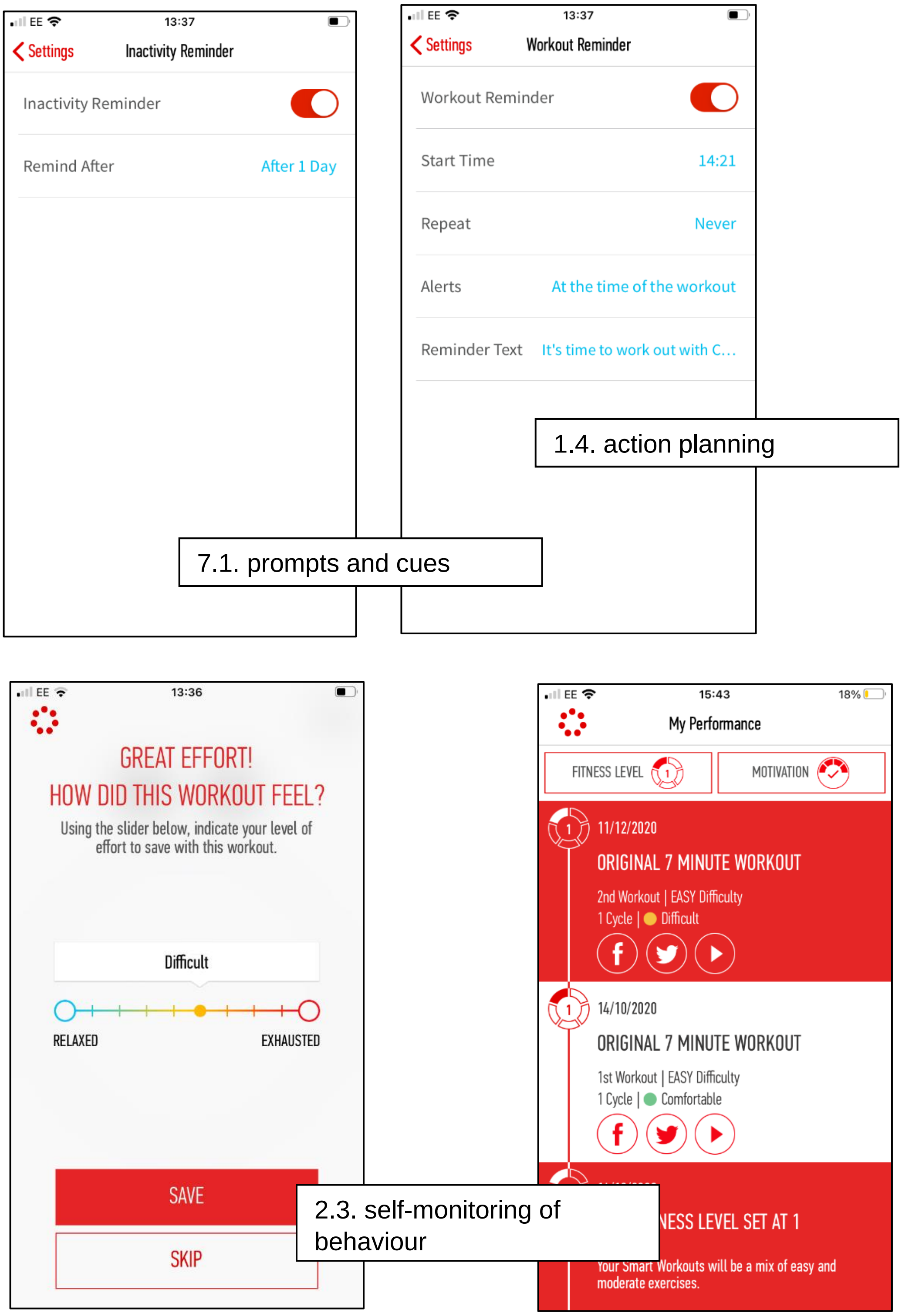


Figure 9. Screenshots of the Johnson & Johnson 7-minute workout app identifying where BCTs have been coded by SS using the BCT taxonomy v1. BCTs include: 1.4 action planning, 2.3 self-monitoring of behaviour, and 7.1 prompts and cues.

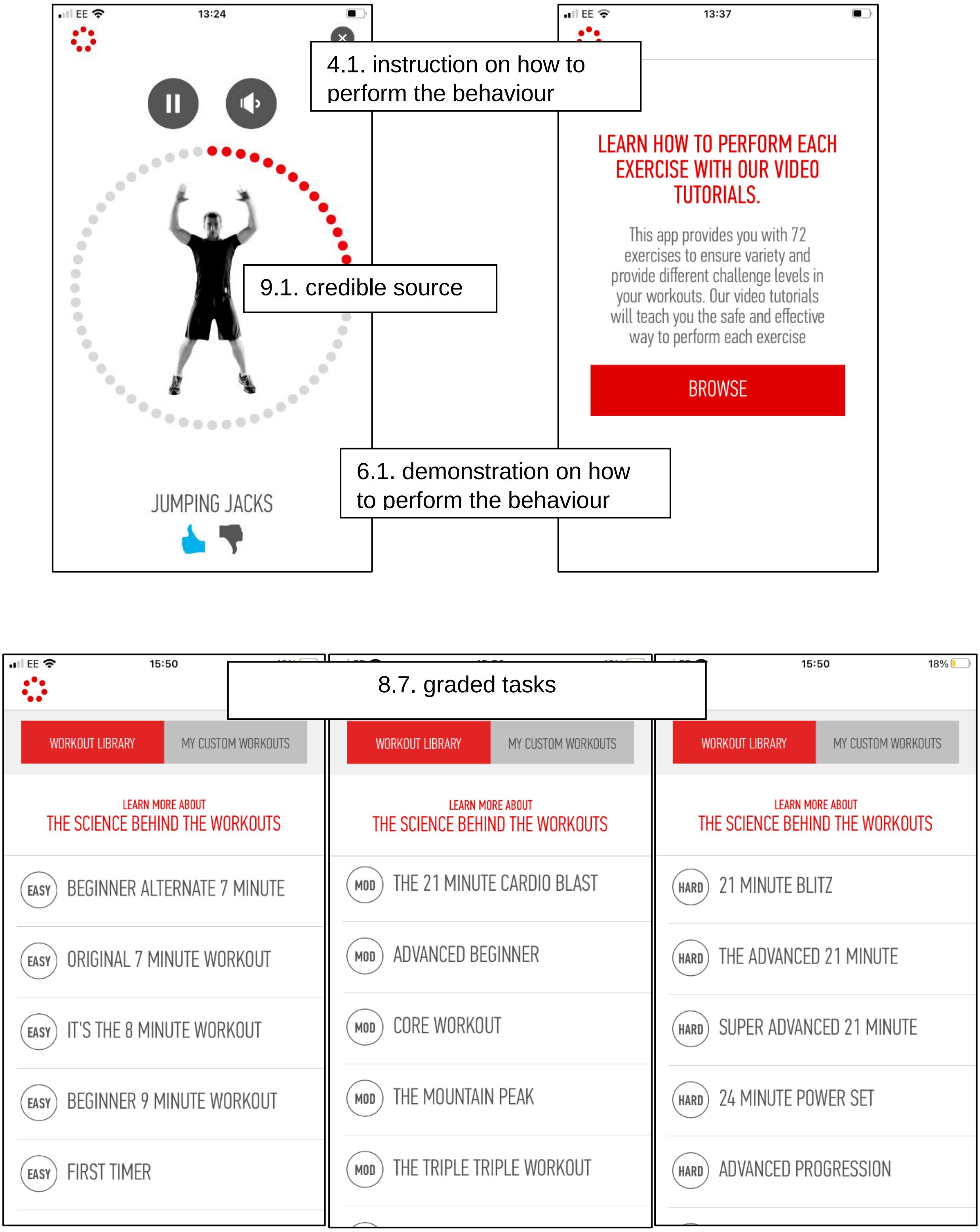


Figure 10. Screenshots of the Johnson & Johnson 7-minute workout app identifying where BCTs have been coded by SS using the BCT taxonomy v1 continued. BCTs include: 4.1 instruction on how to perform the behaviour, 6.1 demonstration on how to perform the behaviour, 8.3 graded tasks, and 9.3 credible source.

6.2.4. Materials

Participants were provided detailed instructions on how to download and set up the two DBCI to ensure the correct DBCI were used (Appendix P). Participants were also given a user diary to complete during the 2-week intervention period (Appendix Q). This was to gain knowledge on their engagement with the DBCI in terms of extent (e.g. amount, frequency, duration, depth) (Perski, et al., 2017). The diaries also had a section for participants to write reflections, opinions, problems, likes, dislikes, to provide an insight to their subjective engagement (e.g. attention, interest, affect) (Perski, et al., 2017). The diaries were used as a memory aid for participants and prompts for the researcher in the interview. Recording their DBCI experiences in real time aimed to reduce the likelihood that participants would mix up or conflate their experiences of each DBCI.

A semi-structured interview schedule (Appendix R) was designed by SS in collaboration with and JR to explore socially isolated older adults' preconceptions of using DBCI for PA, their experiences of using two different DBCI, and to gain insight into users' ideas for the design of future interventions. Participant diaries were used to aid prompting during the interview and were analysed alongside their interview transcripts.

6.2.5. Procedure

The semi-structured interviews were conducted by SS via telephone. They were audio recorded and transcribed verbatim. All interviews took place between February and July 2020. This period included the COVID-19 lockdown period in which nationwide social distancing and limited outdoor activities were enforced, and most of the sport and leisure facilities were closed by the UK Government (Cabinet Office, 2020). Two participants were required to 'shield' during this time, meaning they were unable to leave their homes. This pandemic impacted people's work and life patterns, travel, PA, and SB (Hossain, Sultana and Purohit, 2020). Despite this, both DBCI were able to be used safely by all participants during this time.

In the semi-structured interview at baseline, participants were asked about their previous experiences of using DBCI for PA or their knowledge of them if they had no experience, and also what they thought the potential advantages and disadvantages were of using them. Participants were then asked to spend two consecutive weeks using the two DBCI selected by the PPI group – J&J app and Runme tracker – allowing use for approximately one week each. Participants were asked to complete the user diary during this time to record their experiences and reflections. User diaries were returned before the follow-up interview and used as a prompting aid during the interview. The follow up interview was conducted within one week of participants finishing their intervention trial. This semi-structured interview explored participants' experiences of using the DBCI for PA. In addition, participants were asked about the design of a future DBCI for PA specific to socially isolated older adults, particularly in relation to the types of PA, types of technology and specific features to include or avoid.

6.2.6. Data analysis

Demographic data collected via self-report questionnaire were summarised using descriptive statistics. Descriptive data were also collected on user engagement, the downloading and installing process, previous technology and DBCI for PA experiences from data via the self-report questionnaires and user diaries and were corroborated by interview data.

Experience interview data and diary data were analysed using essentialist framed, inductive thematic analysis including familiarisation, initial coding, generation of themes, reviewing of themes and defining and naming the themes (Braun and Clarke, 2006). Themes were identified at a semantic level, focusing on the experiences directly communicated by participants, although consideration was given to possible latent meanings. Initial coding and development of themes was done by SS, then revised in collaboration with JR. Interview data were managed using NVivo qualitative analysis software v12 (QSR International, Melbourne, Australia).

6.3. Results

As a result of the recruitment campaign, the online participant information sheet web page was visited 768 times. Of those who either completed the consent form (n = 56) or contacted via email (n = 17), 41 were not eligible as they had a Lubben score ≥ 12 (mean 19.49 ± 4.46; range 12 – 27), nine lost contact, five withdrew due to COVID-19 pressures, and three self-identified as not isolated so decided to not complete the online form. A total of 15 eligible participants were recruited. One participant completed the pre-conceptions interview but then withdrew during the 2-week intervention period, leaving 14 participants included in the analysis of DBCI experiences and future interventions. Demographic information of the 14 included participants can be seen in Table 27. The mean age of the participants was 61.92 ± 5.51 years old (range 52 – 69 years) and the participants had a mean Lubben score 8.36 ± 1.54 (range 7 – 11).

6.3.1. User engagement with the digital behaviour change interventions

6.3.1.1. Johnson and Johnson

Participant engagement with the J&J app was assessed using participant diaries and details from interview data. Individual use can be seen in Table 28 . The average number of days the DBCI was used was 5 days (range 3 – 7 days). Most reported using it once in the day, however three participants commented on some days they used it twice. Seven participants used it at different times on different days. Of those who tended to use it at a similar time each day, four participants tended to use it in the morning, two participants tended to use it in the afternoon or evenings, and one participant mentioned using it either before lunch or before dinner. The average number of different workouts tried was 2 (range 1 – 5), with those who were either already active or had previous experience of similar exercise were more likely to try different workouts.

Table 27. Participant demographic information

Characteristic	N baseline interview (total = 15)	% sample	N follow-up interview (total = 14)	% Sample
Age (years)				
50 – 59	5	33.33	5	35.71
60 - 69	9	60.00	9	64.29
70+	1	6.67	0	0
Sex				
Male	6	40.00	5	35.71
Female	9	60.00	9	64.29
Ethnicity				
White British	10	66.67	9	64.29
White European	3	20.00	3	21.43
White Other/Not specified	2	13.33	2	14.29
Marital status				
Single	2	13.33	2	14.29
Married or co-habiting	9	60.00	8	57.14
Divorced or separated	3	30.00	3	21.43
Widowed	1	6.67	1	7.14
Employment status				
Retired	11	73.33	10	71.43
Employed full-time	4	26.67	4	28.57
Highest level of education				
O-Level/GCSE	1	6.67	1	7.14
A-Level	4	26.67	3	21.43
University degree or higher	10	66.67	10	71.43
*Longstanding Illness**				
Yes – not limiting	5	33.33	4	28.57
Yes – limiting	2	13.33	2	14.29
No	8	53.33	8	57.14
RAPA Score				
Active (score ≥ 6)	6	40.00	6	42.86
Inactive (score < 6)	9	60.00	8	57.14
IMD Decile				
4	1	6.67	1	7.14
5	0	0	0	0
6	5	33.33	5	35.71
7	3	20.00	3	21.43
8	3	20.00	3	21.43
9	2	13.33	1	7.14
10	1	6.67	1	7.14

** Long-standing meaning anything that has troubled them, or is likely to affect them, over a period of time. Limiting meaning it limits their activities in some way.*

Table 28. Participant engagement with the Johnson and Johnson 7-minute workout app

P.ID	No. days used	Frequency per day	Time used	No. different workouts tried	Workouts tried
1	4	1	Early Morning	2	First Timer, Original 7 Minute
3	6	1-2	Various	5	First Timer, Original 7 minute, Smart Workout, Core Workout, The Mountain Peak
4	3	1	Early Morning	1	First Timer
5	4	1	Mid-Morning	1	First Timer
6	7	1-2	Various	3	First Timer, The Full Workout, Smart Workout
7	6	1-2	Various	5	First Timer, Original 7 minute, Smart Workout, Beginner Alternate 7 minute, Beginner 9 minute
8	5	1	Mid-Morning	1	First Timer
9	7	1	Afternoon	1	First Timer
10	5	1	Before Lunch or Dinner	1	First Timer
11	5	1	Various	1	First Timer
12	5	1	Afternoon or Evening	1	First Timer
13	5	1	Various	3	First Timer, Original 7 minute, Smart Workout
14	7	1	Various	4	First Timer, Beginner Alternate 7 minute, Original 7 minute, Smart Workout
15	7	1	Various	1	First Timer

6.3.1.2. Runme Fitness tracker and VeryFit Pro app

Participant engagement with the Runme Tracker and VeryFit Pro App was gathered from participant diaries and details from interview data. Participants tended to wear the tracker 24/7, with one participant starting by only wearing it for exercise and another only wearing it during waking hours. On average this DBCI was used for 6 days (range 2 – 7 days). Many participants mentioned that the tracker was comfortable to wear, although a few said it felt a bit clammy in the hot summer weather. Two participants found it odd to wear as well as a watch but did not want to stop wearing their own watch, and one did not like having something on their wrist all the time.

6.3.2. Downloading and installing

6.3.2.1. Johnson and Johnson

Most participants found the downloading process simple and straight forward to do and did not face any problems: *"Oh gosh, it was really easy. Really easy, yeah. It was dead easy. It downloaded really quickly, and it opened really quickly as well" (P4, female, inactive, novice-learner)*. One participant noted that he could not install it on his Amazon Fire tablet but was able to on his smartphone. One participant had to borrow a smartphone from the research team as their personal smartphone was not up to date enough to run Android 4.4 or above.

6.3.2.2. Runme Fitness tracker and VeryFit Pro app

Most participants were able to download the VeryFit Pro app without any problems. One participant had to borrow a smartphone from the research team as their personal smartphone was not up to date enough to run Android 4.4 or above. Many participants were able to successfully connect the tracker to the app and found it relatively easy to do so using the instructions provided by the research team, although two were unable to successfully pair the tracker with the app. One of the most common problems was that those who were able to connect initially had problems with unstable Bluetooth connections and disconnecting the device from the app over the week, which they found confusing and frustrating. Two participants could not connect the tracker to the app at all, despite them restarting their device and using the internet to troubleshoot the problem. A few participants mentioned problems charging the device and tried several different charging options. Some charged it using a USB plug they had, others used a laptop, and one used the USB port on their Smart TV. One participant commented on the voltage of the tracker being out of date and so they struggled to find an appropriate power source to charge it.

6.3.3. Interview data

Semi-structured interviews were conducted between February and July 2020. Data regarding participant preconceptions of using DBCI for PA were collected at the end of the chapter five interviews on barriers and facilitators to PA. DBCI experiences interviews lasted on average 42 minutes (range 18 – 62 minutes). Results are presented as an overview of participants' preconceptions about using DBCI for PA, participants' experiences using the two DBCI for PA, and finally an overview of participant recommendations for a future DBCI for PA in this population.

6.3.3.1. Previous experiences and preconceptions of using digital behaviour change interventions for physical activity

Participants' previous experiences of using technology generally, and specifically DBCI for PA, can be seen in Table 29. Based on their self-reported data, participants were categorised into four levels of prior experience: (i) Novice – has limited experience with smartphone/tablet technology and no experience using DBCI for PA (n = 1); (ii) Novice-learner – regularly uses smartphone/tablet technology and no experience using DBCI for PA (n = 5); (iii) Learner-expert – uses smartphone/tablet technology daily and has experience using one or two DBCI for PA (n = 8); (iv) Expert – uses smartphone/tablet technology daily and has experience of more than two different DBCI for PA (n = 1).

Of the 15 participants who completed the pre-conceptions interview, 11 had some limited experience of using DBCI for PA. Using a fitness tracker, such as a Fitbit or Garmin, was mentioned most; six participants already owned their own and one used their partners'. Two participants said they used YouTube to complete yoga and Pilates workouts, two used their smartphones to map their walks or cycles, and one participant used a step counting app on their smartphone. Nine participants knew of DBCI for PA because they had heard about them or observed them being used by others (spouse = 2, friends = 2, colleagues = 2, acquaintances = 2, strangers = 1). Most participants, even those with limited experience, felt they did not know enough about other DBCIs for PA to comment extensively on them, however many were able to provide information on what they perceived the benefits and drawbacks to using DBCI for PA to be.

6.3.3.2. Perceived benefits and drawbacks of using digital behaviour change interventions for physical activity

The main benefits listed by participants were based on the monitoring of and motivation to do PA. The main drawbacks of using DBCI for PA listed by participants included not being able to understand and use the technology, the potential for someone to become obsessed with the data they produce, not trusting the accuracy of the devices or who else might have access to their data.

Table 29. Participants' previous experiences of using technology and DBCI for PA

Participant Number	Self-reported previous experience with technology (direct quotes from questionnaire)	Self-reported previous experience with DBCI for PA	Prior experience category (Novice/ novice-learner/ learner-expert/ expert)
1	*I have smartphone, laptop and tablet all of which I use regularly. However, I am not keeping up regularly with new technology. Consequently I am not very IT literate or knowledgeable*	*I have not used any technology for my activity other than recording walks on OS maps*	Learner-expert
2	*I have a desk top PC that I use every day. I have a smart phone which is hardly ever turned on. I keep it for emergency use and use Instagram to keep up with family probably every day*	*I've never used technology for physical fitness, however, my wife has a step counter on her phone (which unlike mine is always on) and we do like to know how far we've walked on a day out.*	Novice
3	*I have an iPhone but only use it in a basic way; not very savvy on it, I'm afraid, which I use daily.* *I have an iPad, which I use for general communications, a few apps, used daily.* *I have a laptop for work, which I use daily.* *OK with Microsoft Office programmes for work.*	*I had a Pilates DVD but only used it for a short period as difficult to watch TV at same time as trying to get in position when not facing TV.* *I have a Fitbit Charge 2, which I use to track exercise – minutes and heart-rate during indoor rowing and yoga; novelty of 'steps' wore off quickly; I look at it daily to track sleep and resting heart-rate. I switched off the reminder to 'get moving' as it was impossible when at work, sitting at a desk for long periods.*	Learner-expert
4	*I have a smartphone that I use daily. I also have a tablet and laptop for work on a daily basis.*	*I have never used any kind of technology for fitness activities.*	Novice-learner

Participant Number	Self-reported previous experience with technology (direct quotes from questionnaire)	Self-reported previous experience with DBCI for PA	Prior experience category (Novice/ novice-learner/ learner-expert/ expert)
5	*I have a smartphone, laptop and tablet that I use on a daily basis*	*I have a Pilates DVD I use rarely. I had a Fitbit a few years ago. I use my phone for steps on walks occasionally*	Learner-expert
6	*I am completely computer literate have smartphone laptop and iPad*	*Use Samsung health, Fitbit for daily steps, my fitness pal and map my apps*	Expert
7	*I have a laptop and smartphone that I use daily. I also used to use one for work before I retired.*	*I live cast a YOUTUBE yoga video to the tv.*	Learner-expert
8	*I have a smartphone/tablet/laptop that I use every day. I used computers at work before I retired.*	*I've never used technology for physical activity*	Novice-learner
9	*Laptop and smartphone used regularly. Worked with computers most of my life.*	*None*	Novice-learner
10	*Smartphone, internet user, used to computers for work before retirement and still using, and helping others*	*Sometimes I look at iPhone Health tracking (have been walking much more since lockdown*	Learner-expert
11	*Smart phone, computer*	*Fitbit - does not act as an incentive*	Learner-expert
12	*I am a computer programmer for work. I have a smartphone, tablet and laptop.*	*Garmin watch to track/pace running.*	Learner-expert
13	*I have smartphone and Tablet*	*Sometimes use you tube for exercise. Have old Garmin Watch I use for running to time and record route on Laptop*	Learner-expert

Participant Number	Self-reported previous experience with technology (direct quotes from questionnaire)	Self-reported previous experience with DBCI for PA	Prior experience category (Novice/ novice-learner/ learner-expert/ expert)
14	*I worked in IT for 40 years and have a smartphone, tablet, laptop & homebuilt desktop.*	*I did a few Pilates classes delivered via YouTube*	Novice-learner
15	*I use a laptop and smartphone daily.*	*I use the Stepz App on my phone to judge how far I walk - I aim to walk 6000+ steps daily.*	Novice-learner

Theme: Monitoring and motivation or borderline obsession?

Participants believed monitoring their PA would heighten their awareness of their actual PA behaviours, from which they would become motivated to modify their behaviours:

> *"the motivation comes from if my heart rate, my resting heart rate starts to increase, I will increase the amount of activity I do or the length of time I spend on the rower because I know that gets it down. So it does motivate me" (P3, female, active, learner-expert)*

Participants used goal setting to provide motivation to increase their PA and was often related to step counts or distance: *"So I set my target and when I've hit 6,000 paces it comes up with a little green um bar graph instead of an orange one." (P15, female, inactive, novice-learner)*. Two participants thought that being reminded to move would be helpful as they can lose track of time and sit for long periods engrossed in something else, which they admitted was not good for them. An external prompt would remind them to stand up and take a break.

The monitoring and prompting afforded by a DBCI was reported by three participants as helping with pacing of PA. One, a runner, said *"it stops me goin' off like an idiot and giving up after about 3K sayin' I'm knackered" (P12, male, active, learner-expert)*. Another participant mentioned it might be helpful to monitor their heart rate for safety and to *"stop the bull in a China shop" (P11, female, inactive, learner-expert)*. The last participant found monitoring their activity helpful in managing their chronic condition as they could use the information to learn about how to pace themselves doing everyday things; it provided *"grounding that you had done something that therefore justified the fact that you're tired" (P5, female, inactive, learner-expert)*.

However, several participants were concerned that using DBCI for PA could exacerbate obsessional behaviours for them, or in other people: *"I started becoming slightly addicted to it." (P6, male, active, expert).* Four participants mentioned that the drive to achieve the goals that were set could either be disheartening if they are not achieved, or even become a safety issue: *"you might be driven more to the technology than what your body's feeling. You know, if you do 600 more steps you've done 10,000 and actually your body has really had enough. But you want to get that golden star" (P5, female, inactive, learner-expert).*

One participant commented they felt some other people seemed *"controlled by technology" (P8, male, inactive, novice-learner)* as they had observed people constantly checking their technology, and their behaviours would be driven by their data. One participant noted that having a flat battery on their activity tracker can stop them from doing PA as they felt if PA was not recorded then it did not count: *"when the battery's flat I think 'ohh I'll just wait until I charge it up' or don't go, you know, kind of puts you off going that day if it's not going to be sort of measured." (P13, female, active, learner-expert).*

Theme: Distrust of the technology

Distrust in the accuracy of a fitness tracker was common among participants. Those that had their own trackers mentioned when comparing their tracker data with other sources, they often show different results. Another inactive participant (novice-learner) mentioned that not all steps are equal, for instance walking on a smooth path would be easier than the same number of steps up and down hills on a muddy track, and was not convinced trackers would be able to differentiate this. In addition, participants had concerns about data privacy regarding not wanting a third party to use their data for its own purposes because they felt it was an intrusion of privacy and did not want to be spied on.

Theme: "If it doesn't come to me easily, it ain't gonna happen" (P13)

Many participants expressed worries about being unable to understand and use the technology, and mentioned that if it is not intuitive or easy to use then they are unlikely to spend time learning about it:

“I s’pose for people that don't have that confidence or whatever, if you’re going to struggle with the technology it’s not going to really help I don't think. It’s just going to be frustrating and going to end up putting it in a corner and forgetting about it.” (P14, female, inactive, novice-learner).

Theme: Comparisons with others

The ability to compare data against others was a feature that many participants were not interested in. They felt they were unable to compete, they would feel guilty about how little they had done, or because they were not bothered about how they compare to others at this time in their life. In contrast, one participant mentioned they stopped using their Fitbit because other people at the gym did not use them:

“And I’ll tell you what, they do not wear Fitbits, and do not wear digital [laughs] they’re not that type yeah? They’re a bit tougher than that I think. Erm, so I stopped wearing it to the gym and that was that. And then I decided oh, I won’t bother wearing it anymore.” (P6, male, active, expert)

6.3.3.3. Experiences of using the two digital behaviour change interventions for two weeks

Participant interviews were consistent with the information provided in their diaries and the data presented were from participant interviews unless otherwise stated. The two DBCI were very different in nature as the Runme Tracker had a focus on monitoring, whereas the J&J app focused on instruction and demonstration. An overview of themes for each DBCI can be seen in Table 30.

Table 30. Overview of themes for each DBCI.

Overarching theme	**Johnson & Johnson Themes**	**Runme Tracker & VeryFit Pro app Themes**
Motivation lost and found	*Motivation drain or motivation gain?*	*Shamed into moving just enough*
	Easy to "slot" into your usual routine	
	Making the workout work for me	
	Love and apathy	
Assume can make an 'ass' out of 'u' and 'me'	*"It was very intense and very hard" – the assumption of fitness*	*Putting data into action – the assumption of data literacy*
	Knowledge of exercise is assumed	
	The Bare Necessities – the assumption that users do not have gym equipment at home	
	"I don't want to work to make it work" – the assumption of technological capability	
A matter of trust	*Simple, clear, and helpful instructions/demonstrations from an expert*	*"You liar!" – distrust of the tracker*

Overarching theme: Motivation lost and found

Johnson and Johnson 7-minute workout app

Theme: Motivation drain or motivation gain?

Participants who found the exercises difficult mentioned that they viewed the app as *"a chore" (P9, male, active, novice-learner)* and that they lacked motivation to do the workout: *"rather than looking forward to it I have to persuade myself to keep trying. I'm pretty certain that I would have abandoned this app if I had not been following it for the study." (P8, male, inactive, novice-learner)*. Others found it *"satisfying" (P15, female, inactive, novice-learner)* and were motivated to do it to see what else was on there. Some even felt *"energised" (P7, female,* *inactive, learner-expert)* having completed their workout for the day and motivated to complete their other tasks for the day or even do more PA: *"After this morning's exercise immediately felt mood elevation and motivation to go for long walk in park and will do some aerobic exercise this afternoon" (P6, male, active, expert – participant diary entry).*

Most participants felt the Johnson & Johnson app increased their PA*: "It's increased it, there's no doubt about that" (P14, female, inactive, novice-learner)*. This was the case not only for previously inactive participants but also for those who were already active:

> *"It made me do stuff that I don't normally do. So I've still been going running and everything but then either when I get back from a run I've been doin' the exercises or I've been doin' the exercises on a day I'm not running." (P12, male, active, learner-expert).*

One active female mentioned that the app provided a change in her exercise routine, which she liked, but that she was doing roughly the same amount of PA as before the study. However, an inactive female said it decreased her PA because of *"inadvertent pulling of the odd muscle" (P13, female, inactive, learner-expert).*

Most participants felt this DBCI had no effect on their overall sitting time each day, excluding the time they were doing the exercise: *"I don't think it made any difference if I'm honest" (P7, female, inactive, learner-expert).* Two female participants mentioned they may have actually increased their sitting time having done the 7 minutes of exercise, either because they found it strenuous and needed to rest, or because they felt they had earned their relaxation time*: "I probably sat more during the day erm, having done that workout than I did with the Fitbit. And probably didn't do as much…" (P5, female, inactive, learner-expert).* Two active participants felt it potentially decreased their overall SB: *"it gave me more energy, so I was definitely doing more things, I wasn't sitting the whole time" (P6, male, active, expert).*

Theme: Easy to "slot" into your usual routine

Participants liked that they could do it at any time that worked for them on any given day. This convenience made it easier for participants to, *"slot it in" (P13, female, active, learner-expert)* to their daily routines or around other tasks they needed to do in a day: *"the fact that you could pause it so when you had the ones with the three cycles erm, I could go and check my tea, stir something or you know [laughs] and then go back and do the second cycle" (P3, female, active, learner-expert).*

The short duration of the workout was popular among most participants as they felt they could commit the time in their day to do it: *"Given that it is only around 10 minutes, I was able to do this first thing in the morning and didn't feel that it took up too much time." (P4, female, inactive, novice-learner).* Despite the short duration, most participants felt it was beneficial: *"Although short the workout feels worth doing." (P14, female, inactive, novice-learner).* Others found that the short duration freed up time for them to do other things, whereas their usual walk would take over an hour:

> *"I thought the fact that it was only 7 minutes was very good… which is quite nice because it made a load of extra time for me. Um doing it in the morning was good coz it did mean I had the rest of the day, it did make time for me" (P15, female, inactive, novice-learner).*

Many liked the fact that it could be done at home as it eliminated travel time. Additionally, some participants commented on the fact they could do it before they showered and got ready for the day, even in their pyjamas: *"quite like the idea of being in my pyjamas in the morning and doing my exercises at my leisure." (P1, female, active, learner-expert).*

Theme: Making the workout work for me

Several participants explored the tailoring functions and different workouts in the app, to varying degrees of success. Most participants set their level of fitness which was used in the creation of the smart workouts. For those who tried the smart workout, they mostly enjoyed it although some were unsure as to how the routines were created: *"I don't know how it decided how to ramp things up, and hopefully there is some rhyme and reason behind it and it's not just a set series" (P14, female, inactive, novice-learner).* Some participants used the thumbs up and thumbs down to create workouts that were better suited to them: *"I like the idea where you just erm, you had the thumbs up and thumbs down, so I just put the thumbs down on it (press-up). I thought that was quite good, because it never pops up again, that exercise" (P13, female, active, learner-expert).*

Others tried this function but for some reason the app did not store their preferences and so it did not work: *"But it's frustrating that um, on the app, where you can sort of put the thumbs up or thumbs down if you like exercise, every time I put the thumbs down on the press ups… every time it's come up as an exercise" (P7, female, inactive, learner-expert).*

Those who used the thumbs up/down function all mentioned that it was frustrating that they had to select the thumbs up or thumbs down whilst doing the exercise: *"I found it a pain to have to hit the thumb up or thumb down while I was doing the exercise" (P14, female, inactive, novice-learner).* Many thought it would have been better for this function to be done either in the rest breaks during the exercise or to be able to select them separately in the app.

Only one participant tried to create their own custom workout, but found it difficult as they needed to remember the names of the exercises and after completing their selection, they could not find the workout again: *"I pressed the save button, but then at the end it said there are no custom made exercises... I just didn't know where else to find them." (P1, female, active, learner-expert).* Many participants did not explore the tailoring options and just used the pre-set workouts as they felt they did not have time during the week to explore them: *"I haven't looked at what else is on the app. I've literally not looked at the smart workouts or the workout library or anything like that" (P5, female, inactive, learner-expert).*

Runme Tracker

Theme: Shamed into moving just enough

One male and six female participants felt that the tracker increased their PA, particularly in relation to their step count per day, often encouraging them to go out for a walk if they had not done that many steps, or increasing the length of their walks. Four participants felt guilty or ashamed of a low step count some days so went out for a walk. One participant mentioned walking around the house at night to increase their step count for the day before going to bed: *"I was so ashamed how low this thing, the total steps, so I did start walking backwards and forwards through the kitchen to try and build up more, a few more steps" (P8, male, inactive, novice-learner).*

Four male and two female participants felt the tracker had no impact on their PA. Some felt they were just tracking what they already would have done and did not feel the need to change their PA because they were wearing the device: *"I didn't feel the need because of that thing to do any more or less than I've already been doing" (P9, male, active, novice-learner).*

One active male participant mentioned that the 10,000 step goal may have been detrimental to his PA and promoted SB as once he had reached that goal, he was more inclined to be sedentary for the rest of the day:

> *"Coz I was finding that if I went out for a run, I was generally doin' the 10,000 steps as the run and then that sort of almost made me think later on, well maybe I won't bother*

goin' for a walk coz I've done me steps for the day anyway." (P12, male, active, learner-expert).

Generally, most participants felt that the tracker had no impact on their sitting behaviours. However, some commented that it may have helped reduce their sedentary time as if they could see from the data that they had not been very active during the morning, they were more inclined to plan PA for the afternoon:

> *"there were certainly days when I looked at it at, you know, particularly one day, actually the day when I did the most steps was a nice-ish day and I looked at it in the afternoon and I thought mmm, I should really go for a walk. So I drove down to erm, there's a little wildlife reserve about 5-10 minutes drive and walked around that." (P14, female, inactive, learner-expert).*

Despite participants feeling guilted into moving more, many participants felt a sense of achievement when they looked at their activity for the day, particularly if they had met their goals: *"once when I was out on a really long hike and it all started vibrating and I thought 'oh my goodness' and I realised that it was because I'd gone way over, over my steps for the day. Which is brilliant." (P4, female, inactive, novice-learner).*

Common to both digital behaviour change interventions

Theme: Love and apathy

Those that explored different workouts in the J&J app enjoyed the variety available, both pre-set and using the smart workout feature, as felt this would keep them remain interested in the longer term and offered variety in a way other DBCI do not: *"I mentioned like the random exercise, you know, just choosing exercises for you, or throwing them up for you and I really like that, I really do. You don't get that with Fitbit and things" (P6, male, active, expert).*

Nine participants explicitly expressed that they enjoyed using the J&J app and doing the workouts: *"I wasn't particularly looking forward to doing the, you know, the 7 minute workout and actually I really surprised myself that I actually really enjoy the 7 minute workout." (P4, female, inactive, novice-learner).* A couple of participants even thought they had, *"withdrawal systems" (P9, male, active, novice-learner)* from not doing it when they were trying the other intervention: *"I found myself quite missing the 7-minute workout today!" (P3, female, active, learner-expert).* Those who enjoyed it were more likely to consider using the J&J app after the study was complete. Of the 14 participants that completed the study, 10 mentioned that they are likely to consider or have continued to use this app after the study had finished, and four of these had recommended the app to other people. One participant said that they would like to, but their smartphone was not compatible with the app as it was too old, so could not. Three participants said they would not consider using this app again due to the difficulties they had with the exercises.

Some participants mentioned enjoying using the Runme tracker, finding the data it produced interesting: *"I quite enjoyed having it… I like getting the statistics as well" (P5, female, inactive, learner-expert).* Some found it an interesting activity to try for the short term but did not see a need to have one in the long term: *"The watch as I say, was interesting to have, but I don't see any need for it." (P9, male, active, novice-learner).* Others wore the tracker and briefly looked at the data, but were not interested in exploring the different functions of the DBCI or the data: *"Erm and I wasn't, this sounds awful, but I really wasn't interested enough to look to see what it could do… I slapped it round my wrist and then ignored it basically." (P15, female, inactive, novice-learner).*

Of the 14 participants that completed the study, four already owned and used a fitness tracker (Fitbit brand = 3; Garmin brand = 1), however, at follow up, one was considering upgrading theirs to a newer version with heartrate capability. Two participants have purchased a fitness tracker of their own because of their experiences in study (Fitbit brand = 1; Xiaomi brand = 1).

Two participants were considering purchasing their own tracker but were yet to decide on which one. One participant was undecided, and five participants said they would not consider using a fitness tracker again. Participants' interest and enjoyment of the tracker heavily impacted their decision to consider this technology in the future.

Overarching theme: Assume can make an 'ass' out of 'u' and 'me'

Johnson and Johnson 7-minute workout app

Theme: "It was very intense and very hard" – the assumption of fitness

The most discussed aspect of this DBCI by the participants were the different exercises involved in the different workout, of which many participants found quite hard to do:

> *"If you've never ever done those sort of exercises before, I think people might have found it a bit of a shock… I was a bit surprised that the complete beginners did have like all the press ups straight away in it and whatever without a sort of slow build up to it" (P7, female, inactive, learner-expert).*

Press-ups were particularly challenging for most: *"Well basically anything to do with push up were just well beyond my means" (P9, male, active, novice-learner).* Some participants mentioned feeling disappointed at their level of fitness: *"I was horrified to find out how unfit I had become" (P15, female, inactive, novice-learner).* This feeling for some participants was demotivating and did not encourage them to improve their fitness: *"When most of the exercises for beginners are too hard and not achievable it does not make you feel good but the opposite. I keep being reminded of how unfit I am rather than how well I am doing to achieve the next level." (P1, female, active, learner-expert).*

Some participants did not try other workouts as they wanted to avoid feeling of demotivation: *"I thought I'd feel more disappointed if I had a look and thought, well I can't even do that!" (P5, female, inactive, learner-expert).* Many participants did not attempt anything other than the 'First Timer' workout because they felt that if they could not manage all the exercises in this one, then they were not ready to try/progress onto another. Others erred on the side of caution and did not try harder workouts because they did not want to risk injury: *"I don't want it to get too hard, I want to be able to do this and concentrate on getting the technique right so I don't hurt myself" (P4, female, inactive, novice-learner).*

Some struggled with the intensity of the workout in relation to switching between standing and floor-based exercises:

> *"I mean if you're doing one of the standing up exercises so you know if you're doing squats or whatever, and then at certain points the next one is the plank and you've got a few seconds to get down and get in a plank position before the timers starts and that's just… it felt rushed, for me." (P12, male, active, learner-expert).*

The majority of participants focused on the exercises they were able to do, and this included most from the 'First Timer' workout, the warm-up and cool down, excluding push-ups*: "they all have a certain level of difficulty when you're doing them for the first time… I managed to do them all… I was a bit puffed but you'd expect to be puffed." (P10, male, inactive, learner-expert).* Some participants mentioned adapting the exercises slightly so that they could do them, either by slowing the movements down, completing part of the movement, reducing the amount of time they did each exercise for, lowering the height of the step, or reducing the amount of body weight being lifted by kneeling: *"it's probably better for me to do the kneeling one, get the strength for that and then go on to the other one" (P13, female, active, learner-expert).* Those with more exercise experience and knowledge were more confident in adapting the exercises themselves, whereas those with less experience would have preferred more guidance on how they could have adapted exercises*: "I found myself googling how to modify* *them (lunges), and the basic answer seemed to be don't go down so far it hurts" (P14, female, inactive, novice-learner).* However, one participant – who had experience in differentiating PA from their career before they retired – highlighted that in the 'moment' they became competitive and potentially ignored cues from their body. This exacerbated the fatigue symptom of their chronic condition:

> *"And then I've got a bit competitive… I had to do as much as I could do in the app… I could of easily said 'right, I'm only gonna do 20 seconds today because my arms are tired'. Whereas actually I wanted to try and complete the whole lot anyway, because that was the target and that was what was set." (P5, female, inactive, learner-expert)*

Theme: Knowledge of exercise is assumed

The audio guidance that provided instruction on how to do the exercises and reminders about technique was, *"comforting and reassuring" (P3, female, active, learner-expert)* with two participants highlighting that they liked it having an English rather than American voice. However, several participants commented that there was an expectation that they should have already known something about exercise, even at the beginner levels. The references to specialist exercise terminology led one participant to reflect that he was: *"Still struggling to follow instructions and although image is reasonably clear, for its size, still awkward and they presume knowledge e.g. 'glutes' 'triceps' etc. that I don't possess." (P8, male, inactive, novice-learner).*

Many participants felt some phrases that were used as prompts during the exercise required more explanation for those who are new to this type of exercise: *"it wasn't clear how you 'engage your core', and this could have done with an explanation in the first timers' routine." (P4, female, inactive, novice-learner).*

Some participants mentioned that they were still figuring out what the exercise required during the time they were supposed to be exercising: *"In some cases I did not do the exercise for the full time as I was looking at the app to work out exactly what the exercise involved." (P12, male, active, learner-expert).* However, most commented that after a few sessions they began to recognise the names of the exercises and remembered what they needed to do for them: *"I notice I am learning what some of the exercises are which eases the transition" (P14, female, inactive, novice-learner).* A couple of participants had experience with this type of workout before and felt they were in a good position to understand the terminology and already knew most of the exercises:

> *"the exercises and things were very familiar to me, the language was familiar so it all felt quite easy erm, in that respect... It certainly helped that I had a bit of a background with training and that I know what things are called" (P3, female, active, learner-expert).*

Theme: The Bare Necessities – the assumption that users do not have gym equipment at home

Participants liked that the J&J app did not require any specialist gym equipment to do the exercises, and any equipment that was used could be found around the home: *"It was skipping without a rope, who needs a rope? … You don't need a rope to do skipping! [laughs] you can do it without the rope!" (P4, female, inactive, novice-learner)*. Two participants mentioned not having a wall they would be happy to lean on and three found doing the exercise on their wooden floors slippery. However, most adapted as needed by wearing shoes or putting down a mat. Several participants swapped out the chair for a step for the step-up exercise as they felt a chair would be too high:

> *"The only thing was initially when it said do a step up I was lookin' round the room thinkin' 'which chair's gonna not be too high or too low or give way on me' sort of thing. But that was… once I'd done it once, I knew what to expect." (P7, female, inactive, learner-expert).*

Ten participants felt there was not enough time between exercises to find the chair or wall to use before the exercise actually started, so would have liked a reminder before they started as to what they would need or a slightly longer break between exercises if they needed to move rooms: *"the time between exercises was a bit short if you had to move from one place to the other" (P9, male, active, novice-learner).*

Runme Fitness Tracker

Theme: Putting data into action – the assumption of data literacy

Five participants mentioned that although the data measured by the tracker and presented on the app was potentially useful, they did not know what to do with it or what it really meant:

> *"I thought there still elemental of… but How do I interpret? How do I understand what this is doing for me or what this can tell me about myself? There was still a gap between my ability to understand how to make the most of it and the fact that there was potentially all this useful information there" (P8, male, inactive, novice-learner).*

Most participants left the step goal at the default 10,000 steps, which for some was because they had heard about others aiming for 10,000 steps, but others did not know what to change it to: *"I just left it as it was… I felt like I don't know what to set. I don't know what the right goal would be. I would have to work out what to set." (P14, female, inactive, novice-learner).*

Participants who had experience with either a fitness tracker or step counting app were better able to adjust this goal to be more appropriate to them and their situation. Three participants lowered the step goal, either due to ailments that meant 10,000 was unachievable without pain, or they were shielding and therefore could not leave the house.

Common to both digital behaviour change interventions

Theme: "I don't want to work to make it work" (P1) – the assumption of technological capability

Most participants commented that they liked the simplicity of the design of the J&J app and found it *"easy to navigate" (P3, female, active, learner-expert)*: *"The interface was very clean and just gave you the information you needed. I felt that I could actually focus on the workout itself rather than worrying about the technology and whether I had entered everything correctly." (P4, female, inactive, novice-learner).*

However, several commented that the easiest J&J workout was not the first one on the list, which they found confusing. Three participants actually started on the original 7-minute workout rather than the First Timer workout, which was suggested by the research team, by mistake:

> *"the first time I used it [laughs] I accidentally didn't do the, sort of, very beginners one, what ever they call it. I just did the basic 7 minute one. And then realised what I did so I then re-did it, the right one, so I did 2 on the first day" (P7, female, inactive, learner-expert).*

A couple of participants mentioned that the small screen size of the phone made it more difficult to see what exercises they needed to do when using the J&J app, particularly when doing standing and then floor based exercises. One participant subsequently tried their tablet and found that easier to see, although they still found it difficult to place the tablet so they could see the screen both when stood up and on the floor.

A few participants commented on the fact that the J&J app did not require them to enter lots of personal information and they could just get started with the workout: *"The invasive privacy seems to be reduced to a minimum, absolute minimum. So I think that's a definite plus" (P9, male, active, novice-learner).*

Most participants highlighted that the instruction manual that came with the Runme tracker was too small to read: *"which was awfully cute to look at but so flippin' small!" (P11, female, inactive, learner-expert).* Many therefore did not read the instructions, which may have helped overcome some problems they had with the technology. However, those who did manage to read the instructions did not find them easy to understand: "*I found the, whole instructions were a bit mysterious in a way because I think they were possibly machine translation or something. Erm, some of them were a bit bizarre" (P14, female, inactive, novice-learner).*

Another common issue was that the Runme tracker screen was impossible to read in daylight for many participants, either due to the brightness setting or the fact that the tracker was too small to read without glasses:

> *"If it was sunny at all, you couldn't see what was on the screen which is mainly down to the fact that I need glasses for reading now, so it was all, yeah there's a screen there but I couldn't tell you what it says or anything. Erm, and I don't take my glasses when I go running or anything coz I only need 'em for reading normally. So it just made it difficult to use." (P12, male, active, learner-expert).*

Some participants assumed that the Runme tracker would automatically sense when they were being active based on the increased steps and heartrate: *"I don't know why, I just expected it to know I was doing activity, or not. I s'pose it's measuring is your heart rate and your steps" (P4, female, novice-learner).* Many forgot to set the tracker to record a walk or workout, or thought they had recorded one, only to find out at the end it did not start; others forgot to stop it when they had finished.

Several participants reported that it was difficult to compare their activity across different days and different activities in the Veryfit Pro app: *"I found it slightly awkward moving between trying to see what today's total was and then trying to look back and do a comparison" (P8, male, inactive, novice-learner).* Many participants felt like they had to, *"sort of work it out" (P10, male, inactive, learner-expert).* Participants with experience of using a tracker found the Runme tracker and app easier to use than others with less experience. Some found the app easy to navigate and were happy to explore it, whilst others were just beginning to gain confidence by the end of the week*: "I feel that I was really just beginning to understand the potential of the tracker and app as I finished." (P8, male, inactive, novice-learner)*. A few participants found the app, *"a bit complicated" (P10, male, inactive, learner-expert)* and so did not spend much time using it.

Many participants did not find the sedentary alert on the Runme tracker, some had previous experience with them from their own trackers and decided not to switch it on, and those who did find it found it annoying and either ignored it or switched it off. The main reasons for this were that they had to sit to work, they had been active in the morning and had chosen to have a more relaxed afternoon, and for one participant they were getting reminders to move despite having been active in the previous hour: *"Finding the reminder to move after one hour annoying as sends out an alert even if I've moved in the previous 10 minutes!" (P7, female, inactive, learner-expert).*

Overarching theme: A matter of trust

Johnson and Johnson 7-minute workout app

Theme: Simple, clear, and helpful instructions/demonstrations from an expert

Having demonstrations being done by an exercise professional who can do the exercise with good technique to copy was important to participants. However, four female participants said they would have liked the option to have a female instructor, and one of a similar age: *"I'd like to watch a woman in the app rather than a man, and indeed a woman who is clearly over 50! In other words a woman of my age" (P14, female, inactive, novice-learner).* Having the instructor doing the exercise at the same time felt companionable without it being direct human interaction:

> *"was nice when you had the chap sitting next to you, you know it was also company, you know, he was [laughs] there with me, it sounds really stupid doesn't it? But he was there with me doing the exercises while I was doing it and it felt quite… companionable, you know." (P1, female, active, learner-expert).*

Most participants felt the exercise demonstrations were clear and this was helped by the white background. A few mentioned that they liked being able to see and learn the exercises outside of the workout, although some did not find this feature at first: *"it took me a couple of days to realise that you could actually play those separately each exercise whilst you weren't working out. Can actually see them more clearly" (P7, female, inactive, learner-expert).*

Many participants commented that they liked the countdown timer as it was visually clear how long there was left per exercise, but it also provided motivation*: "it gave you an incentive to keep going, you know pushing yourself still" (P5, female, inactive, learner-expert)*. The *"bleep, bleep, bleep" (P13, female, active, learner-expert)* was also appreciated by participants to signal the exercise was changing over, particularly for exercises where looking at the screen was challenging. Being able to rely on the ‘bleeps’ meant participants were, *“fully committed to each of the exercises” (P3, female, active, learner-expert).*

Runme Fitness Tracker

Theme: “You liar!” (P7) – distrust of the tracker

Most participants believed that the Runme tracker was not accurate across all metrics it measured. Participants even tested this by wearing their own trackers, using Google Earth, manually taking their pulses and counting steps out loud. Generally, participants believed the heartrate sensor was inaccurate, particularly at higher heartrates, although some mentioned that perhaps the sensor was not in close enough contact with the skin, which may have impacted readings: *“[I] noticed the difference in heart-rate with my Fitbit Charge 2 which I’m also wearing. Fitbit said 55 bpm and Veryfitpro said 88! I took my pulse and it was 55.” (P3, female, active, learner-expert).*

Distance was also believed to be inaccurate, and often underestimated distances, as participants checked their routes on Google Earth and compared with their own trackers:

> *“I went for a 4 mile walk and according to Google Earth there are about 4.1 miles and actually, have a Garmin thing which I actually used for my last walk and it was actually 4.5 miles and the tracker only registered both 3.5 or 3.1 miles depending on how it felt. So that wasn't very useful.” (P13, female, active, learner-expert)*

Many participants felt the number of steps were slightly overestimated compared with their own devices, or when they counted their steps out loud. While washing-up dishes, one participant noticed their step count was increasing, which they found disheartening as they were trying to reach a certain step goal:

"I was doing the washing up and suddenly I could see step count was going up [laughs] and at that point I felt so deflated. I'd even put it on my left wrist and I thought that's gonna, you know, be a bit of a safeguard or whatever, and I felt a bit cheated at that point." (P7, female, inactive, learner-expert).

6.3.3.4. Impact of previous technology use on experiences – Confidence is key!

Most participants believed their previous experiences of using technology provided confidence for engaging with these technologies, making it quicker for them to get started using them: *"I think if I hadn't got any I might not have got going as quick using it" (P5, female, inactive, learner-expert).* This was particularly the case for those who had used a fitness tracker before: *"obviously the tracker was very similar to something I was used to" (P3, female, active, learner-expert).* However, one participant mentioned that their previous experience with their Fitbit may have actually hindered their experience with this tracker: *"Because if it doesn't work the same way as the other one was, I don't wanna learn anything new" (P11, female, inactive, learner-expert).*

Three participants worked in computer programming, or did so before retirement, and felt they were more confident in front of a computer but less so in using apps:

"I work in… with IT all the time, I mean, I'm a programmer. I tend to shy away from anything like apps I s'pose. Stick me in front of a computer, I'm happy enough, but get me to download an app and start usin' it, well I'm a beginner in all that." (P12, male, active, learner-expert).

One participant in particular thought that their previous lack of experience using technology potentially held them back from exploring the use of technology for PA, however having gained a positive experience in the study, they felt encouraged to explore other options:

"I mean my use of technology was very limited before. But I think that's been off putting… But I certainly think with the Seven minute workout one, because it was so simple to download and it was so clear and clean and easy to use, that's make me think well there are packages out there that are like this" (P4, female, inactive, novice-learner).

Participants who had some confidence in using technology knew where to go if they needed to troubleshoot a problem they were having. Many searched Google for solutions to their technology problems or to learn more about how to use the DBCI, resulting in them reading internet reviews and watching YouTube videos: *"I just googled it and it happened to be a YouTube clip, which is usually the way that… that's usually where I go if I, you know, if I', struggling with some I.T. stuff." (P3, female, active, learner-novice).*

6.3.3.5. Participants' future digital behaviour change intervention recommendations

Theme: It's got to be easy and convenient

Most participants felt a smartphone or tablet app would be the best form of technology to deliver a future digital PA intervention as it was something that most people owned already and would be, *"comfortable using" (P4, female, inactive, novice-learner)* as: *"most people are familiar with them, even if we are old and crusty" (P15, female, inactive, novice-learner)*. Some mentioned that the advantage of these was the portable nature of the smartphone or tablet, and that many people carried their phone with them most of the time. The ability to use a laptop or computer was also popular among participants, indicating that they felt that some older people were more likely to keep these updated, compared with the latest smartphone: *"chances are that the systems on the computer are quite modern and so it would probably connect more easily. Even to older computers, because basically the systems will still be Windows 10 or whatever the future is." (P9, male, active, novice-learner).* Some felt more confident using a laptop than a smartphone and were also keen to analyse their data, which they felt they could do better on a laptop. Others were aware that people older than themselves may not have smartphones, but many did have laptops and Wi-Fi: *"I know quite a few 70-year olds that have got laptops and Wi-Fi, like my neighbours, but they haven't got smartphones, they've just got the… simple, like, The Nokia phone that just makes phone calls and texts type thing" (P7, female, inactive, learner-expert).*

Screen size was very important and another reason that participants gave for preferring a laptop or computer. Those who were happy with a smartphone or tablet app mentioned they would like an option to screencast to their Smart TV (i.e. transmit the video on their phone/tablet to their TV): *"I would have preferred to have been able to cast it to my TV or laptop as found some of the detail on the screen quite small" (P7, female, inactive, learner-expert).*

Most participants felt being able to do PA without the need for specialist gym equipment was important to make it, *"accessible" (P3, female, active, learner-expert)* to most people. Also, participants were keen for it to have a short duration option because then they were more likely to be able to fit it into their busy lives: *"people are jolly busy. The 7 minutes is pretty jolly good because it's only 7 minutes!" (P15, female, inactive, novice-learner).*

Finally, most participants believed it was important that the DBCI was free/low cost to the end consumer, to make it accessible to more people because they, themselves, would be unwilling to pay for it: *"A lot of things on the Internet are free at the moment and err to pay for this, I'm not sure I'd be prepared to do that" (P9, male, active, novice-learner).* It was also important that there were no hidden charges, for example to unlock features at later stages, as one participant shared their discouraging experience of this: *"at which point you say 'well bollocks to that!' and just go back to Facebook" (P15, female, inactive, novice-learner).*

Theme: Feeling successful

Participants wanted to feel they were being *"successful" (P5, female, inactive, learner-expert)* so they were more likely to continue to use the DBCI to do PA. Many thought that the beginner stages should start extremely easy, potentially incorporating chair-based exercise, have several workouts at the same level for variety, and more stages between the difficulty levels:

> *"It would be really nice to have a number of different first timer options rather than just the one set of exercises because I feel, sometimes if you move up too quickly it can get too hard and that's demotivating. So, it would be nice if, you know, you had maybe 3 or 4 first timer of routines that you could do." (P4, female, inactive, novice-learner)*

The most important factor mentioned by most participants was wanting exercise adaptations for those who may struggle with traditional movements such as, *"a low-key version" (P14, female, inactive, novice-learner).* A few participants commented that people in the ≥50 years age range have a large variety of fitness levels, with many having ailments that could impact their physical capabilities: *"I mean there's a lot of variety of fitness levels of people 50+, you know, people who've picked up all sorts of different, erm, illnesses along the way and those who have had nothing at all" (P5, female, inactive, learner-expert)*. Participants were keen for adaptations for common ailments to be included:

> *"adaptations for anybody so you might be, you know, for people if they experience any kind of back pain, knee pain, hip pain, of those kinds of things, I think would be good… so I'm still getting the same benefit and working the same muscles" (P3, female, active, learner-expert).*

Some wanted to be able to set their own appropriate goals for their abilities and others wanted help with scheduling their PA into their day. Many participants liked being able to track their progress, reporting that seeing what they had done made them feel good about their PA. A couple of participants showed an interest in analysing that data in addition to the types of data collected by a fitness tracker. Lastly, the type of language used throughout the DCBI ought to be carefully considered to avoid inadvertently discouraging or demotivating participants:

> *"instead of calling something 'easy', I think that can be misleading, because I think if you're just starting out on this, and you're thinking, that can be quite disheartening if somebody said this is easy, and you're finding it really tricky… So for me it's saying thigs like 'novice', you know, erm… I think for me that would be, for somebody starting out 'yes I'm a novice, I'm inexperienced at this, but that's OK', whereas if it's 'easy' that kind of implies I'm not doing as well as I could." (P3, female, active, learner-expert).*

Theme: Variety is the spice of life - mixing up the physical activity

All participants felt that variety was key to the types of PA that should be included in a future DBCI. Using a combination of strength training, cardiovascular exercise, stretching and flexibility, and balance exercises would make them feel like they had, *"a proper workout" (P5, female, inactive, learner-expert).* The incorporation of yoga or Pilates movements was felt by some to be good, especially stretching and balance movements. Many also mentioned incorporating walking because, *"it's cheap, it's free, it's easy" (P14, female, inactive, novice-learner)*: *"I certainly think forms of walking, like fast walking, speed walking would be good" (P4, female, inactive, novice-learner).* Others described strength exercises in relation to body parts they felt they personally needed to focus on, particularly the, *"biceps and triceps" (P15, female, inactive, novice-learner)*, feet, neck and back, *"core exercises" (P4, female, inactive, novice-learner)* and *"leg muscles" (P14, female, inactive, novice-learner): "Another major one, which I've and a lot of people have got, is knee problems. So, and that one again is* *strengthening up those thigh muscles to hold the knees in place" (P11, female, inactive, learner-expert).*

Theme: I want to concentrate on me

Most participants wanted a DBCI for PA that focused on them. They were not, on the whole, interested in competition with others and many were reluctant to share or do their PA with others. Some, particularly female participants, thought that being able to connect with others for support with their PA would be a good idea, although were wary of this person being a stranger. Despite this, many, including those who thought it might be good, said that they would be unlikely to use this feature if it did exist because they preferred to do their PA alone and concentrate on themselves: *"Personally I wouldn't get any sort of particular kick out of doing that. Maybe some people do, but not really my thing. I tend, these things I tend to do my myself" (P9, male, active, novice-learner).*

Theme: Guidance and explanation from a trusted source

Participants wanted to be guided through exercises by an exercise professional who was able to perform the movements correctly and of a similar age to the target demographic, i.e., ≥50 years. Participants wanted clear demonstrations with simple instructions and explanations of specialist terminologies, such as, *"engage your core" (P13, female, inactive, learner-expert)* and explanations of the importance of the exercises for everyday life and health. They also wanted the option to see what these were just before they started so they could be informed of and understand exercised them:

> *"it would have been useful to see a list of what the exercises were going to be in advance and to be able to see how to do the new ones if I wasn't sure. Erm, or to be*

given the opportunity to see one in the gap between." (P14, female, inactive, novice-learner)

Theme: Getting the word out

When asked about how people would find out about a new DBCI if it was created, the most common response was social media, and Facebook in particular. Even those who did not use social media themselves suggested this. One participant said their partner was on social media and told them about anything that might be of interest to him, so did not need his own. Some thought that many vulnerable older people may not be on social media, so going through NHS services or local councils would be good if possible. Using the app stores, newspapers, local magazines and newsletters, advertising through community groups or venues could be valuable*: "I think there's still quite a bit to be said for the parish magazines and those sort of things" (P3, female, active, learner-expert).* One participant mentioned pairing with an ageing charity and another with businesses aimed at the target population: *"Saga would be a good place actually because it's aimed at over 50's" (P14, female, inactive, novice-learner).*

6.4. Discussion

The socially isolated older adults in the present study had a generally positive experience using the DBCI for PA, with many stating that they would consider using these DBCIs or something similar once the study had finished. The J&J app was the preferred DBCI, despite some of the exercises being too hard for many participants. The Runme Tracker had a mixed response. Participants who had some experience using wearable activity trackers prior to the study were more accepting of inaccuracies and used the data as an indication of their behaviours, whereas others with less experience found it frustrating and often resulting in despondency or apathy towards the tracker and its associated app. Across both DBCI, common themes of socially isolated older adults' experiences were related to motivation, assumptions of knowledge and capabilities in relation to the technology, PA and trust. Participants made recommendations about the design of a new DBCI for PA in this population based on these experiences.

Before trying the DBCIs, participants believed they would increase their awareness of, and provide motivation to, modify their PA behaviours. This is consistent with the literature as the two main reasons that are reported by older adults (≥50 years) for using mobile devices for PA (i.e. activity tracker, smartwatch, tablet or smartphone) (Seifert, et al., 2017). Older adults who used two commercially available activity trackers found the data recorded about their PA behaviours was useful for their understanding; data provided motivation to take control over their behaviours, with some increasing their PA and others realising they should slow down (Puri, et al., 2017). Indeed, many in the present study experienced changes in motivation. Sometimes this change was linked with their increased awareness of their PA behaviours due to tracking, which led to changes in their PA behaviours. For instance, when participants noticed their step count was not very high at lunchtime, this motivated them to go out for a walk later that afternoon. Some participants found this motivating in a positive way, using terminology such as "satisfying" and "energised", whereas others mentioned feeling “ashamed” and “guilty”. Negative emotions also provided motivation to modify their PA behaviours – mostly increasing their step count. Feeling guilted into increasing ones step count was similarly experienced by older adults (aged 71.1 ± 5.2 years) who were doing far fewer steps than they expected using the STARFISH app; they felt the need to increase their steps later in the day to meet or get closer to their daily step goal (Paul, et al., 2017). At the beginning of the present study, participants were concerned about the potential for them and others to become driven and obsessed by the numbers and technology rather than how their body was feeling. Their experiences having used the DBCIs highlight that many were indeed driven by numbers, particularly produced by the tracker, and for some this led to an increase in PA, which for most was a positive outcome. However, quantifying positive health behaviours, such as PA, can also act as a reconciliation device, and has the potential to provide justification for users to engage in unhealthy health behaviours (Lupton, 2016). For instance, in the present study, one very active participant mentioned that in having met the 10,000 steps for the day, they were more inclined to be sedentary in the evening rather than go for their usual evening walk. In addition, several participants mentioned that having done their workout using the J&J app, they felt they had earned a more relaxed remainder of the day. Thus the DBCI prompted, and accidently fostered, contradictory health behaviours and moralities to co-exist (Phoenix and Orr, 2017). This is important to consider in the development of future DBCI for PA and should be minimised. For instance, if an individual is consistently hitting or overachieving their goals, having the DBCI suggest the goal is revisited and could guide the user to set a new, more appropriate, goal.

DBCI users who were ready and willing to change their behaviours targeted in the intervention were more likely to perceive the DBCI as beneficial. In the present study, participants who indicated higher levels of motivation to increase their PA, although no objective measure was taken, were more likely to discuss that the DBCI had a positive impact on their PA. However, other participants, who seemed more accepting of their current PA levels, did not feel the DBCI impacted their PA. Some essentially monitored what they were doing already, and others who were already active swapped out part of their usual PA routine to incorporate the DBCI. This is consistent with findings from Mercer, et al. (2016), who found that older adults with chronic illness (mean age 64 years) who wanted to make lifestyle changes – e.g. increase their PA – were more likely to comment that a wearable device was useful for increasing their awareness of their behaviours and provided motivation to change. Similarly, older adults (≥65 years) who already had established PA routines found that wearing an activity monitor had no effect on their PA habits because the tracker did not add to their experience or provide the main source of motivation to do PA; they just maintained their usual routine regardless of the tracker's affordances (Ehn, et al., 2018, Kononova, et al., 2018). In addition, older adults (≥65 years) who were confident in their knowledge about their current health status found the data produced by activity trackers interesting, but not necessarily useful; the tracker did not add value to them (Puri, et al., 2017). Perhaps those in the present study, who felt the DBCI were of less value, did so because they were content with their current PA levels, and did not perceive a need for change. Additionally, they may have already had sufficient understanding of their health and PA routines. Therefore, a target populations' understanding of their health and PA behaviours should be considered in addition to their willingness to change their behaviours in the design of future DBCIs.

In the literature, time, convenience, and cost were often reported by older adults as barriers to PA (Bethancourt, et al., 2014, Kelly, et al., 2016, Sims-Gould, et al., 2012, Belza, et al., 2004, Moschny, et al., 2011). Participants in this study were motivated to use the J&J app, and even did so on days when they were less motivated, because it was used for a short period of time and so could be easily incorporated into their schedules without feeling they were sacrificing too much or something else. It appears that these potential barriers were overcome by the J&J app, and this made it easier for participants to engage in the PA. In addition, participants who liked that the J&J workout did not require specialist gym equipment felt it made PA accessible and convenient for more people. Home-based exercise programmes, like the ones in the J&J app, have shown comparable outcomes at 3-, 6- and

12-month follow-ups with a class-based programme in older adults (≥50 years) with chronic health conditions in terms of adherence, level of PA and health outcomes (Fisher, et al., 2018). In addition, Brawley, Rejeski and King (2003) have suggested that balancing the duration per exercise session and frequency of sessions in older adults with chronic conditions is important for sustainability and managing potential adverse effects, such as pain or fatigue. Therefore, future PA intervention designers for socially isolated older adults who are more likely to live with a chronic condition (see chapter four), should consider home-based, short-duration activities, not only for convenience but also to promote sustainable adherence.

Enjoyment of PA is extensively reported in the literature as being an important facilitator of PA in older adults (Kelly, et al., 2016, Buman, Daphna Yasova and Giacobbi, 2010). It has been reported that home-based PA interventions can lack variety, compared with class-based PA, which older adults find boring (Stathi, Mckenna and Fox, 2010). However, participants in the present study who explored the different workouts in the J&J app enjoyed the variety available and believed this would reduce the chance of becoming bored with it. Participants suggested various PA preferences for inclusion in the design of a new DBCI for socially isolated older adults including using a mixture of types of PA (e.g. muscle strengthening endurance, flexibility and balance exercises), concentrating PA on certain areas of the body, and variation in the routines included.

Social support has previously been found to be a crucial motivator for longer-term activity monitoring in older adults. Longer-term users tended to seek accountability from others, engage in competition, cooperation and collaboration with other users (Kononova, et al., 2018). A study that used an app that incorporated a group element (which allowed older adults in the same group to see each other's progress towards their daily step goal) was liked as it introduced an element of competition and social comparison that encouraged them to increase their own (Paul, et al., 2017). However, in relation to social features in the design of a new DBCI for PA in this population, most participants in the present study demonstrated what

Davison (1983) calls a third-person effect: they thought that social features would be motivational and used by others *"but it's not for me" (P9)*. Consistent with findings from the present study, the results from chapter five suggest socially isolated older adults tend not to want social support in the same way as others in relation to their PA, meaning social support would not motivate them to modify their behaviours. Therefore, the incorporation of social features in the design of a DBCI for PA for socially isolated older adults is not suggested as an essential requirement and may even be off-putting for some.

Assumptions that are made by the creators of a DBCI can make-or-break the user experience, significantly impacting the DBCI influence on behaviours. In the present study participants felt there was an assumption of exercise knowledge and basic fitness that most did not have. This led to them feeling despondent about themselves and their capabilities. This suggests that participants lacked the physical and psychological capability assumed by the DBCI developers. It is important to note that the J&J app was a general workout app, and not one specifically designed with older adults in mind, but it was selected by the PPI group over the '10 today' DBCI that was specifically designed for older adults although from the PPI feedback it is unclear why. This suggests a potential for dissonance between older adults self-perceived capabilities and their actual capabilities, which then impacts confidence. Using the BCTs relating to feedback and monitoring may be helpful for addressing this.

Brawley, Rejeski and King (2003) suggest that due to the diverse range of individual needs that older adults have, including short-term and chronic illness, there is a greater need to tailor PA programmes for each individual's needs. Tailored PA interventions are intended for a particular person rather than a group of people and are based on individual-level factors related to PA or associated health outcomes (Kreuter and Skinner, 2000). The J&J app was 'targeted' rather than 'tailored' as participants were able to select their intervention based on their level of fitness and 'personalise' it by excluding exercises they did not want. Those who did explore these options enjoyed using them. For instance, the thumbs up/down and smart workout feature – when the technology worked, were used by participants. Older adults have previously noted that the benefit of a home-based exercise programme allowed them to tailor the exercises to their personal capabilities, needs and goals when compared with group-based interventions (Mehra, et al., 2016, Zubala, et al., 2017). DBCI have considerable capacity to deliver and individually modify interventions that can be programmed to provide automated, behaviourally and contextually tailored information throughout the day and across a variety of settings (Forberger, et al., 2017, King, et al., 2013). Participants in the present study were also keen for a future DBCI for PA to make them feel successful, which would be more likely to happen if they were using a programme specifically designed for their capabilities and needs. Therefore, future DBCI for PA in socially isolated older adults should aim to tailor the intervention to an individual as much as possible, rather than target the whole population. One way to do so could be to utilise tools such as the Senior Fitness Test (Rikli, 1999), whereby participants are assessed on their muscular strength, endurance, agility and balance, after which an appropriate intervention to be designed for them. The DCBI could use the exercises from the Senior Fitness Test that users could do at home without specialist equipment and would then enter their scores. Based on these a tailored selection of PA activities or exercises could be selected in line with their actual physical capabilities and needs. This also offers the opportunity for re-testing to monitor progress.

Participants were wary of not being able to understand the technology prior to the use of the DBCIs, perhaps rightly so. Participants who found using the technology more challenging felt there was an assumption that the user would either already know how to use it, or that it was intuitive enough that they should be able to work it out. Therefore, when they encountered problems with the technology that they could not find a solution to, this led to participants feeling *"ignorant" (P3, female, active, learner-expert)*. This was also experienced in a previous study by older adults (52-84 years) with chronic illness who felt uncomfortable using activity trackers because despite them being 'intuitive' to use, many were unfamiliar with the language they used (e.g. "link with Bluetooth" or "active time") and with 'troubleshooting' any problems they had, so they felt the difficulties they faced were a personal failing (Mercer, et al., 2016). Others have found that differences between older and younger technology use was often not due to actual knowledge, but rather confidence, with older adults tending to underestimate their knowledge and abilities (Mitzner, et al., 2010). Indeed, older adults (≥ 65 years) taking part in a study using activity trackers, often referred to themselves as ‘laggards’ and ‘luddites’, meaning they did not believe they were technologically savvy (Kononova, et al., 2018). In addition, older adults are often unaware of how much they used technology; when observed, they used technology for many more things than they self-reported (Mercer, et al., 2016). Therefore, DBCIs for socially isolated older adults should aim to make users feel confident about using them.

One way to do this would be to provide detailed and accessible instructions on how to use the DBCIs. Participants in the present study commented that they would have liked more guidance on how best to use the DBCIs and to see the different features before using them, either on paper or via a YouTube video. Older adults (≥ 50 years) who used non-commercially available PA apps (STARFISH or VITAMIN) or a consumer wrist-worn activity tracker, expressed that they would have benefited from more extensive instructions prior to using the DBCI (Paul, et al., 2017, Mehra, et al., 2019, Mercer, et al., 2016). In the present study, most participants mentioned that the “tiny” instruction manual that came with the tracker was unreadable, whilst those who could read it stated that it did not contain much useful information. The same has been found in previous studies using activity trackers in older adults (aged 65+) (Kononova, et al., 2018). Older adults (≥65 years) using consumer activity monitors grew frustrated with the technology when they could not figure a problem out and would give up on it (Puri, et al., 2017). In the present study, some participants were more resilient with troubleshooting than others, and although those with more experience of technology seemed more efficient with troubleshooting, giving up on the technology was not necessarily linked with their prior experience. Older adults have been shown to become more confident and comfortable with mHealth devices the longer they actively use them (Spann and Stewart, 2018). Therefore, perhaps those who did have some experience using DBCI for PA prior to the study did not have them for long before the study, or were not 'actively' using them before, so were less confident and comfortable with these new DBCIs than they expected to be. This may have led to feelings of personal failure, as mentioned above, which, depending on their desire to change their PA behaviours, led either to resilient troubleshooting or abandonment of the DBCI. Those who used the DBCI minimally in the study *(i.e. "Well I slapped it round my wrist and then ignored it basically." P15, female, inactive, novice-learner)* would likely have abandoned the DBCI in the real world. Therefore, future DBCIs for socially isolated older adults require much more detailed paper-based or website instruction manuals and videos, that clearly show the set up process, how to use different features of the DBCI, and basic troubleshooting. This is likely to increase older socially isolated adults' confidence and competence with the technology, allowing their primary focus to be on their PA behaviours.

In the present study many socially isolated older adults, particularly those with no prior experience of using an activity tracker, were unsure of how best to use the information gathered by the activity tracker, other than to increase their steps to achieve a goal. Younger users of activity trackers (most aged 20-49 years) have found the data presented by their tracker was meaningful and useful for their PA goals, for instance using heart rate zones when exercising (Pingo and Narayan, 2019). These users typically had Fitbit branded devices which they report presented the data in a simple way, not requiring extra interpretation (Pingo and Narayan, 2019). Despite the Runme Tracker having very similar features to a Fitbit branded device at a fraction of the cost, the associated apps are very different, the Fitbit app helps the user interpret their data, often showing averages for people of a similar age, and explains why certain metrics are important to a user's health. However, the VeryFit Pro app presents the data without additional contextual explanations. It appears from the present study that without a clear purpose for needing the data, or pre-existing user data literacy – the skills and knowledge to be able to transform data into meaningful information and/or action (Koltay, 2015, Wigmore, 2015) – data provided by activity trackers can be meaningless to socially isolated older adults. One experienced activity tracker user in the present study commented, prior to using the two DBCI in this study, that they monitor their resting heart rate using their own activity tracker and if it increased, they increase their PA. This indicates a level of data literacy that participants without prior experience of activity tracking did not have. Therefore, future DBCIs for PA that incorporate data for monitoring should make clear to the users what the data shows, how it compares to government/medical guidelines and what it means for their health and behaviours.

Participants were distrusting of the accuracy of wearable activity trackers prior to the study. This was either because they had experience of inconsistency when comparing their own tracker data with others, or because they believed that not all steps were equal (i.e. 100 steps on flat concrete vs. 100 steps uphill on uneven ground) and they were sceptical that the tracker would be sophisticated enough to detect differences. Interestingly, regardless of previous experience with activity monitoring devices, either wearable or app based, participants 'tested' the accuracy of the Runme tracker device. This suggests not only are these socially isolated older adults more technologically and data literate than they may realise, but do not trust new technology, at least initially. Those with no previous experience using a PA monitoring device were more likely to resort to non-digital comparisons such as counting their steps aloud or manually taking a pulse reading. Participants with their own activity tracking devices compared the DBCI with technology they already had, so presumably they trusted their familiar technology more than the Runme device. Younger activity tracker users (most aged 20-49 years) also found their devices to be inaccurate, but tended to use them as an indicator rather than a definitive metric (Pingo and Narayan, 2019). Some even used multiple tracking devices simultaneously (e.g. a Fitbit and Apple Watch) to complement and compensate for inaccuracies, allowing them to make better informed decisions about their behaviours (Pingo and Narayan, 2019). A qualitative review found that older adults (inclusion criteria: mean age ≥60 years) need mHealth technology and the designers of the technology to be reliable and to work as expected (Spann and Stewart, 2018). It is unsurprising then that older adults (≥75 years) were disappointed when their activity tracker failed to work as expected (Ehn, et al., 2018). Many in the present study were disappointed by the inaccuracy of the tracker, however the reaction to this disappointment and frustration varied among participants. Some were more accepting that it was not a perfect measure but felt it gave a satisfactory indication of their movement behaviours. Interestingly, these participants tended to be those who had some experience of using fitness trackers before the study. Conversely, those with less experience were either more negative or apathetic towards the tracker, leading some to distrust the tracker and others to feel personally cheated. Similarly, a previous study also found older adults (≥65 years) who had no previous experience of using activity trackers found the tracker inaccuracies, particularly step count, and the technology's inability to automatically detect PA, frustrating and disappointing (Kononova, et al., 2018). Perhaps a lack of understanding of the capabilities of the device may lead to inflated expectations, which when not met, inevitably leads to disappointment and distrust.

Participants liked and trusted the exercise demonstrations from the exercise professional on the J&J app. Professional and tailored guidance, and ongoing support was found to improve participation in PA in older adults (Zubala, et al., 2017). This 'human expert' element of the J&J app may have made the app appear instantly more trustworthy, whereas the tracker without a 'human' or 'expert' elements required more time for users to trust. Perhaps the J&J app being delivered on a smartphone or tablet that participants already owned and were familiar with made it easier to trust the DBCI, whereas those new to tracker technology treated it with caution. A qualitative review of older adults' mHealth use found that older adults want easy to use systems that did not require much time to use or learn (Spann and Stewart, 2018). Older adults were more likely to adopt technology if it was seen to add value to living an independent life, was easy to use and affordable, if it fitted in with their current lifestyle, if they felt confident using technology and if the technology was reliable and trustworthy (Lee, 2014). Therefore, utilising technology that older adults had already – smartphones, tablets, laptops, smart TVs – would allow for the DBCI to be delivered in a familiar way, potentially overcoming some technological problems and user distrust related to engaging with new technology.

6.4.1. Strengths and limitations

This is the first study to explore socially isolated older adults' experiences of using DBCI for PA. Participants used each intervention for a very short period, only 1 week each, which for the purpose of informing the initial stages of a new DBCI design was sufficient; however, how the experiences evolve and change over long-term use is unknown. An unexpected benefit of the study taking place during the COVID-19 pandemic was that, because the use of the term 'social isolation' was often confused with 'social distancing' by the public, potentially more volunteers came forward to take part in the study than would have otherwise in an effort to help the pandemic research effort, despite this study not being COVID-19 related, hence the large number of volunteers who did not meet the social isolation criteria. The additional time afforded by the lockdowns as 'normal' routines were disrupted, may have also increased the number of people that could volunteer. Finally, the two DBCIs selected by the PPI group were very different, as there were many features that appeared on one that did not appear on the other. This allowed participants to experience a broader range of PA than what would have been available to them otherwise, and a provided a good foundation on which to build future DBCI design recommendations.

There is a potential, however, that by providing participants with these experiences they became fixated on improving the two chosen DBCI rather than having more creative freedom to make suggestions about a future, independent, DBCI. Another limitation was that the researcher did not own or control the DBCI used, therefore had no input as to when and how the apps were updated. The decision to use the J&J app was made on version 2.8.0 (updated 30th October 2018). Participants 1-9 used versions 2.8.1 (updated 26th December 2019), participants 10-14 used version 2.8.2 (updated 18th May 2020), and participant 15 used version 2.8.3 (updated 25th June 2020). It is unclear what specific changes had been made, as the developers only provide a blanket statement that “This update includes bug fixes and app performance improvements”. Therefore, although it is assumed that as all users will have had the same app to use because they were all version 2.8. and when checked by the research team they, all appeared to look the same and had the same content, it is not possible to guarantee that this was the case.

The sample size, though typical of this type of study, was small, and all participants were of White ethnic background, which may limit the generalisability of these findings to other groups. Representative sampling was not attempted in the present study but should be considered in future studies investigating socially isolated older adults. This study began just before the COVID-19 lockdown occurred in the UK in March 2020, and participants’ usual lifestyles and PA routines were likely to have been disrupted (Hossain, Sultana and Purohit, 2020). It is likely that the socially isolated older adults in the present study were more active than the population average, but the closure of sport and leisure facilities, restricted movement and for some ‘shielding’ meant the participants were not only looking for something to do, but also be able to remain active during these times.

6.5. Conclusion

This is the first study to explore socially isolated older adult's preconceptions and experiences of using DBCI for PA. This population generally had a positive experience using DBCI for PA with many intending to either continue to use the ones used in the study or explore alternative options. Participants found the DBCI motivating and felt they encouraged them to engage in PA. They also felt, however, that the DBCI designers made assumptions about the physical and psychological capabilities of their users, in relation to both PA and technology use, that were beyond their own capabilities. In addition, participants seemed more trusting of the J&J app featuring a human exercise professional than they were of the tracker and app. On the basis of the evidence presented in this study, it is recommended that future DBCI for PA for socially isolated older adults should: (1) offer a more tailored experience based on an individual's PA, technology capabilities and data literacy; (2) utilise and develop technology already owned by and familiar to users; (3) incorporate a human element to build trust in the DBCI.

CHAPTER 7: DISCUSSION

The aim of the PhD was to use the MRC guidance on developing and evaluating complex interventions, in combination with the BCW, to make recommendations for the design of a DBCI for PA and/or SB in socially isolated older adults. In this discussion, findings from the four main chapters will be summarised in relation to the aims of each individual chapter and the contribution they make to the overall aim of the thesis. Consideration is also given to the existing literature on user engagement. Informed by the findings in this thesis, an example DBCI to target PA and/or SB in socially isolated older adults is described. Due to this thesis being completed during the COVID-19 pandemic, additional thought is given to the impact the pandemic has had, and how the findings in this thesis are potentially even more relevant during these times. Finally, recommendations for future research are made, with reference to completing the remaining stages of the MRC guidance for intervention development.

7.1. Chapter 3 – Systematic review and meta-analysis

As the use of DBCI in socially isolated older adults had yet to be investigated, the aim of this chapter was to gain knowledge and understanding of what DBCI have previously been used in older adults. This included exploring the psychological underpinnings and BCTs used in DBCI, their effects on PA and/or SB, and their effects on any physical or mental health, or social outcomes.

The systematic review and meta-analysis presented in chapter 3 found that DBCI were effective for increasing total PA and also MVPA by 52 min/week in older adults (≥ 50 years), which represents 35% of the government 150 min/week recommendation for PA (Department for Health and Social Care, 2019). The DBCI were also effective in reducing sedentary time by 58 min/day. Although current guidelines suggest minimising sedentary time and breaking up longer periods with light activity (Department for Health and Social Care, 2019), and assuming that older adults (≥ 50 years) are asleep for the recommended 8 hours per day – 50-64 years = 7-9 hours; ≥ 65 years 7-8 hours (Hirshkowitz, et al., 2015) – this reduction in sedentary time represents 6% of a waking day. As PA and SB behaviours are connected (Mansoubi, et al., 2014, Saunders, et al., 2020), and the results of the systematic review show no clear evidence otherwise, it is deemed possible for a future DBCI to target both PA and SB simultaneously. Indeed, a systematic review of smartphone apps and wearable interventions to promote PA in adults showed that multi-component interventions demonstrated significant improvements in behavioural and health outcomes (Schoeppe, et al., 2016). However, evidence was lacking that the improvements in PA were maintained long term, thus future DBCI should carefully consider maintenance in the design process and long-term studies.

The systematic review also highlighted that DBCI targeting PA/SB in older adults had the potential to reduce SBP by 11bpm and improve physical functioning (e.g. balance, stamina, strength, coordination). Mobile phones now include a multitude of sensors (e.g. accelerometry, GPS, gyroscope, using the camera and flash to measure heart rate) that increases the opportunity to utilise health informatics in DBCI (Hekler, et al., 2011). These additional benefits could be used without the need to specialist equipment and monitored over time to provide additional motivation, this should therefore be considered in the design and promotion of the DBCI.

Findings of the present review regarding BCT inclusion were in line with previous literature. Therefore a minimum of three BCT clusters (McEwan, et al., 2018) should be used in future DBCI for PA/SB in older adults, and it is recommended that social support, goal setting, feedback on behaviour and self-monitoring are considered for inclusion in the design (Roberts, et al., 2017, Muellmann, et al., 2017) to increase efficacy of the DBCI.

7.2. Chapter 4 – Internet use, social isolation and loneliness in older adults

The aim of this analysis was to explore associations between internet/email use in a large sample of older English adults with their social isolation and loneliness. Loneliness is often reported alongside social isolation, and they are strongly correlated in the literature (Petersen, et al., 2016a, Steptoe, et al., 2013b, Cornwell and Waite, 2009a, Shankar, et al., 2011), therefore both social isolation and loneliness were explored. In addition, as there were no data available on socially isolated older adults' use of technology, a secondary aim was to better understand the demographic characteristics of socially isolated older adults and their current use of technology.

The regression analysis found no association between internet/email use and loneliness; however, once a week and once a month users were less likely to be socially isolated than every day users. Socially isolated older adults in England were more likely to be older, male, unmarried, in a lower SES quintile and have depression when compared with their non-isolated peers. A greater proportion were likely to have longstanding limiting illnesses and be inactive compared with their non-isolated peers. These findings were consistent with previous literature.

In 2019, 93.2% of 55-64 year olds, 83.2% of 65-74 year olds and 46.8% of over 75 year olds were recent internet users in the UK (Office for National Statistics, 2019); however, data specifically for socially isolated older adults was lacking. Chapter 4 addressed this and found that over two thirds of socially isolated older adults used the internet or email at least once a week, with 60% using it daily, and they were more likely to use a laptop to access the internet/email than any other device. Therefore, the use of DBCI is appropriate in this population and consideration should be given to the use of technologies already owned and used by socially isolated older adults.

7.3. Chapter 5 – Exploring the barriers and facilitators of physical activity in socially isolated older adults

Barriers to and facilitators of PA have been explored and reported in the literature, however, not among socially isolated older adults. Therefore the aim of chapter 5 was to complete a needs assessment for PA among socially isolated older adults based on COM-B, the model at the core of the BCW (Michie, Atkins and West, 2014), to identify the barriers and facilitators for PA in this population. This approach enabled the identification of appropriate intervention functions and BCTs for a DBCI for PA in this population.

Chapter 5 highlighted that socially isolated older adults tended to prefer small group or individual PA, although some were keen for support from a key contact whether that be a spouse, friend, or exercise professional. This differed from the literature for the wider population of older adults, for whom group exercise was often the preferred form of PA because it provided a sense of community, fostered friendships, provided competition and motivation to attend (Stathi, Mckenna and Fox, 2010, Mehra, et al., 2016, McGowan, et al., 2018). Therefore, a DBCI for socially isolated older adults should consider individual use, or small group use, as this is more likely to be engaged with in this population.

Participants were aware of ageing related physical declines and previous trauma/injuries that could make certain PA difficult; additionally, they tended to prefer less strenuous PA. A future DBCI should consider including low-to-moderate PA in socially isolated older adults. Participants also preferred to do PA locally, either from their home or inside their home as it is more convenient, and they are less likely to feel judged by others as some did in larger group PA. Therefore, a DBCI that could be used in the home or from home without the need for other people would be ideal for this population. Fun and enjoyment and believing that PA had positive mental and physical health benefits, were commonly mentioned among socially isolated older adults as motivations to engage in PA. Future DBCI should consider highlighting these benefits to users, and where possible make the intervention fun and enjoyable, as these are likely to encourage users to engage with the DBCI more frequently.

Intervention functions that were selected as appropriate based on the needs assessment included education, training, environmental restructuring, modelling, enablement. BCTs included: 2.2 Feedback on behaviour; 2.3 Self-monitoring of behaviour; 2.7 Feedback on outcome(s) of behaviour; 6.1 Demonstration of the behaviour; 7.1 Prompts/cues; and 12.5 Adding objects into the environment. The intervention functions and BCTs should be considered for incorporation into a future DBCI for PA/SB in socially isolated older adults to increase the likelihood of the DBCI being effective.

7.4. Chapter 6 – Exploring socially isolated older adults' experiences of using two commercially available digital behaviour change interventions for physical activity

The aim of chapter 6 was to explore and gather socially isolated older adults' experiences of using two DBCI for PA/SB, and their ideas regarding future DBCIs, to inform the design recommendations for a new DBCI for PA specifically for this population.

Socially isolated older adults were more technologically able than they realised and were open to using DBCI for PA. Participants appreciated short duration exercises which did not require equipment and which they could do at home. However, they felt the exercises offered by the DBCI which featured a workout were too hard. The participants recommended that the PA should be of a lower intensity, with more progression levels, and with adaptable exercises to be inclusive of a wider range of abilities. Therefore, a future DBCI should utilise the short duration home-based exercise that does not require equipment but should better tailor the exercise difficulty to socially isolated older adults, including the use of graded tasks (BCT 8.7). For a new DBCI, participants preferred a mixture of different PA so that they did not become bored with it, mentioning that they wanted to concentrate on elements related to functional fitness – e.g., balance, strength, stamina, flexibility. A future DBCI should consider creating multiple programmes focused on these elements to cater for individuals' differing needs and to increase the likelihood of the DBCI being used long term.

Participants also wanted the ability to better tailor the exercises to their own individual needs and goals. It is important that socially isolated older adults feel they are being successful when using a future DBCI as they find this motivational. Therefore, future DBCI should consider integrating an initial assessment to either highlight to users what their individual needs might be and/or incorporate goal setting (BCT cluster 1 goals and planning) so that when these goals are achieved, participants feel successful.

Participants felt there was an assumption by the designers of the J&J app that users had exercise terminology knowledge. In addition, participants were not equipped to be able to interpret the data presented by the tracker. Thus, a future DBCI should provide guidance on how to interpret any data that is presented (BCT cluster 2 – feedback and monitoring) and consider linking this data to health outcomes (BCT cluster 5 – natural consequences) to make the data relevant to users.

Socially isolated older adults were, to some extent, distrusting of the technology, particularly as regards its accuracy. For some imperfect measurement was accepted and the feedback was used as a guide. For others, however, it became more personal and discouraging. Participants seemed more trusting of the J&J app that included an exercise professional, than the tracker. They liked the idea of a future intervention having an exercise professional who can explain phrases like 'engage your core', guide them through a programme, and who can provide the individual tailoring they want. Therefore, the inclusion of a credible source (BCT 9.1) who can provide instruction (BCT 4.1) and demonstration (BCT 6.1) of the behaviours may be important in future DBCI for socially isolated older adults would potentially encourage users to trust in the DBCI.

The type of technology used was also important, with most participants believing a delivery by smartphone was acceptable, although they would have liked the option to view instructional material on a larger screen, either a laptop/computer or to screencast to a smart TV. Participants also wanted more guidance on how to use the technology, particularly if it was something new to them. They mentioned it would be more convenient if the technology used was already owned by socially isolated older adults, as they were likely to be more confident using it and would not incur extra financial outlay. Therefore, future DBCI for socially isolated older adults should consider using smartphones and/or laptop/computers, incorporating screen casting capabilities where appropriate.

7.5. Digital behaviour change intervention engagement

Engagement with DBCI within behaviour science traditionally focuses on ‘engagement as usage’ (Ritterband, et al., 2009) – e.g. frequency, duration and use of specific content features (Danaher, et al., 2006, Couper, et al., 2010); however, within technology literature engagement is seen as the subjective experience of ‘flow’, enjoyment and attention (O'Brien and Toms, 2008). Therefore, deciding on how to ‘measure’ engagement may be important in the design of a new DBCI, particularly when applying for funding to show returns on investment. Engagement is likely to be greater when the DBCI has the option for personalisation, makes the user feel in control and has professional support features (e.g. link to contact clinician) (Perski, et al., 2017), which the participants in chapter six mentioned. Therefore, it is worth considering incorporating these options where possible into the design of new DBCIs. Particular BCTs have also been associated with increased engagement with DBCIs: feedback, goal setting, reminders, self-monitoring and social support features (Perski, et al., 2017); four of which were recommended for inclusion in the findings of the systematic review in chapter three. Lastly, it should be remembered that sustained engagement is not always needed, rather the focus should be about effective engagement, therefore defining what ‘effective’ engagement would look like when designing DBCI is important to its success (Michie, et al., 2017). For instance, taking the Couch to 5K app as an example, this is supposed to be used three times per week for 30 minutes (approx.) each time. Once a user has completed the programme and is running 5K regularly, there is likely to be no need for them to continue to use the app. If their goal changes to be able to run 10K, the Couch to 5K app would not be of use. However, this would constitute effective engagement.

7.6. An example design for a digital behaviour change intervention for physical activity in socially isolated older adults

Using the knowledge gained from chapters 3 to 6, an example of a DBCI for PA in socially isolated older adults is presented here. This example takes the form of a web-based app that would be accessible on a smartphone, tablet, or laptop/computer (chapters 4 and 6). It would have screen-casting capability once the exercise programme began. This allows those wanting to see it on a bigger screen to do so, and for those who wish to draw on the data to do so readily (chapters four and six). The app could be used at home (chapter 5) or another location where they can access the internet. This app would be similar to the J&J app in that it would provide exercise instructions and video demonstrations to follow. The exercise period would be of a short duration (chapter 6). However, there would be some key differences that make it more appropriate to socially isolated older adults. These features are based on the findings from the studies included in this thesis and they are discussed in detail below.

Once downloaded, the user – a socially isolated older adult - would create an account, so that they could access their profile across multiple devices. Their profile would hold demographic information such as their sex and age, anthropometric measures such as height, weight, and waist circumference, and their current PA assessed via questionnaire. The user would be invited to input this information to the profile, it would be communicated to users that this information helps with the design of their tailored programme (a recommendation from chapter 6), but this data input would be optional as chapter six showed that some socially isolated older adults have privacy concerns regarding sharing personal information.

Before completing any PA, users would be required to complete a PAR-Q to ensure they were safe to engage in PA. Users would then be asked to complete an initial assessment so that an appropriate programme could be designed for them. However, this initial assessment would be optional as some participants in chapter 6 highlighted privacy concerns. This initial assessment would ask users to follow along and complete tasks found in the Senior Fitness Test that could be completed at home (Rikli, 1999) or the Functional Fitness MOT (de Jong, et al., 2018), entering their scores after each task. These tasks could include, but are not limited to:

- Chair stand test - counting the number of sit-to-stand transitions they can do in 30 seconds
- 2-minute step in place test – counting the number of steps on the spot they can do in 2 minutes
- Single leg stance – balancing on one leg for 30 seconds

Tasks that involve the assistance of another person (e.g. spouse/friend).

- Back scratch test – in a standing position, one hand reaches behind the head and down the back towards the floor, the other reaches behind the back and up towards the head. Try to touch both hands together. The gap between their hands would then need to be measured by someone else.
- Chair sit and reach – sitting in a chair with both feet flat on the floor. Extend one leg at the knee holding the ankle at 90^{o} and, keeping a straight back, reach forward towards their toes. The gap between their fingertip and their toes would then need to be measured by someone else.

The results from these tasks, combined with age and sex information, could then be used to provide information regarding the areas that require improvement and those that require maintenance, based on average tables (Rikli, 1999). This will also identify the difficulty level that is most appropriate for the user. Users' results would be available for the them to see and they could re-take the test at any point to see if they have made any progress or have achieved maintenance – this is in-line with BCTs 2.4 self-monitoring of outcome(s) of behaviour and 2.7 feedback on the outcome(s) of behaviour (chapter 3 and 6). In addition, participants would be able to set goals either in relation to the assessment (e.g. improve or maintain certain scores on the assessment), the number of sessions they complete per week/ days used per week, or set their own goal(s) – connected to BCTs 1.1 goal setting behaviour and 1.3 goal setting outcome (chapters 3 and 5). These goals could be reviewed at any point, although users would be prompted once a month to review their goals and make changes if required – BCTs 1.5 review behaviour goal(s), 1.6 discrepancy between current behaviour and goal, and 1.7 review outcome goal(s). Guidance should be provided to support users to set appropriate goals; for instance, if a participant wanted to improve their score for the number of sit-to-stand transitions, the app would suggest increasing by one or two to make the goal realistic and achievable. Participants would be able to use reminders within the app to remind them to complete their session(s) or could choose not to use this function – BCT 7.1 prompts/cues.

The exercises, selected with help from an exercise professional or physiotherapist to ensure suitability and appropriate progression, should be entered into the 'library'. The exercises should be bodyweight-focused without equipment, except potentially the use of a chair or step, and the whole activity should be of a short duration, for example (recommended in chapter 6), for example 5 – 10 minutes, which is similar to the J&J app. A mixture of strength, flexibility and cardiovascular exercises and multiple difficulty levels would be available (as recommended in chapter 6). Each exercise would be performed and recorded by an exercise professional to provide a credible source (BCT 9.1) that the users could trust (an important consideration reported in chapter 5), and to provide instruction and demonstrations of the exercises – BCTs 4.1 and 6.1 (chapter 6). Using calf raises as an example, these could be completed seated, standing with one leg at a time, standing holding onto a chair, standing without balance assistance, standing on a step, and either both legs at the same time or one leg at a time to create more stages of the same exercise – BCT 8.7 graded tasks (chapter 6). Users should also have the option to have motivational comments (phrases such as 'you're doing great'), on or off to provide encouragement directed at the PA behaviour if they would like motivational support– BCT 3.1. social support unspecified (reported in chapter 3).

Each exercise would be filmed separately so that a range of exercises could be 'knitted' together to create a coherent programme. An algorithm (which would need to be designed for this purpose) would do this utilising the scores from the initial assessment and reported PA level to select appropriate exercises. Participants would be able to select from tailored programmes that have the option of focusing on upper, lower, core or whole-body exercises, or to work on strength, stamina, balance and flexibility, or a complete a full workout (chapter 6). Exercises would appear on the screen in a random order each time but would consist of the appropriate level of exercise for the individual, to minimise boredom when used long term (chapter 6).

7.7. The importance of the work in this thesis in relation to the COVID-19 pandemic

The studies in chapters 5 and 6 were conducted during the COVID-19 pandemic UK lockdown. During this time many countries in the world introduced social distancing measures, wearing face coverings and lockdowns to reduce the rate of transmission of the virus. Older adults and people with certain medical conditions were advised to 'shield' for much of 2020, meaning people in this group may not have left their homes for months at a time (Public Health England and Department of Health and Social Care, 2020). As seen in chapter 4, socially isolated older adults were more likely to have longstanding limiting conditions than their non-isolated peers, which may have required them to 'shield' during the pandemic. In addition, older adults who were previously not isolated but had medical conditions that required them to physically distance themselves from others, may have led them to become isolated during this time (Smith, Steinman and Casey, 2020).

In chapters 5 and 6, 12 of the 15 participants' data were collected during the pandemic and when asked whether their contact with relatives or friends had changed because of the pandemic the results varied. Four said they had more contact with relatives, one said less contact, and seven said their contact was about the same. For friends, three said they had more contact, four said less contact and five said their contact was about the same.

A recent systematic review found that PA decreased during the lockdown periods and SB increased (Stockwell, et al., in press). One study found that older adults stopped going to group exercise classes and gyms because they felt attending would be unsafe (Chen, et al., 2020). Physical inactivity has adverse effects on the respiratory system, immune system, cardiovascular system, and musculoskeletal system, meaning that those who were not sufficiently physically active during the pandemic may have suffered deconditioning (Woods, et al., 2020). Therefore, until older adults feel comfortable to return to PA in the presence of other people, provision of home-based PA may be more acceptable, even necessary, to maintain health (Son, et al., 2020).

Older adults have been required to engage with technology during the pandemic, to browse for information, shop and stay connected with family members and the community via social media and videoconferencing applications (Chen, et al., 2020). During the pandemic the UK government introduced the NHS COVID-19 app with integrated QR code scanning which was central to the Test and Trace programme (Department of Health and Social Care, 2020). Although demographic data on users of this app are not currently available, it is likely that older adults used this app at some point during the pandemic. Therefore, the incorporation of QR codes into a DBCI for PA may now be acceptable among this population as they have some experience using them. For instance, to promote walking in the local area, councils could put up QR codes for people to scan on their walks, creating a virtual ‘treasure hunt’ which could involve an automatically updated ‘puzzle of the day/week’ to solve (puzzles could be made age appropriate to target certain demographics based on participant profile information). The incorporated use of a smartphone accelerometer could then track which QR codes have been scanned and where others are located to encourage people to walk in new areas.

During the lockdowns many turned to technology for PA. The celebrity personal trainer and healthy eating coach Joe Wicks provided ‘physical education’ (PE) classes for children, personal training sessions and exercise classes via video conferencing for those that usually attend in person, with some content being made available for free whilst others required payment (Gilliland, 2020). Despite this, provision specifically aimed at older adults was lacking, particularly in engaging (i.e., non-boring – see chapter six) ways. Age UK did provide information on their website with a list of exercises one could do, with pictures illustrating them (Age UK, 2020), however much of the engaging free content was aimed at children and adults with a higher baseline level of fitness than many older adults.

The combination of older adults suffering deconditioning, potential increases in social isolation, and increased use of technology among older adults, makes the development of a DBCI for socially isolated older adults that promotes PA and reduces SB even more relevant than before the Coronavirus pandemic. This highlights an unanticipated, additional, and important benefit that this thesis provides.

7.8. Strengths and limitations of the research in the thesis

The strengths and limitations of each of the four main chapters in this thesis have been discussed within in each chapter. Overall, one strength of this thesis is that it followed a systematic intervention development method, using the MRC framework and BCW, to make recommendations for the design of a future theory and evidenced based intervention. In addition, existing DBCI were utilised to explore users' experiences before the creation and testing of a new DBCI, which was both cost- and time-effective.

One limitation of this research was that self-report measures of PA were used to indicate participants PA levels in chapters 5 and 6. Although this was sufficient for the purposes of the study, it is well documented that self-report measures of PA can both over and underestimate actual PA (Prince, et al., 2008, Dyrstad, et al., 2014), therefore future research should use objective measures of PA particularly when assessing efficacy of the developed intervention. Chapters 5 and 6 both had small sample sizes, which though typical for the types of studies, may mean the results are not generalisable to larger populations. In addition, the participants in chapters 5 and 6 were all White ethnic background, although no attempt was made to conduct representative sampling, therefore the findings may not be generalisable to other ethnicities. Future studies related to this work should actively aim to recruit participants of different ethnic backgrounds to ensure the continued development of the DBCI is inclusive and feasible among different ethnicities. Lastly, it is important to note that the data used in chapter 4 was collected in 2016/2017, and as technology use changes rapidly – perhaps more so due to COVID-19 – it is anticipated that a greater number of socially isolated older adults are online than reported, and their device preferences may have changed. Therefore, future research is required to update this knowledge, and could utilise wave 9 (2018/2019) or wave 10 (2020/2021) data from the ELSA.

7.9. Future direction of this research

The work in this thesis focused on the development phase of the MRC framework, and next steps would be to conduct the feasibility/piloting, evaluation and implementation phases

(Craig, et al., 2006, Craig, et al., 2019). To do this, the new DBCI would need to be created, working in partnership with software developers.

Once developed, it is recommended that the DBCI is feasibility tested with socially isolated older adults to assess the acceptability and practicality of the DBCI (Craig, et al., 2006, Bowen, et al., 2009) using five key objectives: 1) evaluation of recruitment capability; 2) evaluation and refinement of data collection procedures and outcome measures; 3) evaluation of the acceptability and suitability of the intervention and study procedures; 4) evaluation of the resources and ability to manage and implement the study and intervention; and, 5) preliminary evaluation of participant responses to the intervention (Orsmond and Cohn, 2015).

Following this, a pilot study should be conducted to assess the effectiveness of the intervention at promoting PA and reducing SB in socially isolated older adults. This study would provide further information on recruitment and retention that could be used to calculate a full-scale trial sample size. If appropriate, a full-scale trial could be conducted to assess the effectiveness of the DBCI, evaluate the change process and assess the cost-effectiveness (Craig, et al., 2006). It is recommended that the PA/SB outcomes are measured objectively (see chapter 3). An inclinometer device such as the ActivPAL is proposed as it has the capability of distinguishing between sitting and standing SB, as well as measuring PA.

Participants in chapter 6 provided useful information for the implementation phase, highlighting the use of the app stores, GPs and health professionals, social media and local newspapers/newsletters as dissemination avenues. DBCI can afford the ability to monitor long term outcomes and additional questionnaires could be provided to users within the intervention itself, therefore long-term follow up studies are recommended. In addition, it may be possible to collect longitudinal data on users remotely, with the appropriate permissions, and afford the opportunity for additional qualitative feedback regarding the development of the DBCI.

7.10. Conclusion

This thesis followed the systematic MRC intervention development framework to make recommendations for the design of a novel DBCI for PA and/or SB in socially isolated older adults and provided an example of what this may look like in practice. The next phase of this research requires the DBCI to be created for feasibility testing and refinement before efficacy evaluation.

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APPENDICES

Appendix A

Search terms as used in the systematic review and meta-analysis in chapter three

The key word terms used were: (physical activity OR walking OR exercise OR sedentary* OR sedentary behavio* OR sitting) and (older adult* OR aged OR aging OR ageing OR over 50 OR elderly) and (digital behavio* OR digital intervention* OR wearable electronic device* OR fitness tracker* OR fitbit* OR activity tracker* OR fitness tracker* OR ehealth OR mhealth OR video game* OR wii OR xbox OR virtual realit* OR exergam* or mobile phone* or augmented realit*).

Appendix B

JBI Critical appraisal checklist for randomized controlled trials as used in the quality assessment in chapter three

JBI Critical Appraisal Checklist for Randomized Controlled Trials

Reviewer_____________________________Date__________________________________

Author _________________________Year______________Record Number _______

	Yes	No	Unclear	NA
1. Was true randomization used for assignment of participants to treatment groups?	□	□	□	□
2. Was allocation to treatment groups concealed?	□	□	□	□
3. Were treatment groups similar at the baseline?	□	□	□	□
4. Were participants blind to treatment assignment?	□	□	□	□
5. Were those delivering treatment blind to treatment assignment?	□	□	□	□
6. Were outcomes assessors blind to treatment assignment?	□	□	□	□
7. Were treatment groups treated identically other than the intervention of interest?	□	□	□	□
8. Was follow up complete and if not, were differences between groups in terms of their follow up adequately	□	□	□	□
9. Were participants analyzed in the groups to which they were randomized?	□	□	□	□
10. Were outcomes measured in the same way for treatment groups?	□	□	□	□
11. Were outcomes measured in a reliable way?	□	□	□	□
12. Was appropriate statistical analysis used?	□	□	□	□
13. Was the trial design appropriate, and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?	□	□	□	□

Overall appraisal: Include □ Exclude □ Seek further info □

Comments (Including reason for exclusion)

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Appendix C

JBI Critical appraisal checklist for quasi-experimental studies as used in the quality assessment in chapter three

JBI Critical Appraisal Checklist for Quasi-Experimental Studies (non-randomized experimental studies)

Reviewer___________________________________Date___________________________

Author __________________________Year______________Record Number ______

	Yes	No	Unclear	Not applicable
14. Is it clear in the study what is the 'cause' and what is the 'effect' (i.e. there is no confusion about which variable comes first)?	□	□	□	□
15. Were the participants included in any comparisons similar?	□	□	□	□
16. Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	□	□	□	□
17. Was there a control group?	□	□	□	□
18. Were there multiple measurements of the outcome both pre and post the intervention/exposure?	□	□	□	□
19. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	□	□	□	□
20. Were the outcomes of participants included in any comparisons measured in the same way?	□	□	□	□
21. Were outcomes measured in a reliable way?	□	□	□	□
22. Was appropriate statistical analysis used?	□	□	□	□

Overall appraisal: Include □ Exclude □ Seek further info □

Comments (Including reason for exclusion)____

____

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Appendix D

JBI Critical appraisal checklist results as seen in chapter three

	Ashe, 2015	Bickmore, 2013	Broekhuizen,	Cadmus-Bertram,	Cook, 2015	Frederix, 2015	Keogh, 2014	King, 2007	King, 2014	Knight, 2015	Kullgren, 2014	Leutwyler, 2015	Lyons, 2017	Müller, 2016	Nguyen, 2009	O' Brien, 2015	Ruiz, 2012	Strand, 2014	Tiedemann, 2015	Vidoni, 2016	Wijsman, 2013	Williams, 2016
Rank (High, Medium, Low)	**M**	**H**	**M**	**M**	**M**	**M**	**L**	**M**	**M**	**L**	**M**	**L**	**M**	**M**	**M**	**L**	**H**	**L**	**L**	**H**	**M**	**L**
Question number																						
RCT Studies																						
1	Y	N	N	N	Y	Y		N	N		Y		Y	N	N		?			?	N	
2	Y	N	Y	?	N	Y		?	?		N		Y	Y	Y		?			Y	Y	
3	N	Y	Y	Y	Y	Y		Y	Y		N		Y	Y	?		Y			N	Y	
4	N	?	?	Y	N	?		?	?		N		N	N	N		?			N	?	
5	N	N	N	?	N	N		?	?		?		N	N	N		?			N	N	
6	Y	?	?	?	?	Y		Y	Y		Y		N	N	Y		?			?	?	
7	Y	Y	Y	Y	Y	?		Y	Y		Y		Y	Y	Y		?			Y	Y	
8	Y	Y	Y	Y	Y	Y		Y	Y		Y		Y	Y	Y		Y			Y	Y	
9	Y	Y	Y	Y	Y	Y		Y	Y		Y		Y	Y	Y		Y			Y	Y	
10	Y	Y	Y	Y	Y	Y		Y	Y		Y		Y	Y	Y		Y			Y	Y	
11	Y	Y	Y	Y	Y	Y		Y	Y		Y		Y	Y	Y		Y			Y	Y	
12	Y	Y	Y	Y	Y	Y		Y	Y		Y		Y	Y	Y		Y			Y	Y	
13	Y	Y	Y	Y	Y	Y		Y	Y		Y		Y	Y	Y		Y			Y	Y	

Rank (High, Medium, Low)	Ashe, 2015	Bickmore, 2013	Broekhuizen, 2015	Cadmus-Bertram, 2015	Cook, 2015	Frederix, 2015	Keogh, 2014	King, 2007	King, 2014	Knight, 2015	Kullgren, 2014	Leutwyler, 2015	Lyons, 2017	Müller, 2016	Nguyen, 2009	O' Brien, 2015	Ruiz, 2012	Strand, 2014	Tiedemann, 2015	Vidoni, 2016	Wijsman, 2013	Williams, 2016
	M	**H**	**M**	**M**	**M**	**M**	**L**	**M**	**M**	**L**	**M**	**L**	**M**	**M**	**M**	**L**	**H**	**L**	**L**	**H**	**M**	**L**
Quasi-Experimental																						
14							Y			Y		Y				Y		Y	Y			Y
15							Y			Y		Y				Y		Y	Y			Y
16							Y			Y		Y				Y		Y	Y			Y
17							Y			N		N				N		N	N			N
18							Y			Y		Y				Y		Y	Y			Y
19							Y			Y		Y				Y		Y	Y			Y
20							Y			Y		Y				Y		Y	Y			Y
21							Y			Y		Y				Y		Y	Y			Y
22							Y			Y		Y				Y		Y	Y			Y

Y = yes; N = no; ? = unclear; n/a = not applicable

Appendix E

Ethical approval for the studies investigating barriers and facilitators of PA in socially isolated older adults (chapter five) and exploring the experiences of socially isolated older adults using DBCI for PA (chapter six)

Principal investigator:	Stephanie Stockwell
Project supervisor:	Dr. Lee Smith
Project title:	Investigating digital behaviour change interventions targeting physical activity in socially isolated older adults.
SREP code:	ESPGR-10
Approval date	29/01/220

Application decision: **Approve with revisions** under the terms of Anglia Ruskin University's Research Ethics Policy (Dated 8 September 2016, Version 1.7). Approval by SREP is subject to ratification by the FREP.

Changes to be made: These changes should be discussed and approved by your supervisor (all documents must be updated online) but do not need to be communicated to SREP, all changes must be made before data collection can start:

GENERAL COMMENTS FOR THE APPLICANT

- A high quality ethics application submission.

Specific Comments for applicant:
Application Form

- Data confidentiality clear but how (if at all) will participant anonymity will be ensured? Also, at what stage will data be anonymised? This information is in your PIS but not stage 1.

Response: See section 4, point 2 – utilise data that is not publicly available. This information has been copied from the PIS and entered into the stage 1 form.

- If (and when) participants are identified as being socially isolated. Do you pass on this information to any of your voluntary organisations?

Response: See section 4, point 4 – involved participants whose responses could be influenced by your relationship…
Information about participants who are socially isolated will not be passed on to other organizations. Participants will be provided with a list of voluntary organizations and charities in their local area that they are able to contact if they wish to reduce their social isolation at the end of their involvement in the study. Those who are deemed ineligible for the study based on their social isolation scores will be provided with a letter thanking them for their interest, and contact details for Silverline in case they wish to speak to someone about feeling at risk of isolation.

Specific Comments for applicant: **PIS**	• Please note university template/headers/logos for example, it might be appropriate to identify who has access to the collected data (question 2, section B of ARU PI sheet). All letters and information sheets will have the University logo in the header (please see individual documents). Regarding who has access to the data, this is covered in the PIS under the question header 'what will happen to the data and information that is collected?'. 'All information collected by the research team will be stored securely at Anglia Ruskin University in accordance with the GDPR and Data Protection Act (2018), and will only be accessible to the research team members.' Research team members were introduced under the question header 'who are the research team?' in the PIS.
Specific Comments for applicant: **Consent Form**	• Please note university template/headers/logos. Please review the questions related to providing consent on ARU template to current consent form in-case elements are missing. All letters and information sheets will have the University logo in the header (please see individual documents). The consent form questions were based on the ARU template, with additional questions relating to this specific study added. • Change 'sport science department' to 'School of Psychology and Sport Sciences' or FHEMS equivalent This has been changed to 'School of Psychology and Sport Sciences' on all documentation as this is where participants will be posting the trackers and potentially forms to.
Include missing documents:	• N/A
Specific Comments for applicant: **Other Documentation**	• Other documents are reviewed. One specific comment relate to the use of a/your mobile phone number on documentation for participants. Please ensure that this is not your personal mobile phone number (second SIM card?) and has a clear voicemail related to the study (for obvious ethical and risks reasons you can clarify the purpose of the phone number on the voicemail). I'm unsure whether this was mentioned in RA or application, I might have missed this. The mobile phone number used for this research was purchased specifically for use in this study and is not the personal phone number of any research team member. All communication via telephone will be conducted using this phone number. This has been added to the stage 1 form under section 4, point 2.

All documents (PIS, Consent form, Debrief) given to participants, must be printed onto Anglia Ruskin University headed paper.

Any advert must contain the following statement:

The study has received ethics approval by the School Research Ethics Panel (SREP) and ratified by the Faculty Research Ethics Panel under the terms of Anglia Ruskin University's Policy and Code of Practice for the Conduct of Research with Human Participants

If you make changes to any aspect of your approved research, it is important that you discuss this with your supervisor as they can advise you on whether you need any additional ethical approval.

Ethical approval is given for a period of 1 year for undergraduates/masters students. If your research will extend beyond this period, it is your responsibility to apply for an extension before your approval expires.

It is your responsibility to ensure that you comply with Anglia Ruskin University's Research Ethics Policy and the Code of Practice for Applying for Ethical Approval at Anglia Ruskin University available at www.anglia.ac.uk/researchethics including the following.

- The procedure for submitting substantial amendments to the committee, should there be any changes to your research. You cannot implement these amendments until you have received approval from SREP for them.
- The procedure for reporting accidents, adverse events and incidents.
- The General Data Protection Requirement and Data Protection Act (2018).
- Any other legislation relevant to your research. You must also ensure that you are aware of any emerging legislation relating to your research and make any changes to your study (which you will need to obtain ethical approval for) to comply with this.
- Obtaining any further ethical approval required from the organisation or country (if not carrying out research in the UK) where you will be carrying the research out. This includes other Higher Education Institutions if you intend to carry out any research involving their students, staff or premises. Please ensure that you send the FREP/DREP copies of this documentation if required, prior to starting your research.
- Any laws of the country where you are carrying the research and obtaining any other approvals or permissions that are required.
- Any professional codes of conduct relating to research or requirements from your funding body (please note that for externally funded research, where the funding has been obtained via Anglia Ruskin University, a Project Risk Assessment must have been carried out prior to starting the research).
- Completing a Risk Assessment (Health and Safety) if required and updating this annually or if any aspects of your study change which affect this.
- Notifying the SREP Secretary when your study has ended.

Please also note that your research may be subject to monitoring.

Should you have any queries, please do not hesitate to contact me. May I wish you the best of luck with your research.

Yours sincerely,

Dan Gordon
SREP Chair

Date 30.9.2019
V1.5

From: Smith, Lee
Sent: 07 February 2020 20:24
To: Stockwell, Stephanie (Postgraduate Researcher)
Subject: RE: Ethics Approved(ish)

Approved all changes

Dr Lee Smith
Reader in Physical Activity and Public Health
Director of Research and Income Generation, Cambridge Centre for Sport and Exercise Sciences
Anglia Ruskin University
Compass House
Cambridge
CB1 1PT

Appendix F

Participant Information Sheet for the studies investigating barriers and facilitators of PA in socially isolated older adults (chapter five) and exploring the experiences of socially isolated older adults using DBCI for PA (chapter six)

a.r.u.

Exploring the experiences of using digital interventions for physical activity in people aged 50+ at risk of social isolation and/or loneliness

Page 1: Participant Information Sheet

You CAN still take part in this research if you are self-isolating.

All contact is via email/telephone/post, and the activities you can do in your home.

Study Information Letter

Dear Volunteer,

We are conducting research in people aged 50+ who may be at risk of social isolation or loneliness. We are hoping to learn about what helps and hinders people from being physically active, and to find out about their experiences of using digital technology to be active.

Please read this information sheet carefully before deciding whether you would like to take part.

Who are the research team?

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The main researcher is Mrs Stephanie Stockwell who is currently completing her PhD, and this project will form part of her thesis. She is supervised by Dr Lee Smith, Dr Brendon Stubbs and Dr Jennie Rose, who are all staff members at Anglia Ruskin University.

What type of participants are needed?

We are looking for people aged 50 years and older, who may be at risk of isolation or loneliness, who have no medical reason that may stop them from doing some physical activity and who have access to the internet. Participants will need to complete a consent form before starting the project, and meet certain criteria to be eligible to take part in the study. Checking eligibility involves completing a very short questionnaire (6 questions). From this, we can work out whether you are or are not eligible to take part in the study.

What will participants have to do?

If you decide you would like to volunteer for the study and you are eligible to take part, we will arrange a telephone interview to discuss your physical activity and the things that might make being active easier or more difficult. We don't mind how active you are (or are not), we want to learn more about the reasons why people may or may not be active. The interview won't last more than an hour.

You will then be given 2 different digital aids to encourage physical activity to try out over the following 2 weeks. These are a wrist worn Runme Fitness Tracker (cheaper version of a Fitbit) and the Johnson & Johnson 7-minute workout app (on a smartphone or tablet). Whilst you are trying them out, we would like you to complete a short booklet to record your experiences. At the end of the 2 weeks, we'll have another telephone interview to discuss how you got on using the digital interventions, which again won't last more than an hour.

Will it cost the participants any money?

Participants will be provided with the digital interventions free of charge (the Runme Fitness Tracker to borrow, and the Johnson & Johnson 7-minute workout app is free to download) and the University will call the participants at a pre-arranged time for both interviews, so participants won't incur any phone charges.

Why are we doing this research?

If you decide to volunteer and are eligible to take part, you will get the opportunity to try out different digital technologies as part of the research. We hope to use what we learn from this project to design a brand-new digital intervention for physical activity that better meets the needs of people aged 50+ who may be at risk of social isolation.

What are the possible risks of taking part in the study?

You will be asked to do some physical activity during the time of trying out the digital interventions (e.g. walking, chair-assisted squats, chair-assisted push-ups, crunch sit-ups, marching on the spot). The exercises in the digital interventions have been checked by a Physiotherapist and deemed safe for people aged 50+. There is a very small possibility of injury during physical activity, however if you follow the guidance on the interventions, ensure you are wearing appropriate clothing whilst being active, and complete the activity in a safe environment, this will be minimised. If this were to happen, we advise that you stop using the intervention, seek medical advice where appropriate, and to contact the research team.

What will happen to the data and information that is collected?

All information collected by the research team will be stored securely at Anglia Ruskin University in accordance with the GDPR and Data Protection Act (2018), and will only be accessible to the research team members. Data collected will be kept for 3 years and then destroyed securely at the University. The interviews will be audio recorded but only listened to by the research team. Results of the study will be used in a PhD thesis and may be published in an academic journal, but data included will be made anonymous and individual people will not be identifiable (e.g. P1, P2, P3 etc.). We may identify quotes from you that we wish to use in our published research. This could lead to the small risk of identification, although these quotes will be anonymised.

What if I want to withdraw from the study?

If at any point during the study you wish to stop participating, you can withdraw and do not have to provide a reason if you don't want to. This can be done at any point until 1 week after the 2nd interview, as from then on, the data will be anonymised, analysed and written up. If this is the case, please email or call the research team using the details below. You may withdraw and allow us to use what we have already collected or you may withdraw completely including removing all your data from the study.

Will I get to see the results of the study?

On the consent form there is an option you can select if you would like to be informed of the results of the study once it has been completed. You do not have to if you do not want to. A summary of the results will be emailed to those who would like them.

What if I know someone else who might want to take part?

If you know someone who you think may want to take part, please feel free to ask for another hardcopy of this information sheet to give to them, or forward an electronic copy. They are also welcome to contact the research team directly on the email address or telephone number below.

What if I have any questions?

If you have any questions please contact the research team using the details below.

Many thanks,

Mrs Stephanie Stockwell -- stephanie.stockwell1@pgr.anglia.ac.uk -- 07719 769847

Dr Lee Smith -- lee.smith@anglia.ac.uk

The study has received ethics approval by the School Research Ethics Panel (SREP) and ratified by the Faculty Research Ethics Panel under the terms of Anglia Ruskin University's Policy and Code of Practice for the Conduct of Research with Human Participants.

Appendix G

Participant consent form for the studies investigating barriers and facilitators of PA in socially isolated older adults (chapter five) and exploring the experiences of socially isolated older adults using DBCI for PA (chapter six)

Page 2: Participant Consent Form

Please read each statement carefully and select as appropriate.

	* Required	
	Yes	No
Have you received, read and understood a copy of the study information letter?	○	○
Do you understand that participation in the study is entirely voluntary?	○	○
Do you understand that you can withdraw from the study at any point and you do not have to provide a reason?	○	○
Do you understand you are free to ask any questions at any time before and during the study?	○	○
Do you understand what information will be collected from you?	○	○
Do you understand that data collected will be stored and processed at Anglia Ruskin University in accordance with the GDPR and Data Protection Act (2018)?	○	○
Do you understand that the data will be processed only by the research team, kept for 3 years, and then destroyed?	○	○
Do you understand that data will be anonymised in any reports or publications?	○	○
Do you understand that the interviews will be audio recorded and listened to only by the research team?	○	○
I agree that I have no known medical reason why I cannot do the level of physical activity required for this study (outlined in the information sheet).	○	○
I would like to be informed about the results of the study when it is completed.	○	○

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Participant details form for the studies investigating barriers and facilitators of PA in socially isolated older adults (chapter five) and exploring the experiences of socially isolated older adults using DBCI for PA (chapter six)

Page 3: Participant Details

Contact Details

Name (first and surname only): * *Required*

Telephone number(s): * *Required*

Email address: * *Required*

Home postcode: * *Required*

Please tick your preferred method of communication where possible (excluding the telephone interviews): * *Required*

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- Email
- Text message
- Telephone call

Participant details

Age (in years): * *Required*

Sex: * *Required*

- Male
- Female
- Prefer not to say

Ethnicity (please describe): * *Required*

Employment status: * *Required*

- Unemployed
- Employed part-time

- Employed full-time
- Self-employed
- Retired
- Other

If you selected Other, please specify:

Marital status: * Required

- Single
- Married or living with a partner
- Divorced or separated
- Widowed

Highest level of education: * Required

- No formal qualifications
- O-level/GCSE
- A-level
- University degree or higher

Do you have any long-standing illness, disability or infirmity? Long-standing meaning anything that has troubled you over a period of time, or that is likely to affect you over a period of time? * *Required*

- Yes
- No

Does this/do these illness(es) or disability(ies) limit your activities in any way?

- Yes
- No

Page 4: Technology Use

Please tell us about your previous experience of using technology generally: (e.g. I have a smartphone/tablet/laptop that I use every day/occasionally. I used computers at work before I retired/ I use a computer at work currently. I don't use any technology) ✱ *Required*

Please tell us about your previous experience of using technology for physical activity and/or reducing sitting time: (e.g. I have a workout/yoga/Pilates DVD that I use every day/occasionally/rarely, I use/have used a fitness activity tracker [e.g. Fitbit or step counter], I use YouTube for fitness workouts, I use an app to track my walks/runs, I regularly/occasionally use the Wii Fit/Xbox Kinect to exercise. I've never used technology for physical activity). ✱ *Required*

Page 5: Physical Activity

Rapid Assessment of Physical Activity

Physical Activities are activities where you move and increase your heart rate above its resting rate, whether you do them for pleasure, work, or transportation.

The following questions ask about the amount and intensity of physical activity you usually do. The intensity of the activity is related to the amount of energy you use to do these activities.

Examples of physical activity intensity levels:

Light activities

- Your heart beats slightly faster than normal
- You can talk and sing
- E.g. Walking leisurely, stretching, vacuuming or light yard work

Moderate activities

- Your heart beats faster than normal
- You can talk but not sing
- E.g. Walking fast, aerobic class, strength training, swimming gently

Vigorous activities

- Your heart rate increases a lot
- You can't talk or your talking is broken up by large breaths
- E.g. Stair machine, jogging or running, tennis, racquetball, pickleball or badminton

How physically active are you? (Select one answer on each line)

	Does this accurately describe you? * *Required*

	Yes	No
I rarely or never do any physical activities.	○	○
I do some LIGHT or MODERATE physical activities, but not every week.	○	○
I do some LIGHT physical activity every week.	○	○
I do MODERATE physical activities every week, but less than 30 minutes a day or 5 days a week.	○	○
I do VIGOROUS activities every week, but less than 20 minutes a day or 3 days a week.	○	○
I do 30 minutes or more a day of MODERATE physical activities, 5 or more days a week.	○	○
I do 20 minutes or more a day of VIGOROUS physical activities, 3 or more days a week.	○	○
I do activities to increase muscle STRENGTH, such as lifting weights or calisthenics, once a week or more.	○	○
I do activities to improve FLEXIBILITY, such as stretching or yoga, once a week or more.	○	○

Page 6: Social Networks

Please complete the following questionnaire.

There are no right or wrong answers, so please be completely honest. When answering these questions, it's best to think of your life as it generally is now (we all have good and bad days).

FAMILY – Considering the people to whom you are related either by birth or by marriage…

	Answers ✱ *Required*					
	0	1	2	3-4	5-8	9+
How many RELATIVES do you see or hear from at least once a month?	○	○	○	○	○	○
How many RELATIVES do you feel close to such that you could call on them for help?	○	○	○	○	○	○
How many RELATIVES do you feel at ease with that you can talk about private matters?	○	○	○	○	○	○

Do you think the answers given above are different now during the COVID-19 pandemic, to what they were before the pandemic in the UK? ✱ *Required*

- ○ Yes - I've had MORE contact with RELATIVES
- ○ Yes - I've had LESS contact RELATIVES
- ○ No - it's about the same contact with RELATIVES
- ○ Other

If you selected Other, please specify:

FRIENDSHIPS – Considering all of your friends including those who live in your neighbourhood…

	Answers ✱ *Required*					
	0	1	2	3-4	5-8	9+
How many of your FRIENDS do you see or hear from at least once a month?	○	○	○	○	○	○
How many of your FRIENDS do you feel close to such that you could call on them for help?	○	○	○	○	○	○
How many of your FRIENDS do you feel at ease with that you can talk about private matters?	○	○	○	○	○	○

Do you think the answers given above are different now during the COVID-19 pandemic, to what they were before the pandemic in the UK? ✱ *Required*

- ○ Yes - I've had MORE contact with FRIENDS
- ○ Yes - I've had LESS contact FRIENDS
- ○ No - it's about the same contact with FRIENDS
- ○ Other

If you selected Other, please specify:

Page 7: Thank you for your time!

Thank you for completing the online consent form and participant detail forms.

The research team will check your eligibility and will be in touch very soon about the next steps.

In the meantime, if you have any questions, please contact the research team.

Mrs Stephanie Stockwell -- stephanie.stockwell1@pgr.anglia.ac.uk -- 07719 769847

Dr Lee Smith -- lee.smith@anglia.ac.uk

Appendix I

Posters used in the recruitment of participants for the studies investigating barriers and facilitators of PA in socially isolated older adults (chapter five) and exploring the experiences of socially isolated older adults using DBCI for PA (chapter six)


a.r.u. Anglia Ruskin University
Participants required
What is the study about?
We are looking at what someone who might be at risk of social isolation/ loneliness thinks about physical activity and their experience of using digital technology to encourage being more active
Who are we looking for?
• Men & women aged 50+
• Might be at risk of social isolation/ loneliness
Who do they need to contact?
Stephanie Stockwell
07719 769847
stephanie.stockwell1@pgr.anglia.ac.uk
The study has received ethics approval by the School Research Ethics Panel (SREP) and ratified by the Faculty Research Ethics Panel under the terms of Anglia Ruskin University's Policy and Code of Practice for the Conduct of Research with Human Participants
What do they have to do?
• 1x telephone interview about physical activity
• Try out 2 digital interventions
• 1x telephone interview about how they got on with the interventions


Participants required
Who are we looking for?
• Men & women aged 50+
• Might be at risk of social isolation/ loneliness
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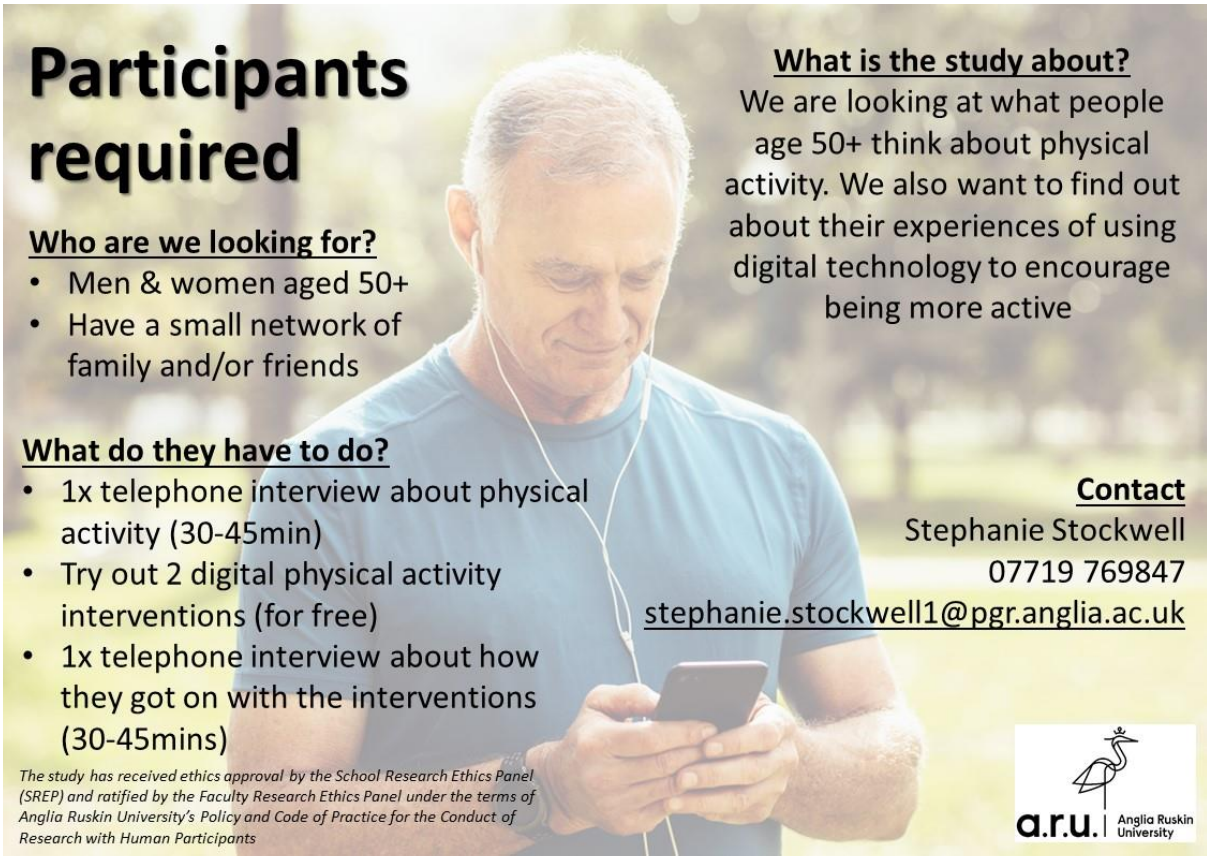
a.r.u. Anglia Ruskin University


a.r.u. Anglia Ruskin University
Participants required
What is the study about?
We are looking at what people age 50+ think about physical activity. We also want to find out about their experiences of using digital technology to encourage being more active
Who are we looking for?
• Men & women aged 50+
• Have a small network of family and/or friends
What do they have to do?
• 1x telephone interview about physical activity (30-45min)
• Try out 2 digital physical activity interventions (for free)
• 1x telephone interview about how they got on with the interventions (30-45mins)
Who do they need to contact?
Stephanie Stockwell
07719 769847
stephanie.stockwell1@pgr.anglia.ac.uk
The study has received ethics approval by the School Research Ethics Panel (SREP) and ratified by the Faculty Research Ethics Panel under the terms of Anglia Ruskin University's Policy and Code of Practice for the Conduct of Research with Human Participants


Participants required
What is the study about?
We are looking at what people age 50+ think about physical activity. We also want to find out about their experiences of using digital technology to encourage being more active
Who are we looking for?
• Men & women aged 50+
• Have a small network of family and/or friends
What do they have to do?
• 1x telephone interview about physical activity (30-45min)
• Try out 2 digital physical activity interventions (for free)
• 1x telephone interview about how they got on with the interventions (30-45mins)
Contact
Stephanie Stockwell
07719 769847
stephanie.stockwell1@pgr.anglia.ac.uk
The study has received ethics approval by the School Research Ethics Panel (SREP) and ratified by the Faculty Research Ethics Panel under the terms of Anglia Ruskin University's Policy and Code of Practice for the Conduct of Research with Human Participants
a.r.u. Anglia Ruskin University

Appendix J

Eligibility letters for participants in the studies investigating barriers and facilitators of PA in socially isolated older adults (chapter five) and exploring the experiences of socially isolated older adults using DBCI for PA (chapter six)

The Positive Ageing Research Institute

a.r.u. | Anglia Ruskin University

Exploring the experiences of using digital interventions for physical activity in people aged 50+ at risk of social isolation and/or loneliness

Dear [INSERT PARTICIPANT NAME],

Thank you for your interest in our study and taking the time to complete the online consent forms. I have checked your eligibility to take part in the study using the information you provided on the social network questionnaire. The score calculated suggests that you are not at risk of social isolation and therefore are not eligible for this study.

If this does not reflect how you feel and would like to talk to someone about this, there are many organisations and charities that are able to help. Silverline are available 24/7 and provide free and confidential information, friendship and advice. Their telephone number is 0800 4 70 80 90 and their website is https://www.thesilverline.org.uk/.

Thank you once again for your interest and for contacting us. If you know of anyone else who might be eligible and interested in taking part, please feel free to pass on my details.
Kindest regards,
Stephanie

S Stockwell

Mrs Stephanie Stockwell
PhD Researcher
stephanie.stockwell1@pgr.anglia.ac.uk
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Dr Lee Smith
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Anglia Ruskin University
School of Psychology and Sport Sciences
Compass House Annex
Newmarket Road
CB5 8DZ

Exploring the experiences of using digital interventions for physical activity in people aged 50+ at risk of social isolation and/or loneliness

Dear [INSERT PARTICIPANT NAME],

Thank you for your interest in our study and taking the time to complete the online consent forms. I have checked your eligibility to take part in the study using the information you provided on the social network questionnaire and **you are eligible to take part.**

The next step is to arrange the first telephone interview to talk about physical activity, which will take about 30 minutes. I am currently available any time between [time] from [date] to [date]. **Please let me know a time that works for you.** If next week doesn't work then we can look at the following week.

I really appreciate you volunteering to take part and look forward to hearing from you.

Kindest regards,

S Stockwell

Stephanie

Mrs Stephanie Stockwell
PhD Researcher
stephanie.stockwell1@pgr.anglia.ac.uk
07719 769847

Anglia Ruskin University
School of Psychology and Sport Sciences
Compass House Annex
Newmarket Road
CB5 8DZ

Dr Lee Smith
Principal Supervisor
lee.smith@anglia.ac.uk

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CB5 8DZ

Appendix K

Interview guide for chapter five

Thank you for agreeing to take part in this study. I'm really interested to find out your experiences of physical activity. If at any point you would like to take a break just let me know, and if you want to stop or withdraw from the study at any point, you are also able to do so. The whole interview should take around 30-45 minutes, and it will be audio recorded.

Check through participant details sheet

Remember, it's a chat about your experiences so there are no right or wrong answers. Before we start, do you have any questions?

START RECORDING

1. **Can you confirm that you are still happy to take part in the research?**

2. **Can you tell me what physical activity means to you?** (Psychological Capability)
   - (Note: do they speak about exercise or movement in general?)

3. **How physically active would you say you are?** (Physical Capability)
   - How often?
   - What types of physical activity do you do?
   - Now? In the past?

4. **Can you tell me about the government physical activity guidelines for people aged 50+?** (Psychological Capability)
   - How long? How often? Intensity?
   - Explain guidelines are 150min moderate or 75min vigorous exercise per week, plus muscle strengthening exercises on 2 days per week
   - What are your thoughts on these guidelines?
   - Do you do more/less than the guidelines? (Reflective Motivation)

5. **Would you like to be more active?** (Reflective motivation)
   - Why? Why not?
   - What would motivate you to be more physically active? What reasons?

6. **What do you think the benefits of being physically active are?** (Reflective Motivation)
   - In general
   - To you personally
   - What might be better if you were physically active?

7. **What do you the disadvantages of being physically active might be?** (Reflective Motivation)
   - In general
   - To you personally
   - What might be worse if you were physically active?

8. **What might make it harder for you to be more physically active?** (Capability)
   - Additional prompts as necessary:
     - What might make you stop being physically active?
     - What problems have you experienced whilst being physically active?
     - What things might make it difficult for you to be physically active?

9. **What might make it easier for you to be physically active?** (Capability)
   - Addition prompts as necessary:
     - What would make you want to be more physically active?
     - What would need to change for you to be more physically active?
     - What might help you overcome some of the difficulties you mentioned? (Reflective Motivation)

10. **How does your environment affect your physical activity?** (Physical Opportunity)

Additional prompts as necessary:

- Home
  - e.g. indoor space big enough/garden?
- Neighbourhood
  - e.g. Is the local area well maintained?
  - e.g. paths, roads, grass areas? Do you feel safe to do physical activity in your neighbourhood?
- Travel
  - e.g. bus, train, car, walk, cycle for most journeys?
- Are there any local facilities centres or clubs?
  - Do you use them? Why/why not?
- Do you feel you have enough time to do physical activity? Tell me more…

11. **How do other people affect your physical activity?** (Social Opportunity)
   - Anyone who increases your physical activity? Why?
   - Anyone who decreases your physical activity? Why?
   - How does the media affect your physical activity? Why?
   - How would having someone else to do it with affect your physical activity?
   - Are there any groups or people who might support you being physically active?
   - Are there any groups or people who might disapprove of you being physically active?

12. How does physical activity make you feel? (Automatic Motivation)

- Before?
- During?
- After?
- How does your mood affect your physical activity?

As you know, the second part of the study is about using digital technology for physical activity.

13. What do you think about using technology for physical activity?

- Positives/Benefits?
- Negatives/Drawbacks?
- Have you got any experience using technology for physical activity? (See self-report questionnaire for details)
- Do you know anyone who uses it?
- Have you read/seen anything about it?

Thank you for answering my questions, I found it really interesting. Before I stop the recorder, **is there anything else you would like to add about your experiences of physical activity that we haven't covered?**

Great. I'm just going to stop the recorder, and then we can talk about the next bit of the study.

STOP RECORDING

The next part of the study involves you trying out 2 digital interventions for physical activity. One is a smartphone app called the Johnson & Johnson 7-minute workout, and the other is a fitness tracker with an app called Veryfit Pro. You can use them in any order you want, but we would like you to use one for 1 week, and the other for 1 week after that. **Is that ok?**

You are able to download the apps yourself for free and I will email you the instructions for downloading the ones you need. I will post the tracker to you later today. The tracker will have all the instructions in for you to follow to set it up. I'll also put in there a pre-paid return envelope for you to send us the tracker back after the 2nd interview. **Is that ok?**

Can you just confirm your address, so that I know I'm posting the tracker to the correct place?

If at any point you get stuck, please get in touch and I can help.

I will also email you a log book for you to complete whilst you are using the 2 digital interventions. Please email this to us at the end of the 2 weeks. I'll send you a reminder. **Would that be ok?** (If not - I can arrange a hard copy to be posted and then posted back).

Can we arrange a time that suits you for the second interview? (Approx. 2.5/3weeks away).

BOOK IN NOW

Do you have any questions about the next part of the study?

Fantastic! Well, I'll send everything you need over today and look forward to hearing about how you get on **(INSERT DATE)**

Appendix L
APEASE criteria decision making process for BCTs in chapter five

Candidate BCT	Intervention function(s) the BCT relates to	Does this BCT meet the APEASE criteria in the context of a physical activity intervention for socially isolated older adults					
		Affordability	**Practicability**	**Effectiveness / Cost-effectiveness**	**Acceptability**	**Side-effects / Safety**	**Equity**
1.1 Goal setting (behaviour)	Enablement	Yes	Yes	Yes	Yes	Yes	Yes
1.2 Problem solving	Enablement	Yes	Yes	Yes	Yes	Yes	Yes
1.3 Goal setting (outcome)	Enablement	Yes	Yes	Yes	Yes	Yes	Yes
1.4. Action planning	Enablement	Yes	Yes	Yes	Yes	Yes	Yes
1.5 Review of behaviour goal(s)	Enablement	Yes	Yes	Yes	Yes	Yes	Yes
1.7 Review of outcome goal(s)	Enablement	Yes	Yes	Yes	Yes	Yes	Yes
2.2 Feedback on the behaviour	Education Training	Possibly if automated or cost (e.g. of professional) is not with user	Yes	Yes	Yes	Yes	Yes

Candidate BCT	Intervention function(s) the BCT relates to	Does this BCT meet the APEASE criteria in the context of a physical activity intervention for socially isolated older adults					
		Affordability	Practicability	Effectiveness / Cost-effectiveness	Acceptability	Side-effects / Safety	Equity
2.3 Self-monitoring of behaviour	Education Training Enablement	Possibly if using devices or methods that do not incur additional cost to user	Yes	Yes	Yes	Yes	Yes
2.7 Feedback on outcome(s) of behaviour	Education Training	Possibly if automated or cost (e.g. of professional) is not with user	Yes	Yes	Yes	Yes	Yes
3.1 Social support (unspecified)	Enablement	Yes	Yes	Possibly for socially isolated older adults that want social support	Possibly for socially isolated older adults that want social support	Possible but would need to ensure users were who they said they were if intervention involves meeting in person outside of a group setting	Possible, but note that some socially isolated older adults have fewer contacts than others
3.2 Social support (practical)	Enablement	Possibly if cost not with end user	Possible if users are local to each other	Possible if users are local to each other	Possibly for those who want it and are local to each other	Possible if users are local to each other, also see above	Possible but would need users to live locally to each other
4.1 Instruction on how to perform the behaviour	Training	Yes	Yes	Yes	Yes	Yes	Yes

Candidate BCT	Intervention function(s) the BCT relates to	Does this BCT meet the APEASE criteria in the context of a physical activity intervention for socially isolated older adults					
		Affordability	**Practicability**	**Effectiveness / Cost-effectiveness**	**Acceptability**	**Side-effects / Safety**	**Equity**
5.1 Information about health consequences	Education	Yes	Yes	Possible but should be combined with other BCTs	Yes	Possible to cause upset if user has or knows someone with a health risk, but delivered in a sensitive manner with appropriate persons to contact should they wish to discuss further (e.g. GP)	Yes
5.3 Information about social and environmental consequences	Education	Yes	Yes	Possible but should be combined with other BCTs	Yes	Possible (see above)	Yes
6.1 Demonstration of the behaviour	Training Modelling	Yes	Yes	Yes	Yes	Yes	Yes
7.1 Prompts and cues	Education Environmental restructuring	Yes	Yes	Yes	Yes	Possible but need to not be so frequent that they then are ignored	Yes
8.1 Behavioural practice/rehearsal	Training	Yes	Yes	Yes	Yes	Yes	Yes

Candidate BCT	Intervention function(s) the BCT relates to	Does this BCT meet the APEASE criteria in the context of a physical activity intervention for socially isolated older adults					
		Affordability	Practicability	Effectiveness / Cost-effectiveness	Acceptability	Side-effects / Safety	Equity
12.1 Restructuring the physical environment	Environmental restructuring Enablement	Possible if cost not with end user	Yes	Yes	Possible as long as no cost to end user and perceived benefits outweigh any drawbacks	Possible but needs to be evaluated in relation to the specific restructure and managed appropriately (e.g. removing bins from every room excluding the kitchen to foster movement around that house, may mean the large bin is too heavy for the user to actually empty each week)	Possible, especially if using what is already there
12.5 Adding objects into the environment	Environmental restructuring Enablement	Possible if cost not with end user	Yes	Yes	Possible as long as no cost to end user	Yes	Yes as long as no cost to end user

DBCI selection process to identify five DBCI to take to the PPI group in the study exploring the experiences of socially isolated older adults using DBCI for PA (chapter six)

Table A – Characteristics of the DBCI

Name	**Category**	**Appeared in WP1**	**In related literature**	**Found via…**	**Type PA**	**Type DBCI**	**Price**
Fitbit inspire HR	Activity Tracker - Watch Device	Yes - brand not specific device	Yes - brand not specific device	Fitbit website	Daily PA	Device, website, app	>£90
Runme Fitness tracker	Activity Tracker - Watch Device	No	No - but trackers are	Amazon	Daily PA	Device, app	>£11
Johnson & Johnson 7-min workout	Programme - Aerobic and Strength	No	Yes	Other literature	Aerobic	Mobile App	Free
The walk	Gamified	No	Yes	Other literature	Walking	Mobile App	Free
10 Today	Programme - Aerobic and Strength	No	No	Google	Stretching	YouTube Video, Podcast	Free
Go4Life National Institute on Ageing Workout Videos	Programme - Aerobic and Strength	No	No	Google	Aerobic and Strength	YouTube Video	Free
Map my fitness	Activity Tracker - Phone	No	Yes	App store	Multi	Mobile App	Free
NHS Strength and flex exercise podcasts	Programme - Strength	No	No	Google	Strength	Podcast	Free

Name	Category	Appeared in WP1	In related literature	Found via…	Type PA	Type DBCI	Price
Wysefit	Programme - Aerobic and Strength	No	No	App store	Aerobic and Strength	Mobile App	Subscription
Moves4Me	Programme - Strength	No	No	App store	Strength	Mobile App	Subscription
Nike Fuel Band	Activity Tracker - Watch Device	Yes	Yes	Systematic Review	Daily PA	Device, website, app	Cannot buy new
JawboneUP	Activity Tracker - Watch Device	Yes	Yes	Systematic Review	Daily PA	Device, website, app	>£20
Garmin Vivofit 4	Activity Tracker - Watch Device	No	Yes - brand not specific device	Google	Daily PA	Device, website, app	>£55
Garmin Vivosmart 4	Activity Tracker - Watch Device	No	Yes - brand not specific device	Google	Daily PA	Device, website, app	>£90
Garmin Vivosport	Activity Tracker - Watch Device	No	Yes - brand not specific device	Google	Daily PA	Device, website, app	>£90
Withings move	Activity Tracker - Watch Device	No	Yes - brand not specific device	Other literature	Daily PA	Device, app	>£70
Withings pulse HR	Activity Tracker - Watch Device	No	Yes - brand not specific device	Google	Daily PA	Device, website, app	>£90
Huawei Band 3 Pro	Activity Tracker - Watch Device	No	No - but trackers are	Argos	Daily PA	Device, app	>£60
Nuband flash HR 2	Activity Tracker - Watch Device	No	No - but trackers are	Argos	Daily PA	Device, app	>£40
Nuband Pro HR GPS	Activity Tracker - Watch Device	No	No - but trackers are	Argos	Daily PA	Device, app	>£60

Name	Category	Appeared in WP1	In related literature	Found via…	Type PA	Type DBCI	Price
Huawei Honor Band 4	Activity Tracker - Watch Device	No	No - but trackers are	Google	Daily PA	Device, app	>£25
Xiaomi Mi Band 4	Activity Tracker - Watch Device	No	No - but trackers are	Google	Daily PA	Device, app	>£30
Amazfit Bip	Activity Tracker - Watch Device	No	No - but trackers are	Google	Daily PA	Device, app	>£65
Amazfit Cor 2	Activity Tracker - Watch Device	No	No - but trackers are	Google	Daily PA	Device, app	>£40
Samsung Galaxy Fit	Activity Tracker - Watch Device	No	No - but trackers are	Google	Daily PA	Device, app	>£30
Moov Now	Activity Tracker - Watch Device	No	No - but trackers are	Google	Daily PA	Device, app	>£60
Willful fitness tracker	Activity Tracker - Watch Device	No	No - but trackers are	Amazon	Daily PA	Device, app	>£30
YAMAY fitness tracker SW336	Activity Tracker - Watch Device	No	No - but trackers are	Amazon	Daily PA	Device, app	>£30
ANCwear fitness tracker	Activity Tracker - Watch Device	No	No - but trackers are	Amazon	Daily PA	Device, app	>£11
YoYoFit Heart rate monitor, fitness tracker	Activity Tracker - Watch Device	No	No - but trackers are	Amazon	Daily PA	Device, app	>£11
GOJI GO HR fitness tracker	Activity Tracker - Watch Device	No	No - but trackers are	Currys	Daily PA	Device, app	>£25
One you couch to 5K	Programme - Aerobic	No	Yes	App store	Running	Mobile App, podcast	Free
PokemonGO	Gamified	No	Yes	App store	Indirect PA	Mobile App	Free
Human	Activity Tracker - Phone	No	Yes	Other literature	Daily PA	Mobile App	Free

Name	Category	Appeared in WP1	In related literature	Found via…	Type PA	Type DBCI	Price
Gorilla workout	Programme - Strength	No	Yes	Other literature	Aerobic and Strength	Mobile App	Free
Yoga studio	Programme - Yoga	No	No	App store	Yoga	Mobile App	Free
Daily yoga	Programme - Yoga	No	No	App store	Yoga	Mobile App	Free
Simply yoga - fitness trainer	Programme - Yoga	No	No	Google	Yoga	Mobile App	Subscription
Daily cardio workout - fitness	Programme - Aerobic	No	No	Google	Yoga	Mobile App	Free
Daily workouts fitness trainer	Programme - Aerobic and Strength	No	No	Google	Aerobic and Strength	Mobile App	Free
Freeletics Bodyweight	Programme - Aerobic and Strength	No	No	App store	Aerobic and Strength	Mobile App	Payment Plan
The Body Coach	Programme - Aerobic and Strength	No	No	Google	Aerobic and Strength	YouTube Video	Free
Geocaching	Gamified	No	Yes	App store	Indirect PA	Mobile App	Free
Home workout - no equipment (Leap Fitness Group)	Programme - Aerobic and Strength	No	No	App store	Strength	Mobile App	Free
Daily Senior Fitness Exercise	Programme - Aerobic and Strength	No	No	App store	Aerobic and Strength	Mobile App	Free
Fitivity senior fitness - strength and flexibility training	Programme - Aerobic and Strength	No	No	App store	Aerobic and Strength	Mobile App	Free

Name	Category	Appeared in WP1	In related literature	Found via…	Type PA	Type DBCI	Price
Map my walk	Activity Tracker - Phone	No	Yes	App store	Walking	Mobile App	Free
Tai Chi for seniors	Programme - Tai Chi	No	No	Google	Tai Chi	Mobile App	Free
Tai Chi Fit OVER 50	Programme - Tai Chi	No	No	App store	Tai Chi	Mobile App	Free
Fitness builder	Programme - Aerobic and Strength	No	No	Google	Aerobic and Strength	Mobile App	Free
Sworkit	Programme - Aerobic and Strength	No	No	Google	Aerobic and Strength	Mobile App	Free
Charity Miles	Activity Tracker - Phone	No	No	Recommended by friend	Walking/Running	Mobile App	Free
Sweatcoin	Activity Tracker - Phone	No	No	Recommended by friend	Walking/Running	Mobile App	Free
Aaptiv	Programme - Aerobic and Strength	No	No	Google	Multi	Mobile App	Free
Nike training club	Programme - Aerobic and Strength	No	Yes	Google	Aerobic and Strength	Mobile App	Free
Endomondo	Activity Tracker - Phone	No	No	Google	Walking/Running	Mobile App	Free
Gixo: exercise live and on demand	Programme - Aerobic and Strength	No	No	Google	Aerobic and Strength	Mobile App	Free
Pilates anytime	Programme - Pilates	No	No	Google	Pilates	Mobile App	Free
Fitocracy	Gamified	No	No	Google	Multi	Mobile App	Free

Name	Category	Appeared in WP1	In related literature	Found via…	Type PA	Type DBCI	Price
iPrescribe exercise	Programme - Aerobic and Strength	No	No	NHS App library	Aerobic and Strength	Mobile App	Free
8fit	Programme - Aerobic and Strength	No	No	Recommended by friend	Aerobic and Strength	Mobile App	Free
Silver Coach	Programme - Strength	No	No	App store	Strength	Mobile App	Free

Table B – DBCI Descriptions, BCTs (if coded in the literature), and decision process

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Fitbit inspire HR	Steps & activity, calories burned, sleep tracking, sleep stages, female health tracking, guided breathing sessions, auto exercise recognition, reminders to move, hourly activity, swim tracking, 15+ exercise modes, 24/7 HR tracking, cardio fitness level, on-screen workouts, GPS.	1.1, 1.3, 1.5, 2.2, 2.3, 3.1, 6.2, 10.3	8	5	Established and recognised brand, website and app, iOS and android, lots of potential BCTs, PA and SB elements, lots of online troubleshooting, social elements, on-screen feedback, GPS option, HR tracking	Cost, no control over updates or data privacy	Take to PPI	Well known brand, expensive but has app, website and device options, social element within the DBCI, previously used in literature and BCT coded	N/A
Runme Fitness tracker	sleep monitoring, HR tracking, steps, distance, calories burned, duration, 14 sport modes.	x	x	x	CHEAP, iOS and android, 80% 5* reviews on amazon	VeryFit Pro app has some strange language - suspect poor translation. Can understand if familiar with the tech but could be tricky for new users?	Take to PPI	Cheap version of Fitbit, with slightly less features	N/A

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Johnson & Johnson 7-min workout	22 pre-set workout, varying intensity and duration ranging from 7-32min. Can gauge fitness and motivation level to create specific workouts	1.4, 2.3, 4.1, 6.1, 7.1, 8.7, 9.1	7	7	Cost, iOS and android. Clear video demonstrations during exercise and time to prepare for next exercise. Can learn exercises before starting workout. Can create a list of exercises you like and dislike. Movements aren't rapid so could be encouraging for people less fit	Some exercises (e.g. step-up may be too tricky - this example has people stepping up onto a chair at beginner level. May need adapting to a step in some cases).	Take to PPI	Free, easy to use, adaptable exercises	N/A
The walk	Gamified walking tracker. Story progresses with steps. Can adjust for fitness levels. First 5 free then can unlock next ones for a one off fee	2.2, 10.3, 10.6	3	2	Cost, iOS and android	May not have enough BCT clusters for effective behaviour change	Take to PPI	Free. Gamified.	N/A
10 Today	Exercise videos (or audio only). Specifically for older adults. Aims to increase physical activity and reduce social isolation with 10mins of exercise. Sport England Funding. Aimed at 55+ years	x	x	x	Cost	May be too simple for some. Not that much variation so after the initial trial, people might get bored	Take to PPI	Free. Easy exercises. Designed specifically for older adults	N/A

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Go4Life National Institute on Ageing Workout Videos	Workout videos specifically for older adults. 10/15/20/60 min workouts	x	x	x	Cost		Runner up	Other similar YouTube video has podcast possibility too.	Better features in cheaper options
Map my fitness	Track and map every workout with MapMyFitness and get feedback and stats to improve your performance. Discover new workout routes, save and share your favourites, and get inspired to reach new fitness goals with a community of over 40 million athletes. Whether you're a beginner doing your first workout or a pro, you'll find the features and tools you need to stay on track and motivated along the way.	x	x	x	Potentially pairable with trackers that don't have their own apps?	Data transferred to USA	Runner up	Activity tracker app only requires phone to be on person at all times. Using a wearable doesn't need to be, but GPS can be used via phone	Better features in cheaper options

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
NHS Strength and flex exercise podcasts	these podcasts talk you through a series of equipment-free exercises to improve your strength and flexibility. Your goal is to work your way up to podcast 5 in five weeks, by doing each podcast three times a week. By week 5, you'll be doing press-ups, squats and stretches with ease, feeling stronger, more flexible and full of energy.	x	x	x			Runner up	Only podcast. Similar podcast has YouTube and podcast possibilities	Better features in cheaper options
Wysefit	Mixture of exercises to build strength, work on balance and flexibility etc.	x	x	x	Designed for 50+, quite short duration	Subscription	Runner up	Subscription required	Subscription
Moves4Me	Exercise programme to help older adults with strength, balance and prevent falls	x	x	x	Designed for older adults	Subscription needed after 14 days, poor reviews	Runner up	Free 14 day trial but then subscription needed	Subscription
Nike Fuel Band	Steps, energy burn	x	x	x	Built in USB, website and app (iOS only), social elements	Discontinued 2014, made inoperable in 2018 due to inability to clear memory.	Not included	Cannot be 'future-proofed' - Discontinued device	Discontinued
JawboneUP	Reminders to move, steps, calories burned, sleep tracking, HR monitoring, active time	x	x	x	Much the same as other wrist trackers	Company went into liquidation 2017	Not included	Cannot be 'future-proofed' - Company liquidated	Company Liquidated

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Garmin Vivofit 4	1 year battery life, steps, move bar, auto goal, sleep tracking, calories burned, floors climbed, distance, intensity minutes,	x	x	x	Established brand, website and app, iOS and android, 1 year battery, on-screen feedback, auto-goals could be interesting, lots of online troubleshooting, social element potential,	Cost, no control over updates or data privacy	Not included	Activity tracker needs HR functionality. Very common even in cheaper brands.	Better features in cheaper options
Garmin Vivosmart 4	7 days battery life, steps, move bar, auto goal, sleep tracking, calories burned, floors climbed, distance, intensity minutes, fitness age, energy monitor, all-day stress tracking, gym activity profiles (strength training, cardio, elliptical, stair stepping, yoga, automatic rep counting), HR tracking,	x	x	x	Established brand, website and app, iOS and android,	Cost	Not included	Too expensive and not seen much in literature, more exercise focused rather than general PA	Expensive
Garmin Vivosport	7 days battery life, steps, move bar, auto goal, sleep tracking, calories burned, floors climbed, distance, intensity minutes, fitness age, energy monitor, all-day stress tracking, GPS, HR tracking,	x	x	x	Established brand, website and app, iOS and android,	Cost	Not included	Too expensive and not seen much in literature, more exercise focused rather than general PA	Expensive

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Withings move	18 month battery life, sleep, steps, distance, calories, swimming duration and calories,	1.1, 1.3, 1.4, 1.5, 2.2, 2.3, 3.1, 5.3, 10.3	9	5	Established brand, website and app, iOS and android,	No HR	Not included	Activity tracker needs HR functionality. Very common even in cheaper brands.	Better features in cheaper options
Withings pulse HR	20 day battery life, steps, distance, calories, HR tracking, Swimming duration and calories, sleep,	x	x	x	iOS and android, website? And app, more classic watch design so may be more appealing to older adults? GPS option, HR tracking	Cost, website is not fully functional which doesn't fill me with confidence for devices and app, lesser known brand, fewer activity tracking features	Not included	Free. Easy exercises. Designed specifically for older adults	Expensive
Huawei Band 3 Pro	Screen, HR, Waterproof, GPS, 14 day battery life, steps, HR tracking, sleep, active minutes, elevation, automatic activity tracking, calories burned, distance, calories burned, multi-sport mode	x	x	x	iOS and android, automatic activity tracking, cheaper, HR tracking, GPS	Lesser known brand, no website option	Not included	Not found in literature, cost	Expensive
Nuband flash HR 2	steps, distance, calories, sleep, HR, multi-sports mode	x	x	x	iOS and android	Cost	Not included	Not found in literature, cost	Expensive
Nuband Pro HR GPS	steps, distance, calories, sleep, GPS, HR, multi-sports mode	x	x	x	iOS and android	Cost	Not included	Not found in literature, cost	Expensive

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Huawei Honor Band 4	Screen, sleep, active minutes, steps, HR tracking, distance,	x	x	x	HR tracking	Lesser known brand, no website option, no GPS	Not included	Not found in literature, cost	Expensive
Xiaomi Mi Band 4	Screen, waterproof, 20+ days battery, sleep, steps, HR, calories burned, distance, goal setting, multi sport mode, 20 day battery life, idle alerts, 6 workout modes (treadmill, exercise, outdoor running, cycling, walking, pool swimming,	x	x	x	iOS and android, cheaper, HR tracking, idle reminders	Lesser known brand, no website option, no auto tracking, no GPS	Not included	Not found in literature, cost	Expensive
Amazfit Bip	30 days battery life, mulit sport tracking, HR tracking, GPS, sleep tracking	x	x	x	HR tracking, GPS	Lesser known brand, no reminders to move	Not included	Not found in literature, cost	Expensive
Amazfit Cor 2	12 days battery life, steps, distance, calories burned, HR tracking, sleep tracking, move reminders,	x	x	x	HR tracking, reminders to move	Lesser known brand, no GPS	Not included	Not found in literature, cost	Expensive
Samsung Galaxy Fit	screen, steps, distance, HR, calories burned, sleep tracking, 7 days battery life	x	x	x	Known brand, HR tracking, iOS and android	No GPS, need to download Galaxy Fit and Samsung health apps - might be confusing.	Not included	Not found in literature, cost	Expensive

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Moov Now	run and walk, cycling, swimming, 7 minute +, cardio boxing, activity and sleep tracking	x	x	x	iOS and android	Lesser known brand, no screen, ugly, no HR, no GPS	Not included	Activity tracker needs HR functionality. Very common even in cheaper brands.	Better features in cheaper options
Willful fitness tracker	sleep monitoring, HR tracking, steps, distance, calories burned, duration, 14 sport modes.	x	x	x	iOS and android	Cost	Not included	Not found in literature, cost	Expensive
YAMAY fitness tracker SW336	14 sport modes (walking, running, cycling, hiking, fitness, treadmill, basketball, tennis, climbing, badminton, dynamic-cycling, yoga, football, dancing), HR monitor, steps, distance, calories	x	x	x	iOS and android	Cost	Not included	Not found in literature, cost	Expensive
ANCwear fitness tracker	HR tracking, sleep monitor, step counter, reminder to move, blood pressure monitor, distance, calories, active minutes, waterproof	x	x	x	CHEAP, iOS and android	Poor reviews on amazon	Not included	Poor reviews	Better features in cheaper options
YoYoFit Heart rate monitor, fitness tracker	sleep monitoring, HR tracking, steps, distance, calories burned, duration, 14 sport modes.	x	x	x	CHEAP, iOS and android	Poor reviews on amazon	Not included	Poor reviews	Better features in cheaper options

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
GOJI GO HR fitness tracker	Screen, steps, distance, calories, sleep, HR, battery life 6 days	x	x	x	iOS and android	Cost	Not included	Not found in literature, cost	Expensive
One you couch to 5K	Gradually build up with a mix of running and walking from couch potato, to 5k hero in just 9 weeks.	x	x	x	Cost	Intensity of running may be too much for some?	Not included	Older adults who are insufficiently active are unlikely to be attracted to running	Activity not suitable for older adults
PokemonGO	Augmented reality game using mobile GPS to locate, capture, battle and train virtual Pokémon creatures (as if in players real world location).	x	x	x	Cost, iOS and android	Designed for millennials but may have some intergenerational aspect that could be useful for reducing social isolation?	Not included	Confusing to use if not tech savvy. Designed for Pokémon fans and most older adults won't know it	Not for UK older adults

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Human	All day activity tracker and shows you how you compare with people like you (in your city/neighbourhood). Minutes of activity not steps.	1.1, 2.2, 2.3, 6.2, 7.1, 10.3	6	5	Cost, iOS and android.	Didn't seem to work properly when tested	Not included	Tracks activity and compares to other near your location. On trial in a town, I was number 1 of 1…. So others around the area are not using this app…. Meaning one of the key USPs is worthless.	Key feature did not work

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Gorilla workout	4 fitness levels and 175 workouts. Tracks progress, social sharing. Bodyweight exercises. Video demonstrations and descriptions of each exercise	4.1, 6.1, 7.1, 8.7	4	4	Cost, iOS and android	Only access 5 work outs free before payment required (£0.99 and in-app purchases). Just gives you written names of exercises and have to search for full written description. Video demonstrations not working on free version.	Not included	The free version just gives you a list of exercises to do. You have to go into something else to get a demonstration of them. Need to then learn the exercises or stop workouts to find out what you are supposed to do.;	Activity not suitable for older adults
Yoga studio	25hrs of HD video classes, 280 poses, can schedule with calendar,	x	x	x	Cost, iOS and android	Advertising app for yoga classes - no actually PA	Not included	No actual work outs. Just contact info for yoga classes in USA	Main purpose not PA

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Daily yoga	250 sessions with different intensities and focuses. Video and voice instruction	x	x	x	Cost, iOS and android. Nice video demonstrations.	Can only start as beginner and have access to 7 workouts (Monthly subscription £18.49/month or £33.99/year)	Not included	Even some basic exercises required a good level of balance or strength that older adults may not have.	Activity not suitable for older adults
Simply yoga - fitness trainer	Yoga routines and videos to follow along to	x	x	x	Seemingly clear instruction videos	Subscription	Not included	Only get one workout free, then have to subscribe	Subscription
Daily cardio workout - fitness	Body weight workout	x	x	x	Cost	PA may not be suitable for older adults	Not included	Types of exercises may be too much for some older adults. No clear guidance on how to make it easier	Activity not suitable for older adults
Daily workouts fitness trainer	10 different 5-10min workout targeted workouts. 10-30min full body workouts/ 100+ exercises. Videos demonstrations. No internet required to do most workouts	x	x	x	Cost, iOS and android	PA may not be suitable for older adults	Not included	Some exercises not appropriate for older adults. Also many exercises required equipment	Activity not suitable for older adults

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Freeletics Bodyweight	HIIT body weight exercises. 10-30min personalised workouts. Fitness planner	x	x	x	Cost, iOS and android	Monthly subscription not viable for PhD testing.	Not included	Monthly subscription not viable for PhD study	Subscription
The Body Coach	weekly HIIT workouts to help you burn fat and get fitter, stronger, healthier and lean. You don't need a gym to get lean and most of my workouts can be done anywhere with no equipment.	x	x	x	Cost	Designed for millennials, HITT may be too intense even using beginners workouts.	Not included	Even the beginner workouts may be too intense for older adults.	Activity not suitable for older adults
Geocaching	Treasure hunt. Not designed for PA but will include some walking/running. Social sharing	x	x	x	Cost	Main focus is not PA, rather that is a by-product.	Not included	Main purpose not PA promotion	Main purpose not PA

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Home workout - no equipment (Leap Fitness Group)	Daily workout routines for all main muscle groups, body weight.	x	x	x	Cost. Clear cartoon demonstrations and count down timer. Can view all exercises before starting workout.	Adverts - need to remind people to ignore them. Subscription required to access most things. £56.99/year. Doesn't give you much rest in between. The pictures on the app are of young, 6-pack/shredded males - not the same as target audience - could be intimidating.	Not included	Target audience doesn't match 50+	Activity not suitable for older adults
Daily Senior Fitness Exercise	It guides you on how to recover from different body parts pain. It also contains daily exercise routines, which if you follow can bring you back to good health. It also has complete pictorial representation of all the exercises. "Daily Senior Fitness Exercise" covers all you required exercises which can remove your unwanted pains.	x	x	x	Cost	Android only	Not included	Android only	Platform

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Fitivity senior fitness - strength and flexibility training	Designed for 60+. Workouts with demonstrations.	x	x	x	Cost	Android only	Not included	Android only	Platform
Map my walk	use your smartphone's GPS to record every detail of your workout. Follow your route on an interactive map while logging time, distance, speed, pace, elevation and calories burned.	x	x	x	No extra equipment, free, PA accessible to most	Only for walking	Not included	Only walking. Map my fitness records walks and other exercise	Other app more features
Tai Chi for seniors	Tai Chi for Senior comprises 64 Tai Chi videos (from 4 angles) with step by step detailed instruction from the Tai Chi master Dejun Xue	x	x	x	Designed for seniors	Apple only	Not included	Apple only	Platform
Tai Chi Fit OVER 50	Mirror-view beginner tai chi moves to the left and right. Low-impact, whole body exercise done sitting or standing. No experience needed; beginner-friendly follow-along workout.	x	x	x	Designed for over 50s	Subscription	Not included	Can only get a preview for free. Requires subscription	Subscription

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Fitness builder	400 workouts in 16 multi-week fitness plans as well as a complete body stat tracker.	x	x	x	Cost	Poor reviews	Not included	Only photos of exercises. More a way of recording what exercises have been done and the sets and reps	Activity not suitable for older adults
Sworkit	Get started on a 6-week program to get "Leaner," "Fitter," or "Stronger." These plans, for beginner, intermediate, or advanced levels, include weight loss, HIIT, Tabata, cardio, strength, yoga, Pilates workouts, and more! We've got a selection of over 400 bodyweight and small equipment exercises as well as 300-plus customizable workouts. Plus, new workouts are added every month. Create your own workouts from scratch or personalize one of our workouts by adding or removing exercises.	x	x	x	Cost	Only 3 workouts, PA may be too hard	Not included	3 workouts in free trial. Exercises not appropriate for older adults	Activity not suitable for older adults

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Charity Miles	Run/walk tracker that equates steps to monetary charity donations	x	x	x	Cost	Have to log each walk/run. Doesn't track daily steps. Most Charities are American so not necessary UK related	Not included	Not UK audience	Not for UK older adults
Sweatcoin	Run/walk tracker that equates steps to 'sweatcoins' that can be translated into real world rewards e.g. charity donation/free music streaming/my protein purchases/money	x	x	x	Cost	Can be a battery drainer, but there is a battery saver mode. You have to earn a lot of coins to gain any benefits and types of benefits unlikely to appeal to older adults	Not included	Kills battery, rewards are not for older adults population.	Drains battery
Aaptiv	Audio only exercise classes. 7min +. Running, cycling, elliptical, stretching, yoga, strength training, HIIT.	x	x	x	Unlimited access is monthly/yearly subscription		Not included	Requires gym equipment. Most things have to be unlocked with subscription	Activity not suitable for older adults

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Nike training club	185+ free workouts from strength and endurance to mobility and yoga. Body part focus, boxing, yoga, strength, endurance and mobility workouts. Beginner, intermediate and advanced levels. Low, moderate and high intensity. Body weight only, light and full equipment. Time based and rep based	x	x	x	Cost	Exercise equipment needed, PA may be too hard	Not included	Exercises require equipment, and may not be suitable for older adults. E.g. kneeling, balances	Activity not suitable for older adults
Endomondo	Track your workouts using GPS, analyse your stats, reach your fitness goals, and be part of our global community of millions of fitness enthusiasts and athletes	x	x	x	Free to use option	Subscription, mostly for walking, cycling, running or distance sports	Not included	Free use is very limited. To get benefit of full app requires subscription	Subscription

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Gixo: exercise live and on demand	Join live group running, walking, HIIT, strength, and Tabata workout classes. Turn your phone into a virtual gym. Gixo live group fitness classes are coached by a real-life trainer who gets to know you, personalizes your experience in real-time, and makes exercising more social and more fun. You can join the live workouts from anywhere on your phone: at home, the gym, even outside. We know you're busy. That's why we offer classes day and night for 15 minutes, 25 minutes or 40 minutes at a time. You can take classes LIVE and pre-recorded classes On Demand 24/7. No equipment. phone tracks personal stats. Monthly fitness challenges an community fundraisers.	x	x	x	In theory there should be classes available 24/7	Subscription	Not included	Requires monthly subscription	Subscription
Pilates anytime	Pilates videos.	x	x	x	All levels and durations	15 day free trial then £12 p/month subscription. Apple only	Not included	Apple only. Subscription auto renews after trial	Platform

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
Fitocracy	Track your workouts, earn points, unlock achievements, beat quests, and slay the laziness dragon. Online community. Free workouts. Gamified	x	x	x	Free and monthly subscription options	PA not appropriate for or older adults	Not included	Exercises even at beginner level are not older adults friendly. E.g. jumping jacks, side planks. Also pictures on app are of young athletics people in the gym using specialist equipment	Activity not suitable for older adults
iPrescribe exercise	Enter resting HR and task 6min walking fitness test. The app will then generate a personalised 12-week exercise plan that tells you how long and at what intensity you should be exercising. This will gradually increase until you meet the recommended levels of five 30-minute periods of exercise a week by the end of your plan. Online community.	x	x	x	Physiotherapist backed, NHS backed	Apple only	Not included	Apple only	Platform

Name	Description / Features	Individual BCTs (see BCTTv1)	BCT No.	BCT Clusters	Pros	Cons	Decision	Reasoning	Category of Rejection
8fit	Custom home workouts and nutrition plans	x	x	x	bodyweight to build muscle strength, increase endurance, improve cardiovascular fitness and lose weight without catabolizing hard earned muscles. The HIIT workout (high intensity interval training) is one of our users' favourites because it is fast and more effective than traditional cardio workouts. 8fit's workouts only take 5-20 minutes. Nutrition element.	PA may be too hard, subscription	Not included	Exercises require a good level of balance and flexibility that older adults may not have	Activity not suitable for older adults
Silver Coach	Body weight workouts	x	x	x	Cost	Subscription, aimed at muscly men	Not included	Subscription required	Subscription

Appendix N

DBCI selection PPI Form for two DBCI to be used in the study exploring the experiences of socially isolated older adults using DBCI for PA (chapter six)

Public Involvement

What is the research about?

My research is looking at how we could use digital interventions to get people who are aged 50+ and at risk of social isolation more physically active. Thank you for offering to help with the project.

What do you need to do?

Firstly, I need help deciding which digital physical activity interventions to use with people aged 50+ who may be at risk of isolation and/or loneliness.

Below I have typed out the descriptions of five digital physical activity interventions. I would like to know which two interventions most appeal to you. Please take a look at the descriptions and pictures, and write your choices in the space provided on the final page.

Please could you also fill in your age and gender at the top of the form below, and complete the social network questionnaire. This will give me a broad indication of how similar/different the public involvement group are to the intended target group.

Digital physical activity intervention choices:

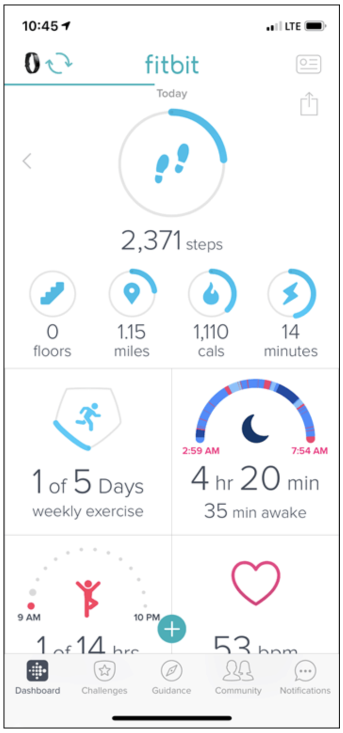
1. **The Walk - £0 for 5 episodes. (Unlock all for £4.99)**
   - Smartphone app

The Walk is more than just a great pedometer/step counter — it's a way to turn walking into a journey, a challenge, and a rip-roaring adventure. The app tracks your steps and depending on how many you have taken, will unlock parts of a story. Created with the NHS and UKs Department of Health.

“A bomb explodes in Inverness station, and you’re given a package that could save the world. You’ll walk the length of the UK while evading capture by the police and enemy agents. Can you work out who set off that bomb in the first place and what their plan is? Get ready for an epic adventure across 65 episodes, 800 minutes of audio, and hundreds of miles. Get rewarded for walking more by collecting clues, scanning for information, and unlocking achievements. The Walk adjusts its difficulty based on individual fitness levels. Everyone's different, and we make sure we give you the right level of challenge!"

2. <u>Fitbit Inspire HR - £90</u>

- A Wearable device
- Smartphone/Tablet App
- Website



A wrist-worn activity tracker that can be paired via Bluetooth to a smartphone or computer. The Fitbit has a screen that displays steps taken, calories burned, heart rate, etc. and an app or website can also be used to track sleep patterns, set physical activity goals, record workouts, monitor physical activity, earn badges, log food, measure hydration, set reminders to move and compete with friends.

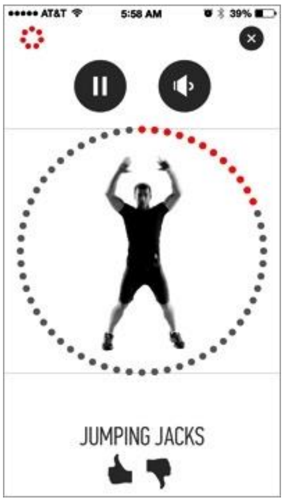
3. <u>10 Today - £0</u>

- Videos
- Soundcloud (audio only)

An innovative exercise programme designed by older people, for older people. 10 Today involves short ten-minute routines to get you stretching and moving. Funded by Big Lottery and Sport England.

4. **<u>Runme Fitness Tracker</u> - £15**
- A Wearable device
- Smartphone/Tablet App

A wrist-worn activity tracker that can be paired via Bluetooth to a smartphone. The device has a screen that displays some metrics (e.g. steps taken, calories burned, heart rate), however the app can be used to further track sleep patterns, set physical activity goals, record workouts, and monitor physical activity.



5. **<u>Johnson & Johnson 7-min workout - £0</u>**
- Smartphone/Tablet App

There are 22 pre-set workouts, including 72 exercises, that vary in intensity and duration (7-32 mins). The smart workout feature gauges your fitness and motivation level and creates a variety of workouts specifically for you. You can set workout and inactivity reminders. You are also able to like and dislike specific exercises so that the workout can be tailored to you.

Please complete the form below:

What is yours age (in years)?

____

Gender (please circle): MALE / FEMALE / PREFER NOT TO SAY

Which 2 digital physical activity interventions have you chosen and why?

Choice Number 1:

____

Why?

Choice Number 2:

____

Why?

Social Networks

Please complete the following questionnaire. There are no right or wrong answers, so please be completely honest.

Questions	Answers (Tick answer)	
FAMILY – Considering the people to whom you are related either by birth or by marriage…		
1. How many relatives do you see or hear from at least once a month?	☐ 0 ☐ 1 ☐ 2	☐ 3 – 4 ☐ 5 – 8 ☐ 9 +
2. How many relatives do you feel close to such that you could call on them for help?	☐ 0 ☐ 1 ☐ 2	☐ 3 – 4 ☐ 5 – 8 ☐ 9 +
3. How many relatives do you feel at ease with that you can talk about private matters?	☐ 0 ☐ 1 ☐ 2	☐ 3 – 4 ☐ 5 – 8 ☐ 9 +
FRIENDSHIPS – Considering all of your friends including those who live in your neighbourhood…		
4. How many of your friends do you see or hear from at least once a month?	☐ 0 ☐ 1 ☐ 2	☐ 3 – 4 ☐ 5 – 8 ☐ 9 +
5. How many of your friends do you feel close to such that you could call on them for help?	☐ 0 ☐ 1 ☐ 2	☐ 3 – 4 ☐ 5 – 8 ☐ 9 +
6. How many of your friends do you feel at ease with that you can talk about private matters?	☐ 0 ☐ 1 ☐ 2	☐ 3 – 4 ☐ 5 – 8 ☐ 9 +

Appendix O

The results of the PPI DBCI selection process for the study exploring the experiences of socially isolated older adults using DBCI for PA (chapter six)

Results for whole PPI group (n = 38)

	Choice 1 (n)	Choice 2 (n)	Total Votes (n)	Rank
The Walk	11	2	13	4
Fitbit	10	6	16	1
10 Today	6	5	11	5
Runme Tracker	6	8	14	2
J&J 7min Workout	3	10	13	3

Highlighted cells indicate the two most popular DBCI selected.

Results for participants with a Lubben score < 12 (socially isolated) (n = 4)

	Choice 1 (n)	Choice 2 (n)	Total Votes (n)	Rank
The Walk	0	0	0	5
Fitbit	0	1	1	3
10 Today	1	0	1	3
Runme Tracker	1	1	2	1
J&J 7min Workout	1	1	2	1

Highlighted cells indicate the two most popular DBCI selected.

Results for participants with a Lubben score ≤ 15 (n = 12)

	Choice 1 (n)	Choice 2 (n)	Total Votes (n)	Rank
The Walk	3	0	3	5
Fitbit	3	1	4	3
10 Today	2	1	3	5
Runme Tracker	1	4	5	1
J&J 7min Workout	1	4	5	1

Highlighted cells indicate the two most popular DBCI selected. This was calculated as a decision based on 4 PPI participants was deemed insufficient, therefore additional consideration was given to the results of those scoring ≤ 50% (max. Lubben score = 30).

Appendix P

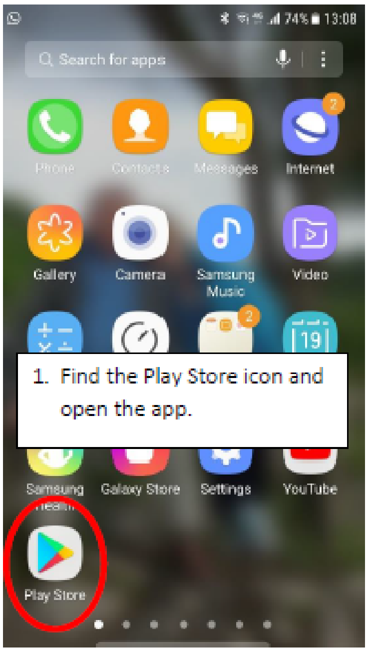
DBCI download instructions (Android version) as given to participants in the study exploring the experiences of socially isolated older adults using DBCI for PA (chapter six)

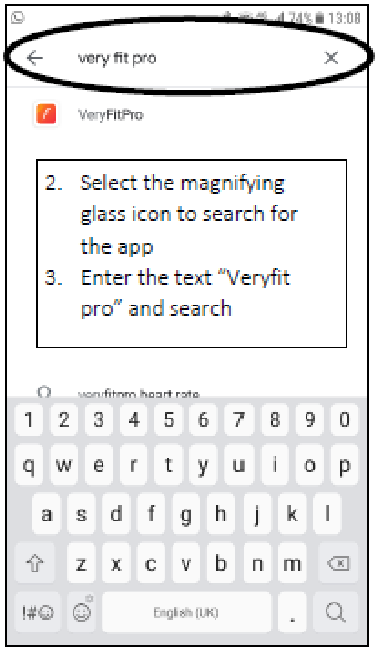
Runme Fitness Tracker & Veryfit Pro app

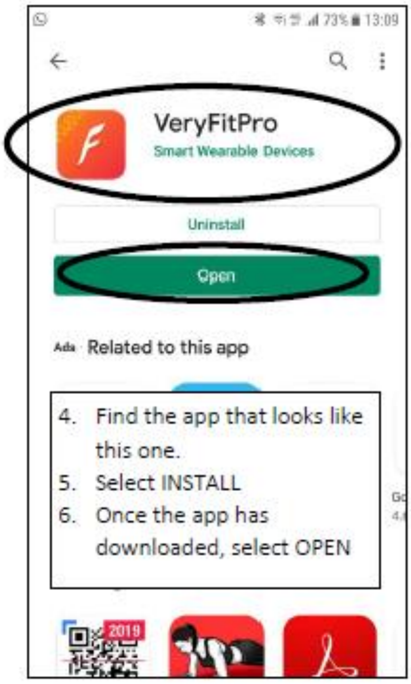
If you are unsure or get stuck with downloading, please contact the research team and they will be able to help you.

If you have an **<u>Android phone/tablet</u>** (e.g. Samsung, Huawei, Sony, Nokia, LG, Motorola, Blackberry, Amazon) please follow these instructions.

<u>How to download the app</u>



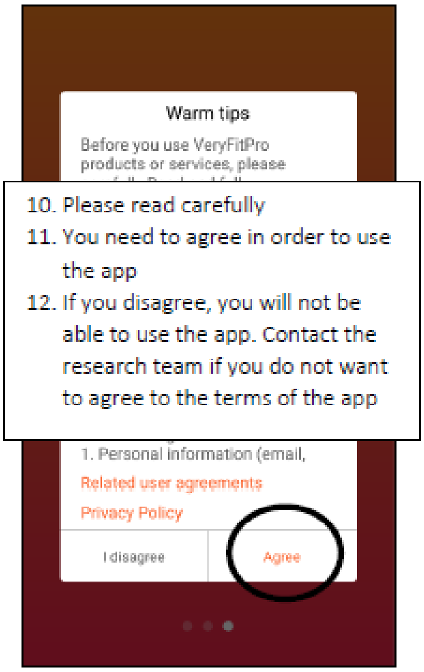



73% 13:09
VeryFitPro
Smart Wearable Devices
Uninstall
Open
Ads · Related to this app
4. Find the app that looks like this one.
5. Select INSTALL
6. Once the app has downloaded, select OPEN
2019

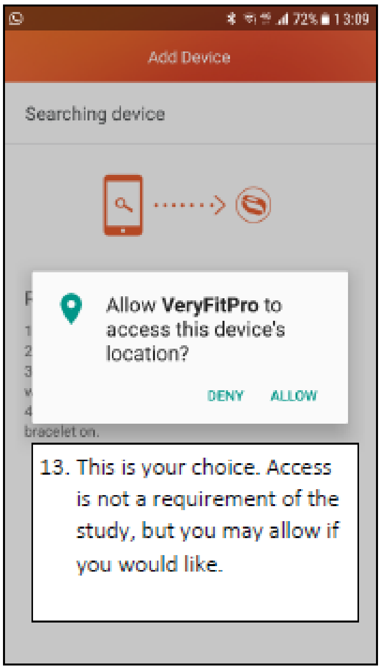

7. Swipe from right to left


8. Swipe from right to left

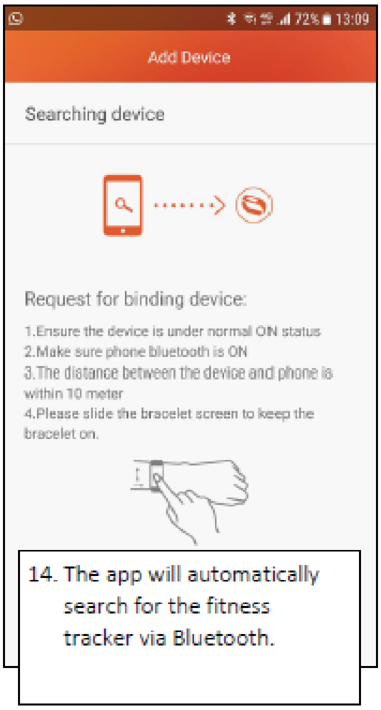

9. Select 'Use Now'
Use now



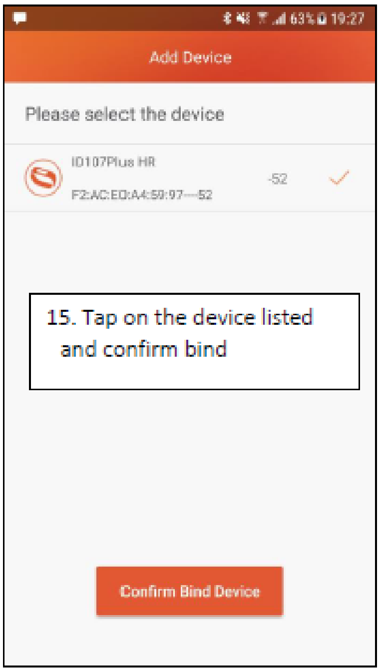
10. Please read carefully
11. You need to agree in order to use the app
12. If you disagree, you will not be able to use the app. Contact the research team if you do not want to agree to the terms of the app



13. This is your choice. Access is not a requirement of the study, but you may allow if you would like.



14. The app will automatically search for the fitness tracker via Bluetooth.



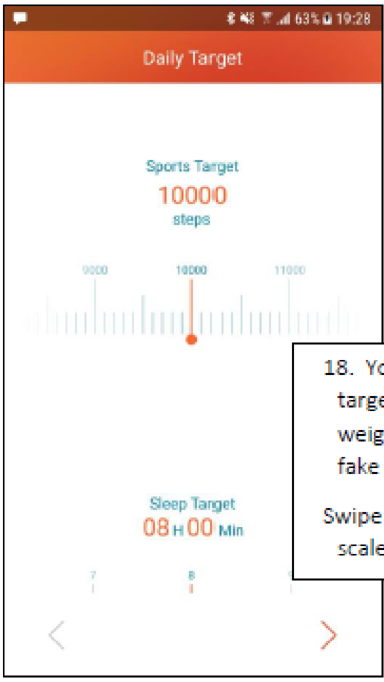
15. Tap on the device listed and confirm bind

16. You will be asked to enter details about your gender, birth year, height and weight.

    You are welcome to enter accurate information if you wish.

    If you don't want to enter this information, you are welcome to enter fake information. In order to use the app some information needs to be entered – true or fake.

17. Select the next arrow after each



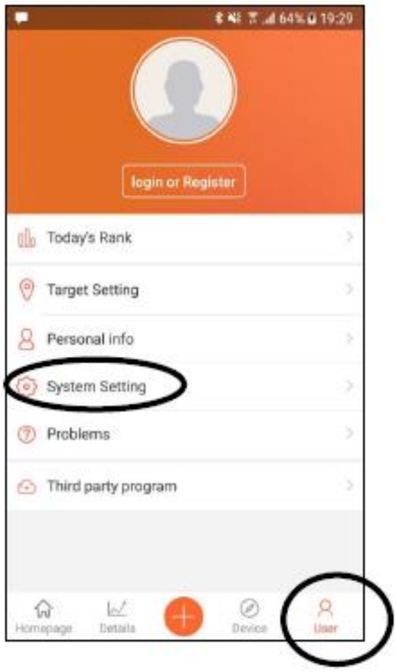
18. You will be asked to set targets for steps, sleep and weight. You can enter true or fake information.

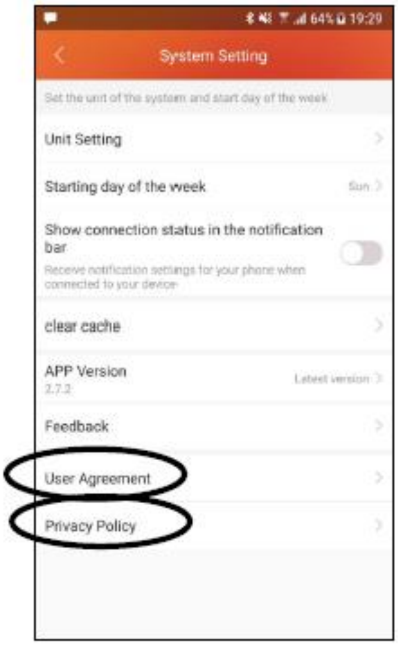
Swipe left or right on the scales to select.

<u>How to switch on and use the fitness tracker</u>

Please follow the instruction leaflet provided by the manufacturer, which was in the fitness tracker box.

How to find the full terms and conditions and privacy details on the app





2. Select the user icon at the bottom of the screen.
3. The select system settings

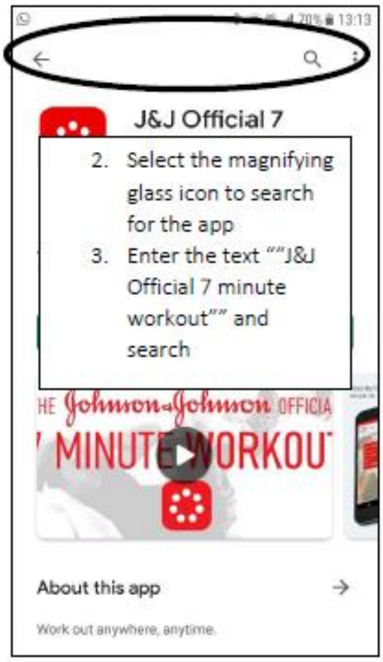
1. Here you can view the user agreement and privacy policy for the app

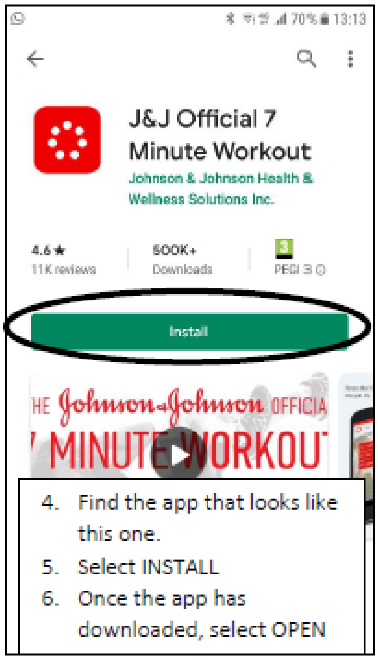
Johnson & Johnson 7-minute workout app

If you are unsure or get stuck with downloading, please contact the research team and they will be able to help you.

If you have an **Android phone/tablet** (e.g. Samsung, Huawei, Sony, Nokia, LG, Motorola, Blackberry, Amazon) please follow these instructions.

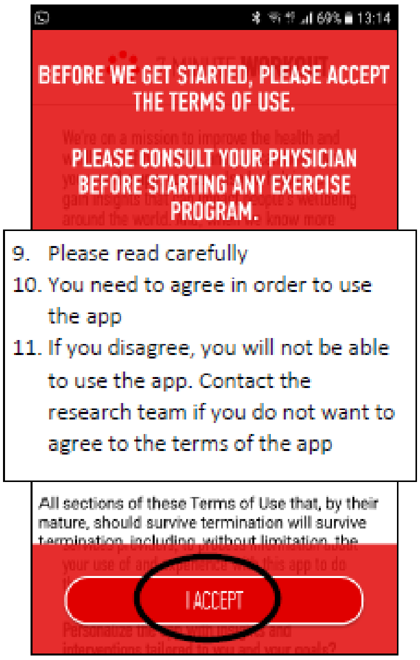
How to download the app



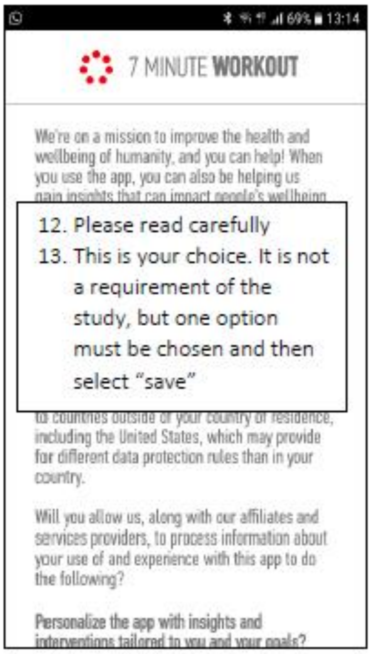


4. Find the app that looks like this one.
5. Select INSTALL
6. Once the app has downloaded, select OPEN

7. Select United Kingdom from the drop-down menu
8. Select confirm country

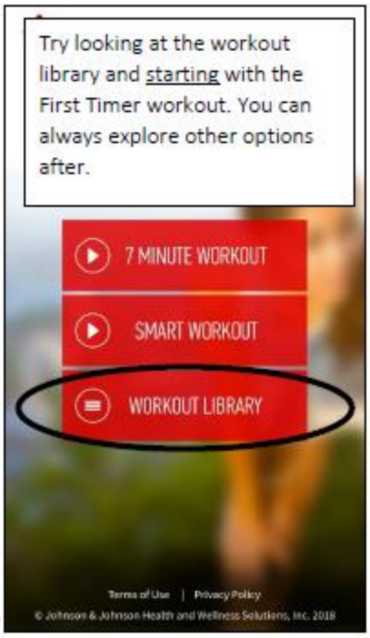


9. Please read carefully
10. You need to agree in order to use the app
11. If you disagree, you will not be able to use the app. Contact the research team if you do not want to agree to the terms of the app


7 MINUTE WORKOUT
We're on a mission to improve the health and wellbeing of humanity, and you can help! When you use the app, you can also be helping us
12. Please read carefully
13. This is your choice. It is not a requirement of the study, but one option must be chosen and then select "save"
including the United States, which may provide for different data protection rules than in your country.
Will you allow us, along with our affiliates and services providers, to process information about your use of and experience with this app to do the following?
Personalize the app with insights and


7 MINUTE WORKOUT
Will you allow us, along with our affiliates and services providers, to process information about your use of and experience with this app to do the following?
Personalize the app with insights and
I'm In! Not Right Now
Help us understand how you use the app so we
I'm In! Not Right Now
You can change your mind and update your consent decision whenever you like using the app Privacy settings.
Remember, you can learn more about how we use and protect your data in our Privacy Policy.
SAVE

Top Tip:


Try looking at the workout library and starting with the First Timer workout. You can always explore other options after.
7 MINUTE WORKOUT
SMART WORKOUT
WORKOUT LIBRARY


WORKOUT LIBRARY
MY CUSTOM WORKOUTS
LEARN MORE ABOUT
THE SCIENCE BEHIND THE WORKOUTS
EASY BEGINNER ALTERNATE 7 MINUTE
EASY ORIGINAL 7 MINUTE WORKOUT
EASY IT'S THE 8 MINUTE WORKOUT
EASY BEGINNER 9 MINUTE WORKOUT
EASY FIRST TIMER

How to find the full terms and conditions and privacy details on the app

1. When you open the app you will see this screen.
2. Terms of use and privacy policy for this app can be found by selecting them at the bottom of the opening screen

Appendix Q

Participant user diary example pages as used in the study exploring the experiences of socially isolated older adults using DBCI for PA (chapter six)

The Positive Ageing Research Institute
Faculty of Health, Education, Medicine and Social Care

Exploring the experiences of using digital interventions for physical activity in people aged 50+ at risk of social isolation and/or loneliness

Participant Log Book

Participant ID:

It does not matter which order you use the 2 digital interventions, but please only use one at a time. Please try each for 1 week.

We would like you to use each intervention at least 3 times during the week you are trying them out. If there are days that you do not use them, that is ok, but please write down that you did not use them and why.

Once you have completed the 2 weeks, please email the completed log book back to Stephanie. If you have any problems during this time, please do not hesitate to contact the research team.

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Anglia Ruskin University
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Compass House Annex
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CB5 8DZ

The Positive Ageing Research Institute
Faculty of Health, Education, Medicine and Social Care

Johnson & Johnson 7-minute workout app – DAY 1

Date	
Time(s) intervention was used	
How long did you use it for (each time if more than once)	
How did you find using the intervention? (Feel free to write in as much detail as you wish)	
Any other comments?	

The Positive Ageing Research Institute
Faculty of Health, Education, Medicine and Social Care

Runme Fitness tracker and VeryfitPro app – DAY 1

Date	
Time(s) intervention was used	
How long did you use it for (each time if more than once)	
How did you find using the intervention? (Feel free to write in as much detail as you wish)	
Any other comments?	

Appendix R

Chapter 6 interview guide

Thank you for agreeing to take part in this study. I'm really interested to find out your experiences of using the digital interventions for physical activity. If at any point you would like to take a break just let me know, and if you want to stop or withdraw from the study at any point, you are also able to do so. The whole interview should take around 30-45 minutes, and it will be audio recorded. Remember, it's a chat about your experiences so there are no right or wrong answers. Before we start, do you have any questions?

START RECORDING

Discussion Point	Details
Recap	Confirm which order the DBCI were used
Download/Install	How did you find downloading/installing/accessing the DBCI?

Runme Tracker	User experiences:
	• How did you get on using the Runme Fitness Tracker?
	• What was your overall opinion of the fitness tracker?
	• What was your overall opinion of the app?
	
	• How did it affect your PA?
	• How did it affect your sitting time?
	
	• What features did you like/dislike? Why?
	
	• Did you use (links to BCTs):
	  ○ The reminders to move? How? When? Why? What did you think? How did it affect your behaviour?
	  ○ Goal setting? How? When? Why? What did you think? How did it affect your behaviour?
	  ○ Self-monitoring. What did you think? How did it affect your behaviour?
	  ○ Feedback on physical activity. How? When? Why? What did you think? How did it affect your behaviour?
	
	• Would you consider continuing to use this DBCI after this study? Why/why not?
	
	• Do you think the DBCI is appropriate for someone like you? / Are there any adaptations you think should be made for this DBCI?

J&J 7-min workout app	User experiences:
	• How did you get on using the J7J 7-min workout app?
	• What was your overall opinion of the J&J 7-min workout app?
	
	• How did it affect PA?
	• How did it affect sitting time?
	
	• What features did you like/dislike? Why?
	
	• Did you use (links to BCTs):
	  ○ Demonstrations/instructions – what did you think?
	  ○ Reminders to use the app? How? When? Why? What did you think? How did it affect your behaviour?

- Prompts/cues
- Graded tasks
- Credible source

	• Would you consider continuing to use this DBCI after this study? Why/why not? • Do you think the DBCI is appropriate for someone like you? / Are there any adaptations you think should be made for this DBCI?
Previous tech experience	Confirm their previous use of technology (using details from questionnaire). Clarify anything as necessary. How did this prior experience affect their use of the DBCI? • Engagement • Troubleshooting • Preconceptions
Design recommendations	Discuss what they think an appropriate DBCI would be for socially isolated 50+. • Type of PA? Why? • Which technology? Why? • What features? Why? Any social features? • How would people find out about it?
Other	Before I stop the recording is there anything else they would like to add?

Great. I'm just going to stop the recorder.

STOP RECORDING
Thank you for your time and your dedication to the study, I really appreciate it. I have all of your completed documents – thank you for sending them through.

Have you posted the fitness tracker back to me yet?

- Yes – Great, thank you. I have a few more participants who need to finish the study, but once they have completed it, I'll be analysing the data and writing up my report.

- No – Ok, do you still have the pre-paid envelope to send it back in? **Could you pop it in the post for me as soon as possible?**

Is there anything else you would like to ask or check?

Thank you again for your time and help with the study.