Digital behavior change interventions to promote physical activity and/or reduce sedentary behavior in older adults: A systematic review and meta-analysis

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

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Abstract

Background: Physical activity and sedentary behaviour are modifiable risk factors for non-communicable disease and healthy ageing, however the majority of older adults remain insufficiently active. Digital behaviour change interventions have the potential to reach many older adults to promote physical activity and reduce sedentary time.

Methods: A systematic review of major databases from inception to 03/2018 was undertaken. Randomised controlled trials (RCT) or pre-post interventions assessing effects of digital behaviour change interventions on physical activity and/or sedentary behaviour in older adults (≥50 years) were included. Random effects meta-analyses were carried out.

Results: Twenty-two studies were included, including 1757 older adults (mean age=67 years, %male=41). Random effects model meta-analyses suggested that digital behaviour change interventions increased total physical activity among RCT studies (SMD=0.28; 95%CI 0.01, 0.56; p=0.04) and pre-post studies (SMD=0.25; 95%CI 0.09, 0.41; p=0.002), increased moderate-to-vigorous physical activity (SMD=0.47; 95%CI 0.32, 0.62, p<0.001; MD=52min/week) and reduced sedentary time (SMD=-0.45; 95%CI -0.69, -0.19; p<0.001; MD=58min/day). Reductions in systolic blood pressure (-11bpm; p=0.04) and improvements in physical functioning (p=0.03) were also observed.

Conclusions: Digital behaviour change interventions may increase physical activity and physical functioning, and reduce sedentary time and systolic blood pressure in older adults.

Keywords: Digital behaviour change intervention, older adult, physical activity, sedentary behaviour

1. Introduction

Older adults (age ≥ 50 years) comprise approximately 35% of the population in the United States of America (USA) (Statistica, 2018) and 40% of Europe (Eurostat, 2018), and the proportion of older adults is projected to continue to increase (Office for National Statistics, 2017). Despite people today living longer than their predecessors, 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). In order 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 (Deandrea et al., 2010; Rikli, 1999). Non-communicable diseases (NCD), 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) and also impact quality of life (QoL) and ability to live independently (Sazlina et al., 2012).

Low levels of physical activity (PA) and excessive sedentary behaviour (SB) are independently associated with multiple NCDs in older adults (Chad et al., 2005; Wirth et al., 2017). For instance, lower levels of PA have been shown to be associated with musculoskeletal, respiratory, heart, circulatory, digestive and kidney/bladder/urinary conditions (Chad et al., 2005). Moreover, higher levels of PA are associated with healthy ageing (Daskalopoulou et al., 2017) and protective against aging-related decline in physical function (Tak et al., 2013). A systematic review found positive correlations between SB and body mass index (BMI), fat mass, cholesterol and insulin levels in older adults (Wirth et al., 2017). Therefore, regular and sustained engagement in PA and reduction in SB has the potential to improve health, QoL and independence in older adults (Chad et al., 2005; Daskalopoulou et al., 2017; Smith et al., 2015; Tak et al., 2013) and are influential in the prevention and/or management of NCD (Global Advocacy for Physical Activity (GAPA) and the Advocacy Council of the International Society for Physical Activity and Health (ISPAH), 2012).

Despite these benefits, a large proportion of older adults fail to meet recommendations for PA. In the USA, the prevalence of older adults doing no activity beyond baseline activities of daily living was 25.4% (95% confidence interval [CI] 25 - 25.9) in older adults aged 50-64 years, 26.9% (95% CI 26.3 – 27.5) in those aged 65-74 years and 35.3% (95% CI 34.5 – 36.1) in those aged ≥ 75 years old (Watson et al., 2016). Across Europe, one in eight older adults ≥ 55 years (12.5%) were found to be physically inactive (defined as never or almost never engaging in MVPA) (Gomes et al., 2017). A systematic review showed that 67% of older adults aged ≥60 years spend ≥8.5 hours per day sitting when objectively measured (Harvey et al., 2013). A cross-sectional study in Scotland found older adults ≥ 65 years old spend an average of 59.2% of their day in SB (range 28.3% - 94%), averaging 14.2 hours/day (Leask et al., 2015).

Interventions to promote sustainable PA and reduce SB in older adults have achieved limited success particularly over the long term (Chad et al., 2005; Daskalopoulou et al., 2017; van der Bij et al., 2002). 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). Many interventions to promote PA and/or reduce SB are only beneficial in the short term, not cost effective and require professional expertise in delivering behaviour change techniques (BCTs) (Lyons et al., 2014). 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). DBCI have previously been used in the promotion of PA participation and dietary behaviours (Flores Mateo et al., 2015; Middelweerd et al., 2014; Rabin et al., 2011), rehabilitation programmes (Rawstorn et al., 2016), medication adherence (Mistry et al., 2015), management of long-term conditions (Jackson et al., 2016; Puszkiewicz et al., 2016; Su et al., 2016; Vinding et al., 2016) and promoting smoking cessation (Spohr et al., 2015).

In the USA, 74% of older adults aged 50-64 years old and 42% aged ≥ 65 years old own a smart phone (Pew Research Centre, 2017); similarly in the UK 51% of older adults aged ≥55 years old have a smartphone and 48% have a tablet device (Ofcom, 2018). The average amount of time spent online on a smartphone per day in adults ≥ 55 years old is 1 hour 42 minutes in males and 2 hours 18 minutes in females (Ofcom, 2018). A survey conducted in the USA found that of smartphone users aged ≥ 50, 26% have software on their phones to track or manage their health, which is comparable to those aged 18 – 29 years old at 24% (Fox and Duggan, 2012). DBCI have previously been used by older adults and are deemed relevant and acceptable for use in this population (Kim and Glanz, 2013; Kolt et al., 2007; Martinson et al., 2010).

Despite this, the overall efficacy of using DBCI 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), even for isolated older adults who have limited contact with traditional person(s) or print based PA interventions (Norman et al., 2007).

Thus, DBCIs have the potential to revolutionise the ways individuals can monitor and improve their health behaviours by improving outcomes, reducing costs and improving patient experience (Michie et al., 2017). Despite this, to our knowledge, no systematic review or meta-analysis has assessed the efficacy of DBCI interventions targeting PA and/or SB in older adults (≥ 50 years). Therefore, we conducted a systematic review and meta-analysis 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.

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).

2.1. Search strategy

Electronic databases were searched via OVID from inception to 2nd March 2018 including MEDLINE, PsycINFO and EMBASE. Grey literature was searched manually by entering terms into internet search engines Google and Bing on 2nd March 2018. Searching methodology included terms and synonyms relating to PA, SB, older adults and DBCI (see appendix A). Results of the searches were included in a bibliographic database and duplicates 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 before making a final decision on eligibility. Any discrepancies were discussed until a decision was reached. A third senior reviewer acted as an adjudicator if a decision was not reached.

2.2. Study inclusion and exclusion

Studies were included if they met the following criteria: (i) randomised controlled trials (RCTs) and pre and post-test studies (ii) in older adults (aged 50+ years; including healthy general population, people with known physical [e.g. diabetes] or mental disease [e.g. depression]) (iii) that use digital interventions (iv) to promote PA and/or reduce SB (v) in settings such as residential homes, community-based, rural-based, sheltered accommodation and assisted-living accommodations. 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 et al., 1985). SB was defined as any waking behaviour characterised 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. Randomised/controlled clinical trials 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.

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), in older adults (age ≥ 50 years old). Secondary outcomes of interest included markers of physical health (e.g. blood

pressure, body mass, BMI, body composition, lipid concentrations, glucose concentrations, cardiometabolic risk, fall risk and physical functioning), mental health (such as depression), and social outcomes (such as reduced isolation, perceived loneliness).

2.4. Data extraction

Data extracted by two reviewers independently included: first author, year, country, region, setting, population, aims of the study, type of the study (controlled or RCT, 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, BCTs used in DBCI (extracted by a trained coder using the Behaviour Change Techniques Taxonomy v1 (BCTTv1) (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.

2.5. Quality assessment

Risk of bias was assessed by two independent researchers 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' (see 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' (see appendix C). Discrepancies between the review authors were resolved by discussion, with involvement of a third review author where necessary. A greater number of 'yes' items indicated higher quality studies, thus lower risk of bias (Tufanaru et al., 2017).

2.6. Statistical analysis

The meta-analysis aimed to: i) establish the effects of DBCI on PA and SB on older adults 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, steps, MVPA and

total SB. For RCT studies meta-analyses investigating total PA and steps, studies were moderated by when measurement was taken – either immediately at the end of the intervention (EI) or at a later follow up (FU) – to allow differentiation between intervention and maintenance effects. Random effects meta-analysis calculating SMD, MD and 95% CI were conducted for pre-post studies for total PA and steps. 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 (USA/non-USA), 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 et al., 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, we 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 is symmetric about the (new) effect size. All analyses were performed using Comprehensive meta-analysis (CMA, version 3) software (Biostat, New Jersey, USA).

3. Results

A total of 1990 records were originally identified from the database and four from grey literature searches. After removal of duplicates and title and abstract screening, 116 studies were selected for full-text review. Ninety-two 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 1.

Insert figure 1 here

Characteristics of the 22 included studies can be found in table 1. All studies were published between 2007 – 2017, with 8 published in 2015. 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; King et al., 2007; King et al., 2014; Kullgren et al., 2014; Lyons et al., 2017; Müller et al., 2016; Nguyen et al., 2009; Ruiz et al., 2012; Wijsman et al., 2013), five were pre-post study designs (n = 175) (Knight et al., 2015; Leutwyler et al., 2015; O'Brien et al., 2015; Strand et al., 2014; Tiedemann et al., 2015), one was a randomised 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.

Table 2 contains information regarding the DBCI, control treatment, BCTs and engagement/adherence in each study. 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; Cook et al., 2015; King et al., 2007; King et al., 2014; O'Brien et al., 2015), 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 et al., 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 et al., 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 et al., 2015; Lyons et al., 2017; Nguyen et al., 2009; O'Brien et al., 2015; Tiedemann et al., 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 et al., 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 et al., 2015; Lyons et al., 2017; Müller et al., 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 et al., 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 et al., 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 et al., 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 et al., 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 et al., 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).

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 et al., 2016; Nguyen et al., 2009; Ruiz et al., 2012; Vidoni et al., 2016; Williams, 2016) and seven with the quasi-experimental (non-randomised) checklist (Keogh et al., 2014; Knight et al., 2015; Leutwyler et al., 2015; O'Brien et al., 2015; Strand et al., 2014; Tiedemann et al., 2015; Williams, 2016). Seven studies were deemed lower risk of bias (Keogh et al., 2014; Knight et al., 2015; Leutwyler et al., 2015; O'Brien et al., 2015; Strand et al., 2014; Tiedemann et al., 2015; Williams, 2016), 12 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 et al., 2016; Nguyen et al., 2009; Wijsman et al., 2013) and three higher risk of bias (Bickmore et al., 2013; Ruiz et al., 2012; Vidoni et al., 2016) (see appendix D).

In RCT studies, true randomisation 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) (see appendix D). Other studies were randomised but stratified by age (Cadmus-Bertram et al., 2015),sex (Broekhuizen et al., 2016; King et al., 2007; King et al., 2014; Nguyen et al., 2009; Wijsman et al., 2013), BMI (Cadmus-Bertram et al., 2015), clinic site and health literacy status (Bickmore et al., 2013) or enrolling with or without their spouse (Müller et al., 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 et al., 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; Lyons et al., 2017; Müller et al., 2016; 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 et al., 2016; Nguyen et al., 2009; Ruiz et al., 2012; Vidoni et al., 2016; Williams, 2016) and deliverers (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 et al., 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 (Lyons et al., 2017; Müller et al., 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 et al., 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 randomised, 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-randomised) tool, all seven studies had clear cause and effect variable, 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 et al., 2015; Leutwyler et al., 2015; O'Brien et al., 2015; Strand et al., 2014; Tiedemann et al., 2015; Williams, 2016) (see appendix D). Six studies did not have a control group; however, one study did have a control group (Keogh et al., 2014).

3.2. Main results

3.2.1. Physical Activity measurement

Outcome measures and confounding variables for each study can be found in table 3. 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 et al., 2015), two used Omron pedometers (Bickmore et al., 2013; Knight et al., 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 et al., 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 et al., 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 Centres Stages of Change Physical Activity (Strand et al., 2014) (see table 3).

3.2.2.1. Total physical activity narrative results

Overall 15 studies, including 10 RCTs (Ashe et al., 2015; Bickmore et al., 2013; Cadmus-Bertram et al., 2015; Frederix et al., 2015; Kullgren et al., 2014; Lyons et al., 2017; Müller et al., 2016; Nguyen et al., 2009; Ruiz et al., 2012; Vidoni et al., 2016) and five pre-post-test studies (Keogh et al., 2014; Knight et al., 2015; O'Brien et al., 2015; Tiedemann et al., 2015; Williams, 2016) 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; Knight et al., 2015; Kullgren et al., 2014; Lyons et al., 2017; Nguyen et al., 2009; O'Brien et al., 2015; Tiedemann et al., 2015; Vidoni et al., 2016), and questionnaire data on PA also used (Keogh et al., 2014; Müller et al., 2016; Ruiz et al., 2012; Williams, 2016). PA measured by step count was reported as median and interquartile range in Frederix et al. (2015) so were not entered into the meta-analysis model. PA in Strand et al. (2014) was reported as the number of people who has a change in self-reported PA; by week 8 five inactive people became active and by week 25 6 more became active. 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).

3.2.2.2. Total physical activity meta-analysis results

This section is very good and thorough but also very wordy! If you want a quick tip for shortening it down, I would say:

(a) leave the publication bias stats just for tables

(b) You don't have to write narratively the number of trials and participants each time, you can abbreviate to inside the stats brackets , for instance, a sentence like:

*"*MVPA data were pooled in a random effects meta-analyses (table 4) and across six RCT, with 349 in the intervention and 345 in the control, increases in MVPA were shown (SMD = 0.47; 95% CI 0.32, 0.62; $p < 0.001$; $I^2 = 0$"

Can become:
"Among RCTs, DBCIs significantly increased MVPA (N=6, n=699, SMD = 0.47; 95% CI 0.32, 0.62; $p < 0.001$; $I^2 = 0\%$).

See how much shorter and punchier that is? Just a suggestion! Especially since you have it all tabled already….

Also you don't need to keep repeating 'random effects meta analysis' if you've said in the Methods that random effects were applied wherever possible ☺

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. A random effects meta-analysis across eight RCT (EI) studies (Ashe et al., 2015; Bickmore et al., 2013; Cadmus-Bertram et al., 2015; Kullgren et al., 2014; Lyons et al., 2017; Müller et al., 2016; Nguyen et al., 2009; Ruiz et al., 2012), including 220 in the intervention and 230 in the control, showed an increase in total PA (SMD= 0.28; 95% CI 0.01, 0.56; p = 0.04; $I^2 = 47\%$; publication bias: Kendall's tau = 0.33, p =0.16; Egger's intercept = 1.99, p = 0.11; trim and fill effect size = 0.25 (95% CI 0.07, 0.44) studies trimmed = 1) (table 4).

A pooled analysis of two RCT (FU) studies (Bickmore et al., 2013; Kullgren et al., 2014), including 122 in the intervention and 133 in the control, showed no increase in total PA (SMD = 0.11; 95% CI -0.14, 0.36; p = 0.39; $I^2 = 0\%$; publication bias: Kendall's tau = 0.17, p = 0.73; Egger's intercept = 1.65, p = 0.04; trim and fill effect size = 0.05 (95% CI -0.16, 0.26) studies trimmed = 2). 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). A random effects meta-analysis across six pre-post studies (Keogh et al., 2014; Knight et al., 2015; O'Brien et al., 2015; Tiedemann et al., 2015; Vidoni et al., 2016; Williams, 2016), including 159 participants, an increase in total PA was seen (SMD = 0.25; 95% CI 0.09, 0.41; p = 0.002; $I^2 = 37\%$; publication bias: Kendall's tau = 0.04, p = 0.90; Egger's intercept = -0.70, p = 0.75; trim and fill effect size = unchanged).

Random effects meta-analysis across seven RCT (EI) studies that measured PA objectively showed no increase in total PA (SMD = 0.28; 95% CI -0.02, 0.06; p = 0.07; I2 = 52%; publication bias: Kendall's tau = 0.31, p = 0.21; Egger's intercept = 1.98, p = 0.15; trim and fill effect size = 0.24 (95% CI 0.05, 0.42) studies trimmed = 1). One RCT (EI) studies that subjectively measured total PA found no increase in total PA (SMD = 0.36, 95%CI -0.27, 1.00, p = 0.27; $I^2 = 0\%$; publication bias: not possible with one study). A between-groups difference in total PA was found between RCT (EI) studies measured objectively or subjectively (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. A random effects meta-analysis of four pre-post studies that objectively measured total PA found increases in total PA (SMD = 0.24; 95% CI 0.02, 0.45; p = 0.03; $I^2 = 51\%$; publication bias: Kendall's tau = 0.00, p = 1.00;

Egger's intercept = -1.37, p = 0.62; trim and fill effect size = unchanged). Two pre-post study that measured total PA subjectively found an increase in total PA (SMD = 0.27; 95% CI 0.02, 0.53; p = 0.04; I^2 = 0%; publication bias: not possible with two studies). 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).

3.2.3.1. 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 increase in steps (n = 5) and who did have an increase in 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).

3.2.3.2. Steps (per day) meta-analysis results

Meta-analysis for steps per day was possible for six RCT studies (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) and three pre-post studies (Knight et al., 2015; O'Brien et al., 2015; Tiedemann et al., 2015). Reported steps per day were pooled in a random effects meta-analysis (table 4). Across six RCTs where measurement occurred at the end of the intervention (EI), including 188 in the intervention and 195 in the control, there was no increase in daily steps (SMD = 0.18; 95% CI -0.03, 0.38; p = 0.09; I^2 = 0%; publication bias: Kendall's tau = 0.29, p = 0.19; Egger's intercept = 1.24, p = 0.13; trim and fill effect size = 0.19 (95% CI -0.005, 0.39) studies trimmed =1; MD = 401 steps; 95% CI -125, 926; p = 0.13). There was no increase in daily steps across two RCT (FU) studies, including 122 in the intervention and 133 in the control (SMD = 0.11; 95% CI -0.14, 0.36; p = 0.39; I^2 = 0%; publication bias: not possible with two studies; MD = 280 steps; 95% CI -508, 1068; p = 0.49), see table 4. No between-groups difference in steps was found between RCT (EI) and RCT (FU) (p = 0.06). A total of three pre-post studies including 122 people showed a decrease in daily steps (SMD = -0.20; 95% CI -0.42, 0.02; p = 0.08; I^2 = 54%; publication bias: Kendall's tau = 0.10, p = 0.81; Egger's intercept = 6.09, p = 0.51); trim and fill effect size = -0.34 (95% CI -0.59, 0.10) studies trimmed = 2; MD = -737 steps; 95% CI -1361, -113; p = 0.02).

3.2.4.1. MVPA (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; Lyons et al., 2017; Nguyen et al., 2009; Wijsman et al., 2013) 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 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.

3.2.4.2. MVPA (min/week) meta-analysis results

Meta-analysis for MVPA was possible for 6 RCT studies (Ashe et al., 2015; Cadmus-Bertram et al., 2015; Frederix et al., 2015; King et al., 2007; Nguyen et al., 2009; Wijsman et al., 2013) as insufficient numbers of pre-post studies reported MVPA. MVPA data were pooled in a random effects meta-analyses (table 4) and across six RCT, with 349 in the intervention and 345 in the control, increases in MVPA were shown (SMD = 0.47; 95% CI 0.32, 0.62; $p < 0.001$; $I^2 = 0\%$; publication bias: Kendal's tau = -0.43, p = 0.23; Egger's intercept = -0.39, p = 0.63; trim and fill effect size = unchanged; MD 3 studies = 51.97; 95% CI 23.91, 80.03; $p < 0.001$) (Ashe et al., 2015; Cadmus-Bertram et al., 2015; King et al., 2007). When split by PA measure, across five RCT (EI) studies that objectively measured PA, with 443 participants in total, increases in MVPA were shown (SMD = 0.53; 95% CI 0.34, 0.72; $p < 0.001$; $I^2 = 0\%$; publication bias: Kendall's tau = 0.00, p = 1; Egger's intercept = 2.48, p = 0.01; trim and fill effect size = unchanged; MD = 10.14; 95% CI -2.33, 22.61; p = 0.11). One RCT (EI) study that subjectively measured PA, with 251 participants in total, increases in MVPA were shown (SMD = 0.38; 95% CI 0.13, 0.63; $p < 0.001$; $I^2 = 0\%$; publication bias: not possible with one study; 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; $p < 0.001$).

3.2.5.1 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 et al.,

2016). Sedentary minutes per day were reported in three studies (Ashe et al., 2015; Lyons et al., 2017; Müller et al., 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).

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

Due to the number of studies with available data, meta-analysis was only possible using five RCT studies (intervention n = 128, control n = 127) (Ashe et al., 2015; Frederix et al., 2015; Lyons et al., 2017; Müller et al., 2016; Nguyen et al., 2009). Across five RCT studies decreases in SB were found (SMD = -0.44; 95% CI -0.69, -0.19; $p < 0.001$; $I^2 = 0\%$; publication bias: Kendall's tau = 0.10, p = 0.81; Egger's intercept = 0.53, p = 0.54; trim and fill effect size = -0.47 (95% CI -0.72, 0.23) studies trimmed = 1; 3 studies MD = 58.49; 95% CI -100.34, -16.64; $p < 0.001$) (table 4) (Ashe et al., 2015; Frederix et al., 2015; Lyons et al., 2017).

Across four RCT (EI) studies that measured SB objectively reductions in SB were found (SMD = -0.45; 95% CI -0.72, -0.17; p = 0.001; $I^2 = 0\%$; publication bias: Kendall's tau = 0.10, p = 0.81; Egger's intercept = 0.53, p = 0.54; trim and fill effect size = -0.49 (95% CI -75, 0.23) studies trimmed = 1; MD = -33.47; 95% CI -90.63, 23.70; p = 0.25). In one RCT (EI) that measured SB subjectively using IPAQ (Müller et al., 2016) no decrease in SB was found (SMD = -0.40; 95% CI -1.04, 0.23; p = 0.22; $I^2 = 0\%$; publication bias: not possible with one study; MD = -0.76, 95% CI -1.95, 0.43; p = 0.21). Between-groups difference was found between objectively and subjectively measured SB in RCT (EI) (SMD = -0.44; 95% CI -0.69, -0.19; $p < 0.001$).

3.2.6 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 3. Due to the number of studies available measuring the respective comparators, meta-analysis was only possible for RCT studies.

3.2.6.1. 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 (Broekhuizen et al., 2016; Knight et al., 2015), thus only RCT meta-analysis was possible. Weight measures were pooled in a random effects meta-analysis, with 233 in the intervention and 233 in the control (table 5); no changes were found in weight (SMD = -0.15; 95% CI -0.33, 0.03; p = 0.10; $I^2 = 0\%$; publication bias: Kendall's tau = -0.10, p = 0.81; Egger's intercept = 0.47, p = 0.59; trim and fill effect size = -0.26 (95% CI -0.40, 0.11) studies trimmed = 3; MD = -0.68kg; -3.45, 2.09; p = 0.63).

3.2.6.2. 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 et al., 2015; O'Brien et al., 2015), thus only meta-analysis on RCT studies could be conducted. A random effects meta-analysis pooled results on blood pressure, reporting systolic and diastolic blood pressure separately (intervention n = 188; control n = 187) (table 5). 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. A decrease in systolic blood pressure (SBP) was found (SMD = -0.14; 95% CI -0.35, 0.07; p = 0.18; I^2 = 4%; publication bias: Kendall's tau = 0.00, p = 1, Egger's intercept = -1.70, p = 0.39; trim and fill effect size = -0.03 (95% CI -0.27, 0.21) studies trimmed = 2; MD = -11bpm; 95% CI -21.96, -0.71, p = 0.04). No changes were observed in diastolic blood pressure (DBP) (SMD = 0.10; 95% CI -0.30, 0.09; p = 0.30; I^2 = 0%; publication bias: Kendall's tau = 0.00, p = 1; Egger's intercept = -1.55, p = 0.40; trim and fill effect size = -0.07 (95% CI -0.30, 0.16) studies trimmed = 1; MD = -3bpm; 95% CI -9.00, 2.93; p = 0.32).

3.2.6.3. Physical Functioning meta-analysis

Nine studies measured physical functioning; seven RCT (Broekhuizen et al., 2016; Frederix et al., 2015; Lyons et al., 2017; Müller et al., 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 et al., 2016; Wijsman et al., 2013).

A random effects meta-analysis was conducted pooling RCT studies only, as there were insufficient pre-post studies to pool (table 5), containing 223 in the intervention and 228 in the control, showed improved physical functioning in older adults (SMD = 0.21; 95% CI 0.03, 0.40; p = 0.03; I2 = 0%; publication bias: Kendall's tau = 0.30, p = 0.46; Egger's intercept = 0.78, p = 0.47; trim and fill effect size = 0.09 (95% CI -0.08, 0.26) studies trimmed = 2).

3.2.6.4. 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). Across three RCT studies, with 185 in the intervention and 187 in the control, no increase in QoL was found (SMD = 0.27; 95% CI -0.2, 0.57; p = 0.07; I2 = 37.92%; publication bias: Kendall's tau = 0.00, p = 1.00; Egger's intercept = 1.91, p = 0.46; trim and fill effect size 0.09 (95% CI -0.08, 0.26) studies trimmed = 2) (table 5).

3.3. 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 (USA/ non-USA), 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 6).

4. Discussion

To the best of our knowledge, 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 suggested that DBCI increased total PA among older adults (≥ 50 years) in RCT (End Intervention) studies and pre-post studies, increased MVPA by approximately 52 minutes per week and reduced sedentary time by approximately 58 minutes per week. Reductions in systolic blood pressure and improvements in physical functioning were also identified.

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 increases in PA in older adults (≥ 50 years), but effective maintenance beyond one year was unclear. It appears 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 overestimates actual PA levels (Colbert et al., 2011; Prince et al., 2008) 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 (End Intervention) 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.

The present meta-analyses showed DBCIs 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 has previously been shown to significantly underestimate SB in older adults (Copeland et al., 2017; Van Cauwenberg et al., 2014), therefore future studies should aim to measure SB objectively when possible.

One of the most common BCTs in the present review was social support, and 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). 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.

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 programme 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 (De Queiroz et al., 2017; Howes et al., 2017; Molina et al., 2014; Pope et al., 2017; Skjaeret et al., 2016), web-based (Irvine et al., 2013) and non-digital PA and exercise programmes (Barnett et al., 2003; Chodzko-Zajko et al., 2009; Taylor et al.,

2004). 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.

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 (Chad et al., 2005; Daskalopoulou et al., 2017; Smith et al., 2015; 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 maximised, for the individual and for society.

4.1. Strengths and limitations

Strengths of this review include that it is 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 our findings were completely relevant to this specific population. 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 we cannot be sure 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), should be interpreted with caution. It was not possible to compare DBCI to a wait-list/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 minimise this.

Future research should continue to investigate the efficacy of DBCI compared with non-digital control conditions as well as wait-list/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. Investigators should continue to use objective measures of PA and SB where possible.

4.2. 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 future research is needed to identify specifically the effectiveness of each BCT, which will enhance DBCI design. Researchers should also consider coding BCTs from control groups as there may be overlaps with the DBCI, which could influence effect sizes.

5. Tables and Figures

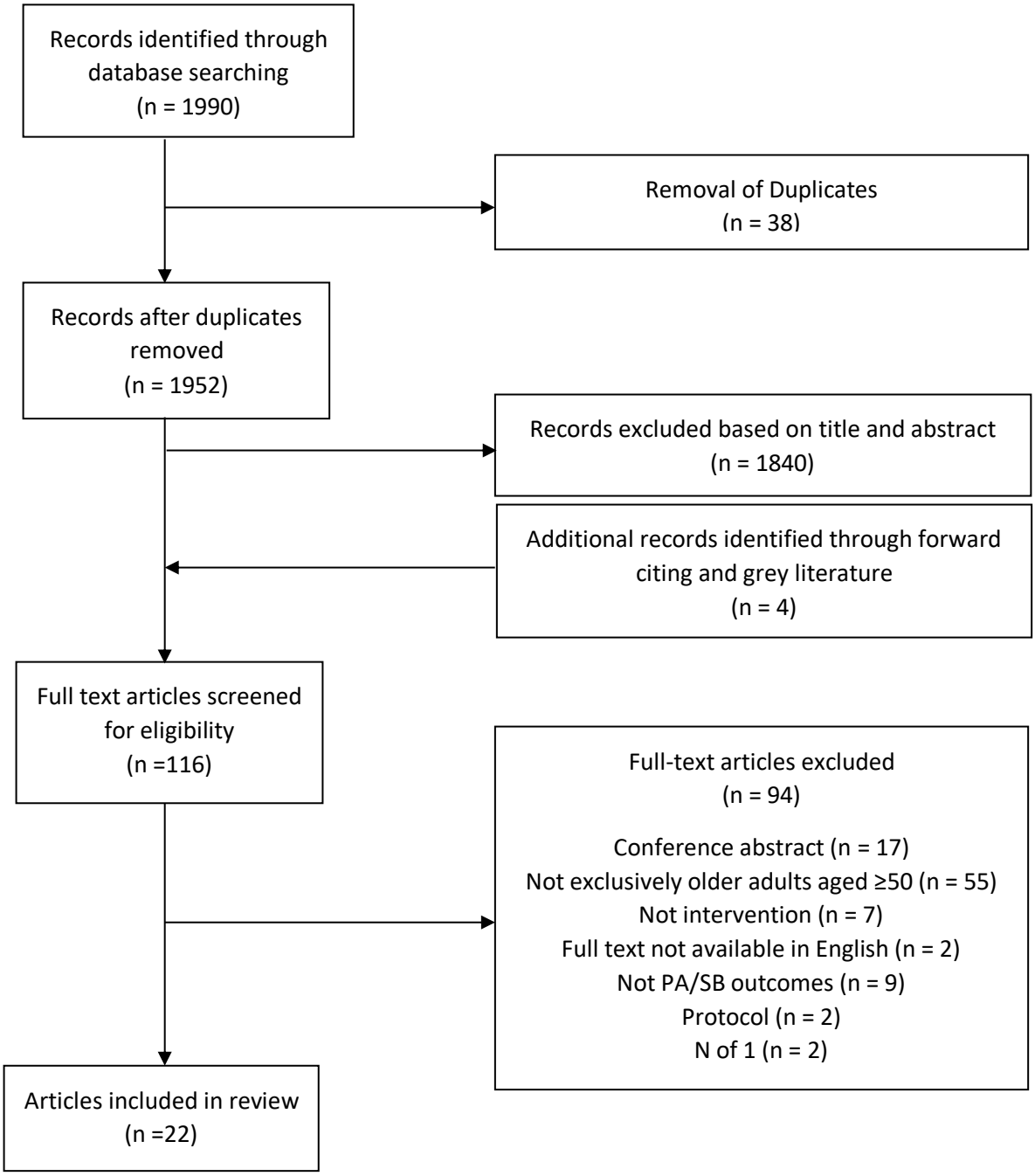

Figure 1. PRISMA flow diagram illustrating article selection strategy

Table 1. Characteristics of included studies

Author, year	Country	Study design	Sample size	Retention rate at follow-up	Men %	Age in years mean (SD)	Age range (yrs)	Physical activity measurement	Sedentary behaviour measurement
Ashe, 2015	Canada	RCT	20 Int. = 12 Con. = 8	80% (20/25)	0	64.95 (4.7)	55-70	Accelerometer (Actigraph GT3X+)	Accelerometer (Actigraph GT3X+)
Bickmore, 2013	USA	RCT	113 Int. = 55 Con. = 58	48.7% (128/263)	38.8	71.3 (5.4)	65+	Accelerometer (Omron pedometer HJ-720ITC)	n/a
Broekhuizen, 2016	Netherlands	RCT	216 Int. = 107 Cont. = 109	95.7% (225/235)	59.1	64.8 (2.9)	60-70	Accelerometer (GeneActiv – wrist worn)	n/a
Cadmus-Bertram, 2015	USA	RCT	51 Int. = 25 Con. = 26	100% (51/51)	0	60 (7.1)	Not provided	Accelerometer (Actigraph GT3X+)	n/a
Cook, 2015	USA	RCT	278 Int. = 138 Con. = 140	100% (278/278)	67.3	Not provided	50-68	Godin Leisure-time exercise questionnaire	n/a
Frederix, 2015	Belgium	RCT	139 Int. = 69 Con. = 70	99.3% (139/140)	81.4	61 (8.5)	Not provided	Accelerometer (Yorbody)	IPAQ
Keogh, 2014	New Zealand	Pre – post mixed methods	26 Int. = 13 Con. = 13	100% (34/34)	11.8	83 (8)	Not provided	Rapid Assessment of Physical Activity questionnaire (RAPA)	n/a

King, 2007	Canada	RCT	189 Automated = 61 Human = 66 Con. = 62	78.3% (148/189)	Not Provided	60 (5.5)	55+	Stanford 7-day physical activity recall (PAR)	n/a
King, 2014	Canada	RCT	127 Automated = 61 Human = 66	86.7% (189/218)	30.7	60 (5.5)	55+	Stanford 7-day physical activity recall (PAR)	n/a
Knight, 2015	Canada	Pre – post	45 Exercise = 15 Sedentary = 14 Counselling = 16	100% (45/45)	44.4	63 (5)	55-75	Accelerometer (Omron pedometer HJ-150)	n/a
Kullgren, 2014	Canada	RCT	92 Financial = 20 Peer = 22 Combined = 25 Con. = 25	92.4% (85/92)	30	71.9 (5.6)	65+	Accelerometer (Fitbit)	n/a
Leutwyler, 2015	Canada	Pre – post	15	100% (20/20)	80	60.3 (4.4)	55+	Accelerometer (SenseWear Pro Armband)	Accelerometer (SenseWear Pro Armband)

Lyons, 2017	USA	RCT	40 Int. = 20 Con. = 20	100% (40/40)	15	61.5 (5.6)	55-79	Accelerometer (ActivPAL)	Accelerometer (ActivPAL)
Müller, 2016	Malaysia	RCT	39 Int. 18 Con. = 21	90.7% (39/43)	26	63.3 (4.5)	55-70	IPAQ	IPAQ
Nguyen, 2009	USA	RCT	17 Int. = 9 Con. = 8	94.4% (17/18)	35.3	68 (10.5)	40+	Accelerometer (Stepwatch 3 Activity Monitor)	Accelerometer (Stepwatch 3 Activity Monitor)
O'Brien, 2015	Canada	Pre – post	34	100% (34/34)	35	73.5 (9.4)	60-96	Accelerometer (Nike Fuel wristband)	n/a
Ruiz, 2012	Canada	RCT	21 Self = 7 Other = 7 Con. = 7	93.3% (28/30)	96.4	62 (6)	50+	Accelerometer (Actigraph GT3X)	n/a
Strand, 2014	Canada	Pre – post	46	67.6% (46/68)	13	Not provided	60+	Cancer Prevention Research Centers Stages of Change Physical Activity	n/a
Tiedemann, 2015	Australia	Pre – post	35	92.1% (35/38)	34	67.7 (5.5)	60+	Accelerometer (Pre-Actigraph; Post-Fitbit)	n/a
Vidoni, 2016	Canada	Randomised cross over	20 Cog Imp = 12 Con. = 8	69% (20/29)	69	71 (5.5)	60-85	Accelerometer (Fitbit Zip)	n/a
Wijsman, 2013	Netherlands	RCT	216 Int. = 107 Con. = 109	96.2% (226/235)	59.1	64.8 (2.9)	60-70	Accelerometer (Geneactiv ankle and wrist worn)	n/a

Williams, 2016	Canada	Pre – post quasi-experimental	24	100% (24/24)	33.3	79.33 (11.09)	50-99	RAPA Questionnaire	n/a

Int., Intervention; Con., Control

Table 2 Intervention types from included studies

Author, year	Intervention type	Study duration (weeks)	Description of intervention	Control group treatment	Behaviour change techniques (BCTs)*	Approaches to measurement of engagement/ adherence
Ashe, 2015	Fitbit One	24	Group-based education and social support, individualised 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 (n=16)	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).
Bickmore, 2013	Tablet, app, pedometers	52	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 (n=9)	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	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 (n=8)	Not reported
Cadmus-Bertram, 2015	Fitbit One and Fitbit website (PA data only)	16	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 (n=4)	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	HealthyPast50 - web-based multimedia program with information and guidance on major health promotion topics of healthy aging, diet, physical activity, 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 (n=4)	Mean log-ins 4.33 (SD=4.28; range 0-28). Mean minutes in programme 102.26 minutes (SD=148.32). Mean number of pages viewed 11.04 (SD=20.08; range 0-120)

Frederix, 2015	Website, accelerometer, semiautomatic SMS text messages, emails, dietary telecoaching	24	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 (n=6)	Patients transmitted activity data mean 1.0 (SD=0.3) times/week.
Keogh, 2014	Nintendo Wii Sports (NWS)	8	Nintendo Wii Sports (baseball, boxing, golf, tennis and 10-pin bowling). Participants selected the frequency,	No treatment. Underwent normal activities of daily living	3.1 Social support (unspecified), 4.1 Instruction on how to perform the behaviour) (n=2)	Mean 30 ± 24 minutes (range 1-105 min) of NWS/week.

			duration and type of games they wished to play.			
King, 2007	Automated computer controlled interactive phone system	78	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 (n=8)	Not reported
King, 2014	Automated computer controlled interactive phone system	26	CHAT - homebased moderate intensity PA program delivered by automated computer controlled interactive telephone system or human advice via telephone.	Weekly health education classes	Follow-up study to King 2007	Not reported
Knight, 2015	Smartphone app (healthanywhere),	12	All groups had access to smartphone, app, Bluetooth blood	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	Not reported

	Blackberry Curve 8530, bluetooth enabled blood pressure monitor, glucometer with polymap wireless adaptor, pedometer		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-intensity daily activity. Comprehensive counselling group: Activity prescription targeting both Exercise and Sedentary behaviours (see above).		(n=3)		
Kullgren, 2014	Fitbit pedometer,	24	Financial incentive group:	Fitbit pedometer. Goal to increase daily	1.1 Goal setting (behaviour), 2.2 Feedback on behaviour, 3.1 Social support		Posts in Peer network and combined group by

automated email/text feedback	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	steps by 50%. No specific instructions but provided links to National Institutes of Health information on exercise and walking.	(unspecified) (peer only), 10.1 Material incentive (behaviour) (financial only) (n=4)	individual (median =1 post, range 0-27), and peer group (median 5 posts, range 0-71). 47% never posted a message.

Leutwyler, 2015	Xbox 360 Kinect	6	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 (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	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 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	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.

					the environment, 15.3 Focus on past success (n=23)	
Müller, 2016	SMS text messaging	12	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 (n=6)	50% read all 60 SMS messages 39% ignored SMS messages after some time
Nguyen, 2009	Mobile Coaching, pedometer	12	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 (n=10)	MOBILE-C 87% submitted exercise and symptom data MOBILE-SM 66% submitted exercise and symptom data
O'Brien, 2015	Nike Fuel Band	12	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	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 (n=6)	Not reported

			walking session each week led by researcher			
Ruiz, 2012	Virtual reality	8	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 (n=4)	Not reported

Strand, 2014	Nintendo Wii Active	24	LIFE Programme - Wii active onsite exergaming (8wks) lead by younger adult trainers (aged 19-26 years) 2x week. Then newsletter intervention for following 16wks	n/a	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, 12.5 Adding objects into the environment (n=5)	Not reported
Tiedemann, 2015	Telephone coaching, Fitbit	12	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 (n=5)	All participants used the Fitbit enhanced pedometer and synchronised it at least once//week with internet-based software
Vidoni, 2016	Fitbit Zip and coach	16	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 (n=5)	Not reported
Wijsman, 2013	Website, e-coach, accelerometer	12	Internet based PA program - DirectLife - accelerometer based activity monitor, personal website and e-coach	3-month wait-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 (n=8)	Intervention group: 91.2% (104/114) completed 12-week program

Williams, 2016	Nintendo Wii Sports	6	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	1.1 Goal setting (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, 12.5 Adding objects into the environment (n=6)	Average number sessions attended 9.67. 25% participants (n=6) attended all 12 sessions

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

**Individualised intervention duration. Range provided.

Table 3 Outcome measures for studies included

Author, year	Physical Activity outcome Measures	Sedentary Behaviour outcome measures	Other outcomes measured	Confounding Variables	Risk of bias
Ashe, 2015	PA min/day Steps/day	% time/day	BMI, weight, SBP, DBP, Behaviour intentions, exercise self-efficacy, self-rated health, social support	Education, employment, baseline measures	Low
Bickmore, 2013	Steps/day	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	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	n/a	Technology use, weight, BMI	Age, weartime	Medium
Cook, 2015	Steps/day Change in IPAQ scores	SB min/week	Diet, BMI, symptoms of distress, coping with stress, aging beliefs	Gender, age, race, marital status, education, income	Medium
Frederix, 2015	PA min/day	n/a	VO2 peak, HR max, Watts, Watts (pred%), first ventilatory threshold (Watts and bpm), oxygen uptake efficiency slope,	None mentioned	Medium

			weight, BMI, DBP, SBP, Heart-QoL		
Keogh, 2014	PA min/day Energy expenditure MVPA days/week	n/a	Functional performance, QoL	None mentioned	Low
King, 2007	Steps/day	n/a	None	Adjusted for 12-month measures	Medium
King, 2014	Steps/day	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	n/a	Weight, SBP, DBP, blood glucose	Age, sex, group assignment	Low
Kullgren, 2014	Change in steps/day Number of days walking goals met	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)	Change in sedentary hours (Number of participants)	None	Smoking status, residence, race	Low
Lyons, 2017	PA min/day Steps/day	SB min/day	Body fat %, weight, fitness	Cohort,	Low

Müller, 2016	PA related energy expenditure (MET-min per week)	SB hours/day (change in)	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	% time/day	Incremental cycle test, six-minute walk, peak performance, changes in health-related QoL	None mentioned	Medium
O'Brien, 2015	Steps/day	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	n/a	Self-efficacy	None mentioned	Medium
Strand, 2014	Change in self-report PA (Number of participants)	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 physical activity participation	Low
Tiedemann, 2015	Steps/day	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	Low

				balance fair/poor, self-rated fear of falling ≥moderate.	
Vidoni, 2016	Steps/week	n/a	Mini physical performance test, 6-min walk (yards), QoL-AD, Self-efficacy	None mentioned	Medium
Wijsman, 2013	Change in PA min/day	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	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.

Table 4 Meta-analysis of effects of DBCIs on physical activity and total sedentary time

Analysis	No. studies	No. participants	Meta-analysis SMD	Meta-analysis 95% CI		P value	Between group P value	No. studies	Meta-analysis MD	Meta-analysis 95% CI		P value	Heterogeneity Q	Heterogeneity P value	Heterogeneity I^2	Publication Bias Kendal l'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	450	**0.28**	**0.01**	**0.56**	**0.04**		n/a	n/a	n/a	n/a	n/a	18.86	0.04	46.98	0.33	0.16	1.99	0.11	0.25 (0.07, 0.44) [1]
RCTs (FU)	2	255	0.11	-0.14	0.36	0.39	**0.05**	n/a	n/a	n/a	n/a	n/a	0.51	0.92	0.00	0.17	0.73	1.65	0.04	0.05 (-0.16, 0.26) [2]
Pre-post	6	159	**0.25**	**0.09**	**0.41**	**0.002**	n/a	n/a	n/a	n/a	n/a	n/a	11.04	0.14	36.60	0.04	0.90	-0.70	0.75	Unchanged
PA Measure																				
Objective RCT (EI)	7	476	0.28	-0.02	0.06	0.07		n/a	n/a	n/a	n/a	n/a	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	39	0.36	-0.27	1.00	0.27	**0.03**	n/a	n/a	n/a	n/a	n/a	0.00	1	0.00	n/a	n/a	n/a	n/a	n/a
Objective Pre-post	4	122	**0.24**	**0.02**	**0.45**	**0.03**		n/a	n/a	n/a	n/a	n/a	10.28	0.07	51.36	0.00	1.00	-1.37	0.62	Unchanged
Subjective Pre-post	2	37	**0.27**	**0.02**	**0.53**	**0.04**	**0.003**	n/a	n/a	n/a	n/a	n/a	0.75	0.39	0.00	n/a	n/a	n/a	n/a	n/a
Steps																				
Study Design																				
RCTs (EI)	6	383	0.18	-0.03	0.38	0.09		6	401	-125	926	0.13	0.17	0.68	0	0.29	0.19	1.24	0.13	0.19 (-0.005, 0.39) [1]
RCTs (FU)	2	255	0.11	-0.14	0.36	0.39	0.06	2	280	-508	1068	0.49	6.03	0.87	0	n/a	n/a	n/a	n/a	n/a
Pre-post	3	122	-0.20	-0.42	0.02	0.08	n/a	3	**-737**	**-1361**	**-113**	**0.02**	8.61	0.07	53.55	0.10	0.81	6.09	0.51	-0.34 (-0.59, -0.10) [2]
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**	3.10	0.80	0	-0.43	0.23	-0.39	0.63	Unchanged
PA Measure																				

Objective RCT (EI)	5	443	**0.53**	**0.34**	**0.72**	**<0.001**		5	10.14	-2.33	22.61	0.11	0.93	0.33	0	0.00	1	2.48	0.01	Unchanged
Subjective RCT (EI)	1	251	**0.38**	**0.13**	**0.63**	**<0.001**	**<0.001**	**1**	**49.71**	**17.17**	**82.26**	**0.003**	3.10	0.80	0	0.00	n/a	n/a	n/a	n/a
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**	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	216	**-0.45**	**-0.72**	**-0.17**	**0.001**		4	-33.47	-90.63	23.70	0.25	0.02	0.90	0	0.10	0.81	0.53	0.54	-0.49 (-0.75, -0.23) [1]
Subjective RCT (EI)	1	39	-0.40	-1.04	0.23	0.22	**<0.001**	1	-0.76	-1.95	0.43	0.21	1.54	0.82	0	n/a	n/a	n/a	n/a	n/a

SMD, standardised 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, randomised control trial.

Heterogeneity and publication bias scores based on standardised mean differences

p ≤ 0.05 in bold

Table 5 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	Heterogeneity Q	P value	I^2	Publication bias Kendall's Tau	P value	Egger intercept	P value	Trim and fill analysis Effect size (95% CI) [Number studies trimmed]
Weight	5	466	-0.15	-0.33	0.03	0.10	5	-0.68	-3.45	2.09	0.63	1.71	0.79	0	-0.10	0.81	0.47	0.59	-0.26 (-0.40, -0.11) [3]
SBP	3	375	-0.14	-0.35	0.07	0.18	2	**-11.33**	**-21.96**	**-0.71**	**0.04**	2.09	0.35	4.19	0.00	1	-1.70	0.39	-0.03 (-0.27, 0.21) [2]
DBP	3	375	-0.10	-0.30	0.09	0.30	2	-3.04	-9.00	2.93	0.32	1.80	0.40	0	0.00	1	-1.55	0.40	-0.07 (-0.30, 0.16) [1]
Physical functioning	5	451	**0.21**	**0.03**	**0.40**	**0.03**	n/a	n/a	n/a	n/a	n/a	3.69	0.45	0.00	0.30	0.46	0.78	0.47	0.19 (0.005, 0.37) [1]
QoL	3	372	0.27	-0.02	0.57	0.07	n/a	n/a	n/a	n/a	n/a	3.22	0.20	37.92	0.00	1	1.91	0.46	0.09 (-0.08, 0.26) [2]

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

Heterogeneity and publication bias scores based on standardised mean differences

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

$p \leq 0.05$ in bold

Table 6 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 BCT	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 (USA/ non-USA); Setting (community based/ non-community based).

$p \leq 0.05$ in bold

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Appendix

Appendix A – Search terms

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

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 described and analyzed?	☐	☐	☐	☐
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

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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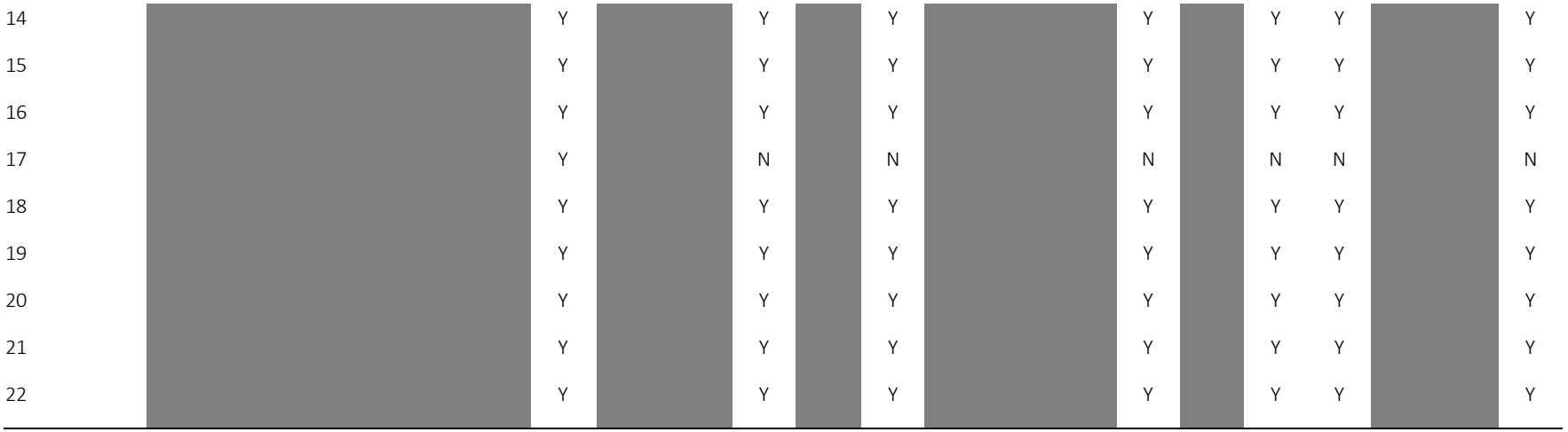
Appendix D – JBI Critical appraisal checklist results

	Ashe, 2015	Bickmore, 2013	Broekhuizen, 2016	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
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	

Quasi-Experimental



14							Y				Y				Y				Y				Y
15							Y				Y				Y				Y				Y
16							Y				Y				Y				Y				Y
17							Y				N				N				N				N
18							Y				Y				Y				Y				Y
19							Y				Y				Y				Y				Y
20							Y				Y				Y				Y				Y
21							Y				Y				Y				Y				Y
22							Y				Y				Y				Y				Y

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

References

Ashe, M.C., Winters, M., Hoppmann, C.A., Dawes, M.G., Gardiner, P.A., Giangregorio, L.M., Madden, K.M., McAllister, M.M., Wong, G., Puyat, J.H., Singer, J., Sims-Gould, J., McKay, H.A., 2015. "Not just another walking program": Everyday Activity Supports You (EASY) model—a randomized pilot study for a parallel randomized controlled trial. Pilot and Feasibility Studies 1, 4.

Barnett, A., Smith, B., Lord, S.R., Williams, M., Baumand, A., 2003. Community-based group exercise improves balance and reduces falls in at-risk older people: a randomised controlled trial. Age and Ageing 32, 407-414.

Beard, J.R., Officer, A., de Carvalho, I.A., Sadana, R., Pot, A.M., Michel, J.-P., Lloyd-Sherlock, P., Epping-Jordan, J.E., Peeters, G.M.E.E., Mahanani, W.R., Thiyagarajan, J.A., Chatterji, S., 2016. The World report on ageing and health: a policy framework for healthy ageing. The Lancet 387, 2145-2154.

Begg, C.B., Mazumdar, M., 1994. Operating characteristics of a rank correlation test for publication bias. Biometrics 50, 1088-1101.

Bickmore, T.W., Silliman, R.A., Nelson, K., Cheng, D.M., Winter, M., Henault, L., Paasche-Orlow, M.K., 2013. A randomized controlled trial of an automated exercise coach for older adults. Journal of American Geriatrics Society 61, 1676-1683.

Broekhuizen, K., de Gelder, J., Wijsman, C.A., Wijsman, L.W., Westendorp, R.G., Verhagen, E., Slagboom, P.E., de Craen, A.J., van Mechelen, W., van Heemst, D., van der Ouderaa, F., Mooijaart, S.P., 2016. An Internet-Based Physical Activity Intervention to Improve Quality of Life of Inactive Older Adults: A Randomized Controlled Trial. Journal Of Medical Internet Research 18, e74.

Cadmus-Bertram, L.A., Marcus, B.H., Patterson, R.E., Parker, B.A., Morey, B.L., 2015. Randomized Trial of a Fitbit-Based Physical Activity Intervention for Women. American Journal of Preventive Medicine 49, 414-418.

Caspersen, C.J., Powell, K.E., Christenson, G.M., 1985. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public health reports (Washington, D.C. : 1974) 100, 126-131.

Chad, K.E., Reeder, B.A., Harrison, E.L., Ashworth, N.L., Shappard, S.M., Schultz, S.L., Bruner, B.G., Fisher, K.L., Lawson, J.A., 2005. Profile of Physical Activity Levels in Community-Dwelling Older Adults. Medicine & Science in Sports & Exercise 37, 1774-1784.

Chase, J.-A.D., 2015. Interventions to Increase Physical Activity Among Older Adults: A Meta-Analysis. The Gerontologist 55, 706-718.

Chodzko-Zajko, W.J., Proctor, D.N., Fiatarone Singh, M.A., Minson, C.T., Nigg, C.R., Salem, G.J., Skinner, J.S., 2009. American College of Sports Medicine position stand. Exercise and physical activity for older adults. Medicine and Science in Sports and Exercise 41, 1510-1530.

Colbert, L.H., Matthews, C.E., Havighurst, T.C., Kim, K., Schoeller, D.A., 2011. Comparative Validity of Physical Activity Measures in Older Adults. Medicine and Science in Sports and Exercise 43, 867-876.

Cook, R.F., Hersch, R.K., Schlossberg, D., Leaf, S.L., 2015. A Web-based health promotion program for older workers: randomized controlled trial. Journal Of Medical Internet Research 17, e82.

Copeland, J.L., Ashe, M.C., Biddle, S.J., Brown, W.J., Buman, M.P., Chastin, S., Gardiner, P.A., Inoue, S., Jefferis, B.J., Oka, K., Owen, N., Sardinha, L.B., Skelton, D.A., Sugiyama, T., Dogra, S., 2017. Sedentary time in older adults: a critical review of measurement, associations with health, and interventions. British journal of sports medicine 51, 1539.

Daskalopoulou, C., Stubbs, B., Kralj, C., Koukounari, A., Prince, M., Prina, A.M., 2017. Physical activity and healthy ageing: A systematic review and meta-analysis of longitudinal cohort studies. Ageing Research Reviews 38, 6-17.

De Queiroz, B.M., Borgatto, A.F., Barbosa, A.R., GuimarÃEs, A.V., 2017. Exergame vs. Aerobic Exercise and Functional Fitness of Older Adults: A Randomized Controlled Trial. Journal of Physical Education & Sport 17, 740-747.

Deandrea, S., Lucenteforte, E., Bravi, F., Foschi, R., La Vecchia, C., Negri, E., 2010. Risk factors for falls in community-dwelling older people: a systematic review and meta-analysis. Epidemiology (Cambridge, Mass.) 21, 658-668.

Egger, M., Davey Smith, G., Schneider, M., Minder, C., 1997. Bias in meta-analysis detected by a simple, graphical test. British Medical Journal 315, 629-634.

Eurostat, 2018. Population by age group.

Flores Mateo, G., Granado-Font, E., Ferré-Grau, C., Montaña-Carreras, X., 2015. Mobile Phone Apps to Promote Weight Loss and Increase Physical Activity: A Systematic Review and Meta-Analysis. Journal of Medical Internet Research 17, e253.

Forberger, S., Bammann, K., Bauer, J., Boll, S., Bolte, G., Brand, T., Hein, A., Koppelin, F., Lippke, S., Meyer, J., Pischke, C.R., Voelcker-Rehage, C., Zeeb, H., 2017. How to Tackle Key Challenges in the Promotion of Physical Activity among Older Adults (65+): The AEQUIPA Network Approach. International Journal of Environmental Research and Public Health 14, 379.

Fox, S., Duggan, M., 2012. Mobile Health 2012. Pew Research Center, Online.

Frederix, I., Hansen, D., Coninx, K., Vandervoort, P., Vandijck, D., Hens, N., Van Craenenbroeck, E., Van Driessche, N., Dendale, P., 2015. Medium-Term Effectiveness of a Comprehensive Internet-Based and Patient-Specific Telerehabilitation Program With Text Messaging Support for Cardiac Patients: Randomized Controlled Trial. Journal Of Medical Internet Research 17, e185.

Gal, R., May, A.M., van Overmeeren, E.J., Simons, M., Monninkhof, E.M., 2018. The Effect of Physical Activity Interventions Comprising Wearables and Smartphone Applications on Physical Activity: a Systematic Review and Meta-analysis. Sports medicine - open 4, 42-42.

Global Advocacy for Physical Activity (GAPA) and the Advocacy Council of the International Society for Physical Activity and Health (ISPAH), 2012. NCD Prevention: Investments that Work for Physical Activity. British Journal of Sports Medicine 46, 709 - 712.

Gomes, M., Figueiredo, D., Teixeira, L., Poveda, V., Paúl, C., Santos-Silva, A., Costa, E., 2017. Physical inactivity among older adults across Europe based on the SHARE database. Age and Ageing 46, 71-77.

Harvey, J.A., Chastin, S.F.M., Skelton, D.A., 2013. Prevalence of sedentary behavior in older adults: a systematic review. International journal of environmental research and public health 10, 6645.

Hekler, E.B., King, A.C., Banerjee, B., Robinson, T., Alonso, M., Cirimele, J., Buman, M.P., Chen, F., 2011. A case study of BSUED: Behavioral Science-informed User Experience Design, Online.

Higgins, J.P., Thompson, S.G., 2002. Quantifying heterogeneity in a meta-analysis. Stat. Med. 21, 1539-1558.

Higgins, J.P.T., Thompson, S.G., Deeks, J.J., Altman, D.G., 2003. Measuring inconsistency in meta-analyses. British Medical Journal 327, 557-560.

Howes, S.C., Charles, D.K., Marley, J., Pedlow, K., McDonough, S.M., 2017. Gaming for Health: Systematic Review and Meta-analysis of the Physical and Cognitive Effects of Active Computer Gaming in Older Adults. Physical Therapy 97, 1122-1137.

Ioannidis, J.P.A., Patsopoulos, N.A., Evangelou, E., 2007. Uncertainty in heterogeneity estimates in meta-analyses. British Medical Journal 335, 914-916.

Irvine, B.A., Gelatt, A.V., Seeley, R.J., Macfarlane, P., Gau, M.J., 2013. Web-based Intervention to Promote Physical Activity by Sedentary Older Adults: Randomized Controlled Trial. Journal Of Medical Internet Research 15, e19.

Jackson, B.D., Gray, K., Knowles, S.R., De Cruz, P., 2016. EHealth Technologies in Inflammatory Bowel Disease: A Systematic Review. Journal of Crohn's and Colitis 10, 1103-1121.

James, S.L., Abate, D., Abate, K.H., Abay, S.M., Abbafati, C., Abbasi, N., Abbastabar, H., Abd-Allah, F., Abdela, J., Abdelalim, A., Abdollahpour, I., Abdulkader, R.S., Abebe, Z., Abera, S.F., Abil, O.Z., Abraha, H.N., Abu-Raddad, L.J., Abu-Rmeileh, N.M.E., Accrombessi, M.M.K., Acharya, D., Acharya, P., Ackerman, I.N., Adamu, A.A., Adebayo, O.M., Adekanmbi, V., Adetokunboh, O.O., Adib, M.G., Adsuar, J.C., Afanvi, K.A., Afarideh, M., Afshin, A., Agarwal, G., Agesa, K.M., Aggarwal, R., Aghayan, S.A., Agrawal, S., Ahmadi, A., Ahmadi, M., Ahmadieh, H., Ahmed, M.B., Aichour, A.N., Aichour, I., Aichour, M.T.E., Akinyemiju, T., Akseer, N., Al-Aly, Z., Al-Eyadhy, A., Al-Mekhlafi, H.M., Al-

Raddadi, R.M., Alahdab, F., Alam, K., Alam, T., Alashi, A., Alavian, S.M., Alene, K.A., Alijanzadeh, M., Alizadeh-Navaei, R., Aljunid, S.M., Alkerwi, A.a., Alla, F., Allebeck, P., Alouani, M.M.L., Altirkawi, K., Alvis-Guzman, N., Amare, A.T., Aminde, L.N., Ammar, W., Amoako, Y.A., Anber, N.H., Andrei, C.L., Androudi, S., Animut, M.D., Anjomshoa, M., Ansha, M.G., Antonio, C.A.T., Anwari, P., Arabloo, J., Arauz, A., Aremu, O., Ariani, F., Armoon, B., Ärnlöv, J., Arora, A., Artaman, A., Aryal, K.K., Asayesh, H., Asghar, R.J., Ataro, Z., Atre, S.R., Ausloos, M., Avila-Burgos, L., Avokpaho, E.F.G.A., Awasthi, A., Ayala Quintanilla, B.P., Ayer, R., Azzopardi, P.S., Babazadeh, A., Badali, H., Badawi, A., Bali, A.G., Ballesteros, K.E., Ballew, S.H., Banach, M., Banoub, J.A.M., Banstola, A., Barac, A., Barboza, M.A., Barker-Collo, S.L., Bärnighausen, T.W., Barrero, L.H., Baune, B.T., Bazargan-Hejazi, S., Bedi, N., Beghi, E., Behzadifar, M., Behzadifar, M., Béjot, Y., Belachew, A.B., Belay, Y.A., Bell, M.L., Bello, A.K., Bensenor, I.M., Bernabe, E., Bernstein, R.S., Beuran, M., Beyranvand, T., Bhala, N., Bhattarai, S., Bhaumik, S., Bhutta, Z.A., Biadgo, B., Bijani, A., Bikbov, B., Bilano, V., Bililign, N., Bin Sayeed, M.S., Bisanzio, D., Blacker, B.F., Blyth, F.M., Bou-Orm, I.R., Boufous, S., Bourne, R., Brady, O.J., Brainin, M., Brant, L.C., Brazinova, A., Breitborde, N.J.K., Brenner, H., Briant, P.S., Briggs, A.M., Briko, A.N., Britton, G., Brugha, T., Buchbinder, R., Busse, R., Butt, Z.A., Cahuana-Hurtado, L., Cano, J., Cárdenas, R., Carrero, J.J., Carter, A., Carvalho, F., Castañeda-Orjuela, C.A., Castillo Rivas, J., Castro, F., Catalá-López, F., Cercy, K.M., Cerin, E., Chaiah, Y., Chang, A.R., Chang, H.-Y., Chang, J.-C., Charlson, F.J., Chattopadhyay, A., Chattu, V.K., Chaturvedi, P., Chiang, P.P.-C., Chin, K.L., Chitheer, A., Choi, J.-Y.J., Chowdhury, R., Christensen, H., Christopher, D.J., Cicuttini, F.M., Ciobanu, L.G., Cirillo, M., Claro, R.M., Collado-Mateo, D., Cooper, C., Coresh, J., Cortesi, P.A., Cortinovis, M., Costa, M., Cousin, E., Criqui, M.H., Cromwell, E.A., Cross, M., Crump, J.A., Dadi, A.F., Dandona, L., Dandona, R., Dargan, P.I., Daryani, A., Das Gupta, R., Das Neves, J., Dasa, T.T., Davey, G., Davis, A.C., Davitoiu, D.V., De Courten, B., De La Hoz, F.P., De Leo, D., De Neve, J.-W., Degefa, M.G., Degenhardt, L., Deiparine, S., Dellavalle, R.P., Demoz, G.T., Deribe, K., Dervenis, N., Des Jarlais, D.C., Dessie, G.A., Dey, S., Dharmaratne, S.D., Dinberu, M.T., Dirac, M.A., Djalalinia, S., Doan, L., Dokova, K., Doku, D.T., Dorsey, E.R., Doyle, K.E., Driscoll, T.R., Dubey, M., Dubljanin, E., Duken, E.E., Duncan, B.B., Duraes, A.R., Ebrahimi, H., Ebrahimpour, S., Echko, M.M., Edvardsson, D., Effiong, A., Ehrlich, J.R., El Bcheraoui, C., El Sayed Zaki, M., El-Khatib, Z., Elkout, H., Elyazar, I.R.F., Enayati, A., Endries, A.Y., Er, B., Erskine, H.E., Eshrati, B., Eskandarieh, S., Esteghamati, A., Esteghamati, S., Fakhim, H., Fallah Omrani, V., Faramarzi, M., Fareed, M., Farhadi, F., Farid, T.A., Farinha, C.S.E.s., Farioli, A., Faro, A., Farvid, M.S., Farzadfar, F., Feigin, V.L., Fentahun, N., Fereshtehnejad, S.-M., Fernandes, E., Fernandes, J.C., Ferrari, A.J., Feyissa, G.T., Filip, I., Fischer, F., Fitzmaurice, C., Foigt, N.A., Foreman, K.J., Fox, J., Frank, T.D., Fukumoto, T., Fullman, N., Fürst, T., Furtado, J.M., Futran, N.D., Gall, S., Ganji, M., Gankpe, F.G., Garcia-Basteiro, A.L., Gardner, W.M., Gebre, A.K., Gebremedhin, A.T., Gebremichael, T.G., Gelano, T.F., Geleijnse, J.M., Genova-Maleras, R., Geramo, Y.C.D., Gething, P.W., Gezae, K.E., Ghadiri, K., Ghasemi Falavarjani, K., Ghasemi-Kasman, M., Ghimire, M., Ghosh, R., Ghoshal, A.G., Giampaoli, S., Gill, P.S., Gill, T.K., Ginawi, I.A., Giussani, G., Gnedovskaya, E.V., Goldberg, E.M., Goli, S., Gómez-Dantés, H., Gona, P.N., Gopalani, S.V., Gorman, T.M., Goulart, A.C., Goulart, B.N.G., Grada, A., Grams, M.E., Grosso, G., Gugnani, H.C., Guo, Y., Gupta, P.C., Gupta, R., Gupta, R., Gupta, T., Gyawali, B., Haagsma, J.A., Hachinski, V., Hafezi-Nejad, N., Haghparast Bidgoli, H., Hagos, T.B.,

Hailu, G.B., Haj-Mirzaian, A., Haj-Mirzaian, A., Hamadeh, R.R., Hamidi, S., Handal, A.J., Hankey, G.J., Hao, Y., Harb, H.L., Harikrishnan, S., Haro, J.M., Hasan, M., Hassankhani, H., Hassen, H.Y., Havmoeller, R., Hawley, C.N., Hay, R.J., Hay, S.I., Hedayatizadeh-Omran, A., Heibati, B., Hendrie, D., Henok, A., Herteliu, C., Heydarpour, S., Hibstu, D.T., Hoang, H.T., Hoek, H.W., Hoffman, H.J., Hole, M.K., Homaie Rad, E., Hoogar, P., Hosgood, H.D., Hosseini, S.M., Hosseinzadeh, M., Hostiuc, M., Hostiuc, S., Hotez, P.J., Hoy, D.G., Hsairi, M., Htet, A.S., Hu, G., Huang, J.J., Huynh, C.K., Iburg, K.M., Ikeda, C.T., Ileanu, B., Ilesanmi, O.S., Iqbal, U., Irvani, S.S.N., Irvine, C.M.S., Islam, S.M.S., Islami, F., Jacobsen, K.H., Jahangiry, L., Jahanmehr, N., Jain, S.K., Jakovljevic, M., Javanbakht, M., Jayatilleke, A.U., Jeemon, P., Jha, R.P., Jha, V., Ji, J.S., Johnson, C.O., Jonas, J.B., Jozwiak, J.J., Jungari, S.B., Jürisson, M., Kabir, Z., Kadel, R., Kahsay, A., Kalani, R., Kanchan, T., Karami, M., Karami Matin, B., Karch, A., Karema, C., Karimi, N., Karimi, S.M., Kasaeian, A., Kassa, D.H., Kassa, G.M., Kassa, T.D., Kassebaum, N.J., Katikireddi, S.V., Kawakami, N., Karyani, A.K., Keighobadi, M.M., Keiyoro, P.N., Kemmer, L., Kemp, G.R., Kengne, A.P., Keren, A., Khader, Y.S., Khafaei, B., Khafaie, M.A., Khajavi, A., Khalil, I.A., Khan, E.A., Khan, M.S., Khan, M.A., Khang, Y.-H., Khazaei, M., Khoja, A.T., Khosravi, A., Khosravi, M.H., Kiadaliri, A.A., Kiirithio, D.N., Kim, C.-I., Kim, D., Kim, P., Kim, Y.-E., Kim, Y.J., Kimokoti, R.W., Kinfu, Y., Kisa, A., Kissimova-Skarbek, K., Kivimäki, M., Knudsen, A.K.S., Kocarnik, J.M., Kochhar, S., Kokubo, Y., Kolola, T., Kopec, J.A., Kosen, S., Kotsakis, G.A., Koul, P.A., Koyanagi, A., Kravchenko, M.A., Krishan, K., Krohn, K.J., Kuate Defo, B., Kucuk Bicer, B., Kumar, G.A., Kumar, M., Kyu, H.H., Lad, D.P., Lad, S.D., Lafranconi, A., Lalloo, R., Lallukka, T., Lami, F.H., Lansingh, V.C., Latifi, A., Lau, K.M.-M., Lazarus, J.V., Leasher, J.L., Ledesma, J.R., Lee, P.H., Leigh, J., Leung, J., Levi, M., Lewycka, S., Li, S., Li, Y., Liao, Y., Liben, M.L., Lim, L.-L., Lim, S.S., Liu, S., Lodha, R., Looker, K.J., Lopez, A.D., Lorkowski, S., Lotufo, P.A., Low, N., Lozano, R., Lucas, T.C.D., Lucchesi, L.R., Lunevicius, R., Lyons, R.A., Ma, S., Macarayan, E.R.K., Mackay, M.T., Madotto, F., Magdy Abd El Razek, H., Magdy Abd El Razek, M., Maghavani, D.P., Mahotra, N.B., Mai, H.T., Majdan, M., Majdzadeh, R., Majeed, A., Malekzadeh, R., Malta, D.C., Mamun, A.A., Manda, A.-L., Manguerra, H., Manhertz, T., Mansournia, M.A., Mantovani, L.G., Mapoma, C.C., Maravilla, J.C., Marcenes, W., Marks, A., Martins-Melo, F.R., Martopullo, I., März, W., Marzan, M.B., Mashamba-Thompson, T.P., Massenburg, B.B., Mathur, M.R., Matsushita, K., Maulik, P.K., Mazidi, M., McAlinden, C., McGrath, J.J., McKee, M., Mehndiratta, M.M., Mehrotra, R., Mehta, K.M., Mehta, V., Mejia-Rodriguez, F., Mekonen, T., Melese, A., Melku, M., Meltzer, M., Memiah, P.T.N., Memish, Z.A., Mendoza, W., Mengistu, D.T., Mengistu, G., Mensah, G.A., Mereta, S.T., Meretoja, A., Meretoja, T.J., Mestrovic, T., Mezerji, N.M.G., Miazgowski, B., Miazgowski, T., Millear, A.I., Miller, T.R., Miltz, B., Mini, G.K., Mirarefin, M., Mirrakhimov, E.M., Misganaw, A.T., Mitchell, P.B., Mitiku, H., Moazen, B., Mohajer, B., Mohammad, K.A., Mohammadifard, N., Mohammadnia-Afrouzi, M., Mohammed, M.A., Mohammed, S., Mohebi, F., Moitra, M., Mokdad, A.H., Molokhia, M., Monasta, L., Moodley, Y., Moosazadeh, M., Moradi, G., Moradi-Lakeh, M., Moradinazar, M., Moraga, P., Morawska, L., Moreno Velásquez, I., Morgado-Da-Costa, J., Morrison, S.D., Moschos, M.M., Mousavi, S.M., Mruts, K.B., Muche, A.A., Muchie, K.F., Mueller, U.O., Muhammed, O.S., Mukhopadhyay, S., Muller, K., Mumford, J.E., Murhekar, M., Musa, J., Musa, K.I., Mustafa, G., Nabhan, A.F., Nagata, C., Naghavi, M., Naheed, A., Nahvijou, A., Naik, G., Naik, N., Najafi, F., Naldi, L., Nam, H.S., Nangia, V., Nansseu, J.R., Nascimento, B.R., Natarajan, G., Neamati, N., Negoi, I.,

Negoi, R.I., Neupane, S., Newton, C.R.J., Ngunjiri, J.W., Nguyen, A.Q., Nguyen, H.T., Nguyen, H.L.T., Nguyen, H.T., Nguyen, L.H., Nguyen, M., Nguyen, N.B., Nguyen, S.H., Nichols, E., Ningrum, D.N.A., Nixon, M.R., Nolutshungu, N., Nomura, S., Norheim, O.F., Noroozi, M., Norrving, B., Noubiap, J.J., Nouri, H.R., Nourollahpour Shiadeh, M., Nowroozi, M.R., Nsoesie, E.O., Nyasulu, P.S., Odell, C.M., Ofori-Asenso, R., Ogbo, F.A., Oh, I.-H., Oladimeji, O., Olagunju, A.T., Olagunju, T.O., Olivares, P.R., Olsen, H.E., Olusanya, B.O., Ong, K.L., Ong, S.K., Oren, E., Ortiz, A., Ota, E., Otstavnov, S.S., Øverland, S., Owolabi, M.O., P A, M., Pacella, R., Pakpour, A.H., Pana, A., Panda-Jonas, S., Parisi, A., Park, E.-K., Parry, C.D.H., Patel, S., Pati, S., Patil, S.T., Patle, A., Patton, G.C., Paturi, V.R., Paulson, K.R., Pearce, N., Pereira, D.M., Perico, N., Pesudovs, K., Pham, H.Q., Phillips, M.R., Pigott, D.M., Pillay, J.D., Piradov, M.A., Pirsaheb, M., Pishgar, F., Plana-Ripoll, O., Plass, D., Polinder, S., Popova, S., Postma, M.J., Pourshams, A., Poustchi, H., Prabhakaran, D., Prakash, S., Prakash, V., Purcell, C.A., Purwar, M.B., Qorbani, M., Quistberg, D.A., Radfar, A., Rafay, A., Rafiei, A., Rahim, F., Rahimi, K., Rahimi-Movaghar, A., Rahimi-Movaghar, V., Rahman, M., Rahman, M.H.u., Rahman, M.A., Rahman, S.U., Rai, R.K., Rajati, F., Ram, U., Ranjan, P., Ranta, A., Rao, P.C., Rawaf, D.L., Rawaf, S., Reddy, K.S., Reiner, R.C., Reinig, N., Reitsma, M.B., Remuzzi, G., Renzaho, A.M.N., Resnikoff, S., Rezaei, S., Rezai, M.S., Ribeiro, A.L.P., Robinson, S.R., Roever, L., Ronfani, L., Roshandel, G., Rostami, A., Roth, G.A., Roy, A., Rubagotti, E., Sachdev, P.S., Sadat, N., Saddik, B., Sadeghi, E., Saeedi Moghaddam, S., Safari, H., Safari, Y., Safari-Faramani, R., Safdarian, M., Safi, S., Safiri, S., Sagar, R., Sahebkar, A., Sahraian, M.A., Sajadi, H.S., Salam, N., Salama, J.S., Salamati, P., Saleem, K., Saleem, Z., Salimi, Y., Salomon, J.A., Salvi, S.S., Salz, I., Samy, A.M., Sanabria, J., Sang, Y., Santomauro, D.F., Santos, I.S., Santos, J.V., Santric Milicevic, M.M., Sao Jose, B.P., Sardana, M., Sarker, A.R., Sarrafzadegan, N., Sartorius, B., Sarvi, S., Sathian, B., Satpathy, M., Sawant, A.R., Sawhney, M., Saxena, S., Saylan, M., Schaeffner, E., Schmidt, M.I., Schneider, I.J.C., Schöttker, B., Schwebel, D.C., Schwendicke, F., Scott, J.G., Sekerija, M., Sepanlou, S.G., Serván-Mori, E., Seyedmousavi, S., Shabaninejad, H., Shafieesabet, A., Shahbazi, M., Shaheen, A.A., Shaikh, M.A., Shams-Beyranvand, M., Shamsi, M., Shamsizadeh, M., Sharafi, H., Sharafi, K., Sharif, M., Sharif-Alhoseini, M., Sharma, M., Sharma, R., She, J., Sheikh, A., Shi, P., Shibuya, K., Shigematsu, M., Shiri, R., Shirkoohi, R., Shishani, K., Shiue, I., Shokraneh, F., Shoman, H., Shrime, M.G., Si, S., Siabani, S., Siddiqi, T.J., Sigfusdottir, I.D., Sigurvinsdottir, R., Silva, J.P., Silveira, D.G.A., Singam, N.S.V., Singh, J.A., Singh, N.P., Singh, V., Sinha, D.N., Skiadaresi, E., Slepak, E.L.N., Sliwa, K., Smith, D.L., Smith, M., Soares Filho, A.M., Sobaih, B.H., Sobhani, S., Sobngwi, E., Soneji, S.S., Soofi, M., Soosaraei, M., Sorensen, R.J.D., Soriano, J.B., Soyiri, I.N., Sposato, L.A., Sreeramareddy, C.T., Srinivasan, V., Stanaway, J.D., Stein, D.J., Steiner, C., Steiner, T.J., Stokes, M.A., Stovner, L.J., Subart, M.L., Sudaryanto, A., Sufiyan, M.a.B., Sunguya, B.F., Sur, P.J., Sutradhar, I., Sykes, B.L., Sylte, D.O., Tabarés-Seisdedos, R., Tadakamadla, S.K., Tadesse, B.T., Tandon, N., Tassew, S.G., Tavakkoli, M., Taveira, N., Taylor, H.R., Tehrani-Banihashemi, A., Tekalign, T.G., Tekelemedhin, S.W., Tekle, M.G., Temesgen, H., Temsah, M.-H., Temsah, O., Terkawi, A.S., Teweldemedhin, M., Thankappan, K.R., Thomas, N., Tilahun, B., To, Q.G., Tonelli, M., Topor-Madry, R., Topouzis, F., Torre, A.E., Tortajada-Girbés, M., Touvier, M., Tovani-Palone, M.R., Towbin, J.A., Tran, B.X., Tran, K.B., Troeger, C.E., Truelsen, T.C., Tsilimbaris, M.K., Tsoi, D., Tudor Car, L., Tuzcu, E.M., Ukwaja, K.N., Ullah, I., Undurraga, E.A., Unutzer, J., Updike, R.L., Usman, M.S., Uthman, O.A., Vaduganathan,

M., Vaezi, A., Valdez, P.R., Varughese, S., Vasankari, T.J., Venketasubramanian, N., Villafaina, S., Violante, F.S., Vladimirov, S.K., Vlassov, V., Vollset, S.E., Vosoughi, K., Vujcic, I.S., Wagnew, F.S., Waheed, Y., Waller, S.G., Wang, Y., Wang, Y.-P., Weiderpass, E., Weintraub, R.G., Weiss, D.J., Weldegebreal, F., Weldegwergs, K.G., Werdecker, A., West, T.E., Whiteford, H.A., Widecka, J., Wijeratne, T., Wilner, L.B., Wilson, S., Winkler, A.S., Wiyeh, A.B., Wiysonge, C.S., Wolfe, C.D.A., Woolf, A.D., Wu, S., Wu, Y.-C., Wyper, G.M.A., Xavier, D., Xu, G., Yadgir, S., Yadollahpour, A., Yahyazadeh Jabbari, S.H., Yamada, T., Yan, L.L., Yano, Y., Yaseri, M., Yasin, Y.J., Yeshaneh, A., Yimer, E.M., Yip, P., Yisma, E., Yonemoto, N., Yoon, S.-J., Yotebieng, M., Younis, M.Z., Yousefifard, M., Yu, C., Zadnik, V., Zaidi, Z., Zaman, S.B., Zamani, M., Zare, Z., Zeleke, A.J., Zenebe, Z.M., Zhang, K., Zhao, Z., Zhou, M., Zodpey, S., Zucker, I., Vos, T., Murray, C.J.L., 2018. Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. The Lancet 392, 1789-1858.

Jantunen, H., Wasenius, N., Salonen, M.K., Perala, M.M., Osmond, C., Kautiainen, H., Simonen, M., Pohjolainen, P., Kajantie, E., Rantanen, T., von Bonsdorff, M.B., Eriksson, J.G., 2017. Objectively measured physical activity and physical performance in old age. Age and ageing 46, 232-237.

Keogh, J.W., Power, N., Wooller, L., Lucas, P., Whatman, C., 2014. Physical and psychosocial function in residential aged-care elders: effect of Nintendo Wii Sports games. Journal of Aging and Physical Activity 22, 235-244.

Kerr, J., Rosenberg, D., Millstein, R.A., Bolling, K., Crist, K., Takemoto, M., Godbole, S., Moran, K., Natarajan, L., Castro-Sweet, C., Buchner, D., 2018. Cluster randomized controlled trial of a multilevel physical activity intervention for older adults. International Journal of Behavioral Nutrition and Physical Activity 15, 32.

Kim, B.H., Glanz, K., 2013. Text messaging to motivate walking in older African Americans: a randomized controlled trial. American Journal of Preventive Medicine 44, 71-75.

King, A.C., Friedman, R., Marcus, B., Castro, C., Napolitano, M., Ahn, D., Baker, L., 2007. Ongoing physical activity advice by humans versus computers: The Community Health Advice by Telephone (CHAT) Trial. Health Psychology 26, 718-727.

King, A.C., Hekler, E.B., Castro, C.M., Buman, M.P., Marcus, B.H., Friedman, R.H., Napolitano, M.A., 2014. Exercise advice by humans versus computers: maintenance effects at 18 months. Health Psychology 33, 192-196.

King, A.C., Hekler, E.B., Grieco, L.A., Winter, S.J., Sheats, J.L., Buman, M.P., Banerjee, B., Robinson, T.N., Cirimele, J., 2013. Harnessing Different Motivational Frames via Mobile Phones to Promote Daily Physical Activity and Reduce Sedentary Behavior in Aging Adults. PLOS ONE 8, e62613.

Knight, E., Stuckey, M.I., Petrella, R.J., 2015. Health promotion through primary care: enhancing self-management with activity prescription and mHealth. The Physician and sportsmedicine 42, 90-99.

Kolt, G.S., Schofield, G.M., Kerse, N., Garrett, N., Oliver, M., 2007. Effect of Telephone Counseling on Physical Activity for Low-Active Older People in Primary Care: A Randomized, Controlled Trial. Journal of the American Geriatrics Society 55, 986-992.

Kullgren, J.T., Harkins, K.A., Bellamy, S.L., Gonzales, A., Tao, Y., Zhu, J., Volpp, K.G., Asch, D.A., Heisler, M., Karlawish, J., 2014. A mixed-methods randomized controlled trial of financial incentives and peer networks to promote walking among older adults. Health education & behavior : the official publication of the Society for Public Health Education 41, 43s-50s.

Leask, C.F., Harvey, J.A., Skelton, D.A., Chastin, S.F., 2015. Exploring the context of sedentary behaviour in older adults (what, where, why, when and with whom). European Review of Aging and Physical Activity 12, 4.

Leutwyler, H., Hubbard, E., Cooper, B., Dowling, G., 2015. The Impact of a Videogame-Based Pilot Physical Activity Program in Older Adults with Schizophrenia on Subjectively and Objectively Measured Physical Activity. Frontiers in Psychiatry 6, 180.

Lewis, L.K., Rowlands, A.V., Gardiner, P.A., Standage, M., English, C., Olds, T., 2016. Small Steps: Preliminary effectiveness and feasibility of an incremental goal-setting intervention to reduce sitting time in older adults. Maturitas 85, 64-70.

Lyons, E.J., Lewis, Z.H., Mayrsohn, B.G., Rowland, J.L., 2014. Behavior Change Techniques Implemented in Electronic Lifestyle Activity Monitors: A Systematic Content Analysis. Journal Of Medical Internet Research 16, e192.

Lyons, E.J., Swartz, M.C., Lewis, Z.H., Martinez, E., Jennings, K., 2017. Feasibility and Acceptability of a Wearable Technology Physical Activity Intervention With Telephone Counseling for Mid-Aged and Older Adults: A Randomized Controlled Pilot Trial. JMIR mHealth And uHealth 5, e28-e28.

MacDonald, J.R., 2002. Potential causes, mechanisms, and implications of post exercise hypotension. J. Hum. Hypertens. 16, 225-236.

Martinson, B.C., Sherwood, N.E., Crain, A.L., Hayes, M.G., King, A.C., Pronk, N.P., O'Connor, P.J., 2010. Maintaining physical activity among older adults: 24-month outcomes of the Keep Active Minnesota randomized controlled trial. Preventive Medicine 51, 37-44.

Michie, S., Richardson, M., Johnston, M., Abraham, C., Francis, J., Hardeman, W., Eccles, M.P., Cane, J., Wood, C.E., 2013. The Behavior Change Technique Taxonomy (v1) of 93 Hierarchically Clustered Techniques: Building an International Consensus for the Reporting of Behavior Change Interventions. Annals of Behavioral Medicine 46, 81-95.

Michie, S., Yardley, L., West, R., Patrick, K., Greaves, F., 2017. Developing and Evaluating Digital Interventions to Promote Behavior Change in Health and Health Care: Recommendations Resulting From an International Workshop. Journal Of Medical Internet Research 19, e232.

Middelweerd, A., Mollee, J.S., van der Wal, C.N., Brug, J., te Velde, S.J., 2014. Apps to promote physical activity among adults: a review and content analysis. International Journal of Behavioral Nutrition and Physical Activity 11, 97.

Mistry, N., Keepanasseril, A., Wilczynski, N.L., Nieuwlaat, R., Ravall, M., Haynes, R.B., 2015. Technology-mediated interventions for enhancing medication adherence. Journal of the American Medical Informatics Association 22, e177-e193.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., 2009. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. International Journal of Surgery 8, 336-341.

Molina, K.I., Ricci, N.A., de Moraes, S.A., Perracini, M.R., 2014. Virtual reality using games for improving physical functioning in older adults: a systematic review. Journal of Neuroengineering and Rehabilitation 11, 156.

Muellmann, S., Forberger, S., Mollers, T., Broring, E., Zeeb, H., Pischke, C.R., 2017. Effectiveness of eHealth interventions for the promotion of physical activity in older adults: A systematic review. Preventive Medicine 108, 93-110.

Müller, M.A., Khoo, S., Morris, T., 2016. Text Messaging for Exercise Promotion in Older Adults From an Upper-Middle-Income Country: Randomized Controlled Trial. Journal Medical Internet Research 18, e5.

Nguyen, H.Q., Gill, D.P., Wolpin, S., Steele, B.G., Benditt, J.O., 2009. Pilot study of a cell phone-based exercise persistence intervention post-rehabilitation for COPD. International Journal of Chronic Obstructive Pulmonary Disorder 4, 301-313.

Norman, G.J., Zabinski, M.F., Adams, M.A., Rosenberg, D.E., Yaroch, A.L., Atienza, A.A., 2007. A review of eHealth interventions for physical activity and dietary behavior change. American Journal of Preventive Medicine 33, 336-345.

O'Brien, T., Troutman-Jordan, M., Hathaway, D., Armstrong, S., Moore, M., 2015. Acceptability of wristband activity trackers among community dwelling older adults. Geriatric Nursing 36, S21-25.

Ofcom, 2018. Communications Market Report, Online.

Office for National Statistics, 2017. Expectation of life, principal projection, England.

Pew Research Centre, 2017. Mobile Fact Sheet, Online.

Pope, Z., Zeng, N., Gao, Z., 2017. The effects of active video games on patients' rehabilitative outcomes: A meta-analysis. Preventive Medicine 95, 38-46.

Prince, S.A., Adamo, K.B., Hamel, M.E., Hardt, J., Connor Gorber, S., Tremblay, M., 2008. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. International Journal of Behavioral Nutrition and Physical Activity 5, 56.

Public Health England, 2014. Everybody active, every day: An evidence based approch to physical activity, in: England, P.H. (Ed.). Public Health England, London.

Puszkiewicz, P., Roberts, A., Smith, L., Wardle, J., Fisher, A., 2016. Feasibility of a mobile phone application to promote physical activity in cancer survivors. Frontiers in Public Health 2.

Rabin, C., Dunsiger, S., Ness, K.K., Marcus, B.H., 2011. Internet-Based Physical Activity Intervention Targeting Young Adult Cancer Survivors. Journal of Adolescent and Young Adult Oncology 1, 188-194.

Rawstorn, J.C., Gant, N., Direito, A., Beckmann, C., Maddison, R., 2016. Telehealth exercise-based cardiac rehabilitation: a systematic review and meta-analysis. Heart 102, 1183-1192.

Rikli, R.E.a.J., C. J., 1999. Development and Validation of a Functional Fitness Test for Community-Residing Older Adults. Journal of Aging and Physical Activity 7, 129 - 161.

Roberts, A.L., Fisher, A., Smith, L., Heinrich, M., Potts, H.W.W., 2017. Digital health behaviour change interventions targeting physical activity and diet in cancer survivors: a systematic review and meta-analysis. Journal of Cancer Survivorship 11, 704-719.

Ruiz, J.G., Andrade, A.D., Anam, R., Aguiar, R., Sun, H., Roos, B.A., 2012. Using anthropomorphic avatars resembling sedentary older individuals as models to enhance self-efficacy and adherence to physical activity: psychophysiological correlates. Stud. Health Technol. Inform. 173, 405-411.

Sazlina, S.G., Zaiton, A., Nor Afiah, M.Z., Hayati, K.S., 2012. Predictors of health related quality of life in older people with non-communicable diseases attending three primary care clinics in Malaysia. The journal of nutrition, health & aging 16, 498-502.

Schoeppe, S., Alley, S., Van Lippevelde, W., Bray, N.A., Williams, S.L., Duncan, M.J., Vandelanotte, C., 2016. Efficacy of interventions that use apps to improve diet, physical activity and sedentary behaviour: a systematic review. International Journal of Behavioral Nutrition and Physical Activity 13, 127.

Skjaeret, N., Nawaz, A., Morat, T., Schoene, D., Helbostad, J.L., Vereijken, B., 2016. Exercise and rehabilitation delivered through exergames in older adults: An integrative review of technologies, safety and efficacy. Int. J. Med. Inform. 85, 1-16.

Smith, L., Gardner, B., Fisher, A., Hamer, M., 2015. Patterns and correlates of physical activity behaviour over 10 years in older adults: prospective analyses from the English Longitudinal Study of Ageing. British Medical Journal Open 5.

Spohr, S.A., Nandy, R., Gandhiraj, D., Vemulapalli, A., Anne, S., Walters, S.T., 2015. Efficacy of SMS Text Message Interventions for Smoking Cessation: A Meta-Analysis. Journal of Substance Abuse Treatment 56, 1-10.

Statistica, 2018. Resident population of the United States by sex and age as of July 2017 (in millions).

Strand, K.A., Francis, S.L., Margrett, J.A., Franke, W.D., Peterson, M.J., 2014. Community-Based Exergaming Program Increases Physical Activity and Perceived Wellness in Older Adults. Journal of Aging and Physical Activity 22, 364-371.

Su, D., Zhou, J., Kelley, M.S., Michaud, T.L., Siahpush, M., Kim, J., Wilson, F., Stimpson, J.P., Pagán, J.A., 2016. Does telemedicine improve treatment outcomes for diabetes? A meta-analysis of results from 55 randomized controlled trials. Diabetes Research and Clinical Practice 116, 136-148.

Tak, E., Kuiper, R., Chorus, A., Hopman-Rock, M., 2013. Prevention of onset and progression of basic ADL disability by physical activity in community dwelling older adults: A meta-analysis. Ageing Research Reviews 12, 329-338.

Taylor, A.H., Cable, N.T., Faulkner, G., Hillsdon, M., Narici, M., van der Bij, A.K., 2004. Physical activity and older adults: a review of health benefits and the effectiveness of interventions. Journal of Sports Sciences 22, 703-725.

Tiedemann, A., Hassett, L., Sherrington, C., 2015. A novel approach to the issue of physical inactivity in older age. Preventive Medicine Reports 2, 595-597.

Tremblay, M.S., Aubert, S., Barnes, J.D., Saunders, T.J., Carson, V., Latimer-Cheung, A.E., Chastin, S.F.M., Altenburg, T.M., Chinapaw, M.J.M., 2017. Sedentary Behavior Research Network (SBRN) – Terminology Consensus Project process and outcome. International Journal of Behavioral Nutrition and Physical Activity 14, 75.

Tufanaru, C., Munn, Z., Aromataris, E., Campbell, J., Hopp, L., 2017. Chapter 3: Systematic reviews of effectiveness., in: Aromataris, E., Munn, Z. (Eds.), Joanna Briggs Institute Reviewer's Manual. , Online.

Van Cauwenberg, J., Van Holle, V., De Bourdeaudhuij, I., Owen, N., Deforche, B., 2014. Older adults' reporting of specific sedentary behaviors: validity and reliability. BMC public health 14, 734-734.

van der Bij, A.K., Laurant, M.G.H., Wensing, M., 2002. Effectiveness of physical activity interventions for older adults: a review. American Journal of Preventive Medicine 22, 120-133.

Vidoni, E.D., Watts, A.S., Burns, J.M., Greer, C.S., Graves, R.S., Van Sciver, A., Black, J.R., Cooper, S.K., Nagely, A.C., Uphoff, E., Volmer, J.M., Bieberle, N.A., 2016. Feasibility of a Memory Clinic-Based Physical Activity Prescription Program. Journal of Alzheimers Disease 53, 161-170.

Vinding, K.K., Elsberg, H., Thorkilgaard, T., Belard, E., Pedersen, N., Elkjaer, M., Marker, D., Carlsen, K., Burisch, J., Munkholm, P., 2016. Fecal Calprotectin Measured By Patients at Home Using Smartphones--A New Clinical Tool in Monitoring Patients with Inflammatory Bowel Disease. Inflammatory bowel diseases 22, 336-344.

Watson, K., Carlson, S., Gunn, J., Galuska, D., O'Connor, A., Greenlund, K., Fulton, J., 2016. Physical inactivity among adults ageds 50 years and older - United States, 2014, MMWR Morbidity and Mortality Weekly Report. U.S. Department of Health and Human Sciences, Online, pp. 954-958.

Wijsman, C.A., Westendorp, R.G., Verhagen, E.A., Catt, M., Slagboom, P.E., de Craen, A.J., Broekhuizen, K., van Mechelen, W., van Heemst, D., van der Ouderaa, F., Mooijaart, S.P., 2013. Effects of a web-based intervention on physical activity and metabolism in older adults: randomized controlled trial. Journal of Medical Internet Research 15, e233.

Williams, T.M., 2016. The effect of video gaming on physical activity among nursing home residents., Faculty of the graduate school. The University of North Carolina at Greensboro, Online.

Wirth, K., Klenk, J., Brefka, S., Dallmeier, D., Faehling, K., Roqué i Figuls, M., Tully, M.A., Giné-Garriga, M., Caserotti, P., Salvà, A., Rothenbacher, D., Denkinger, M., Stubbs, B., 2017. Biomarkers associated with sedentary behaviour in older adults: A systematic review. Ageing Research Reviews 35, 87-111.

Yardley, L., Choudhury, T., Patrick, K., Michie, S., 2016. Current Issues and Future Directions for Research Into Digital Behavior Change Interventions. American Journal of Preventive Medicine 51, 814-815.

Zubala, A., Macgillivray, S., Frost, H., Kroll, T., Skelton, D.A., Gavine, A., Gray, N.M., Toma, M., Morris, J., 2017. Promotion of physical activity interventions for community dwelling older adults: A systematic review of reviews. PLoS ONE 12, 1-36.