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Review Article

A systematic review of Behaviour Change Interventions to improve exercise self-efficacy and adherence in people with Parkinson's disease using the Theoretical Domains Framework

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Abstract

Physical activity and exercise can limit the development of sarcopenia in Parkinson's Disease. This review aims to evaluate the potential effects of behavioural change (BC) interventions on exercise self-efficacy and adherence in people with Parkinson's. We searched nine databases and included randomised and non-randomised studies reporting exercise self-efficacy, quality of life (QoL), physical function and/or exercise adherence. Two reviewers independently screened, data extracted, and assessed risk of bias and certainty of evidence. The interventions were mapped to the Theoretical Domains Framework. Eleven studies (n=901) were included. Four were randomised trials and risk of bias was mixed. Most interventions were multi-component, including education, behavioural techniques, and support groups. The most effective domains appear to be *Behavioural regulation, Belief about Capabilities, Social influences, Reinforcement and Goals*. Future research should examine multi-component BC interventions encompassing the five most effective TDF domains.

Keywords: Behavioural Change Interventions, Parkinson's Disease, Physical Function, Quality of Life, Theoretical Domains Framework

Introduction

Parkinson's Disease is a progressive neurodegenerative condition with motor and non-motor symptoms[1,2]. Disease progression leads to muscle atrophy, reduced physical capacity, and impacts vitality. People with Parkinson's (PwP) are three times more likely to develop sarcopenia and fall twice as often compared to age-matched healthy controls[2-5]. PwP have an annual falls incidence of 60%[6], highlighting falls are a serious concern.

Maintaining an active lifestyle is essential to reduce sarcopenia and fall risk in PwP[7]. However, PwP are 30% less active than healthy age-matched controls[8,9], keeping active for only 30% of the day[9]. Only 30% of PwP meet the World Health Organisation's recommended activity guidelines[9]. "Physical activity" is described as any bodily movement produced by skeletal muscles resulting in energy expenditure[10], including unstructured or incidental movement while "exercise" is planned, structured, and purposeful, with the aim to improve or maintain one or more components of physical fitness[10].

Exercises can improve muscle strength, aerobic fitness, and balance in PwP[11]. A recent pilot study[12] (n=30) showed that a 24-week high intensity interval training

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Inclusion Criteria	Exclusion Criteria
Population, or participants and conditions of interest: Community dwelling independently mobile people with Parkinson's (Hoehn and Yahr stage 1-4; i.e. mobile without assistance of another person when "on").	a) Diagnosis of Atypical Parkinson's (e.g. Progressive supranuclear palsy) b) Current inpatients or had a recent hospital admission (< 6 weeks ago) c) Immobile or a wheelchair-user d) Severe visual or auditory impairment, serious medical conditions in major organs (heart, lung, or kidney) or other illnesses which prevented independent ambulation. e) Identified as a high falls risk (fallers)
Intervention: Any form of behavioural change intervention (e.g. education, behavioural technology) or support strategy used in conjunction with exercise	The intervention; a) did not include self- efficacy strategies or behavioural change strategies. b) did not include an exercise component c) focused solely on falls prevention
Comparator: Comparator groups must include people with a Parkinson's diagnosis. A specific intervention type was not defined for the purpose of inclusion (comparator groups including but not limited to exercise alone, usual care or waiting list were included)	Comparator group including non-Parkinson's individuals.
Outcomes of interest: a) Exercise self-efficacy measures (e.g. Self-efficacy for exercise scale, Physical Activity Assessment Inventory) b) Quality of life (e.g. PDQ-39. PDQ-8, EQ5D) c) Physical function (e.g. 6MWT, gait velocity) d) Exercise adherence (e.g. self-log, activity monitors).	Other outcomes (e.g. medication adherence, changes in anxiety and depression) Self-efficacy outcomes related to the management of a chronic condition rather than exercise self-efficacy
Setting: Community gyms/halls, community outpatient facilities, acute hospitals (if the intervention was conducted with community dwelling PwP in hospital-based gyms or clinics), or the home environment	Study interventions carried out in acute hospitals with inpatients, or in long-term care facilities
Study design: Interventional studies: Randomized control trials, quasi-experimental trials, pilot interventional studies, pre- and post- interventional studies, and feasibility studies.	Qualitative studies, observational studies, or systematic reviews

Table 1. Inclusion and exclusion criteria.

significantly increased leg lean mass, appendicular muscle mass, walking endurance and physical performance[12]. While a systematic review conducted Chung et al.[13] (7 studies, n=401 participants) demonstrates that intensive progressive resistance training, 2-3 times per week over 8-10 weeks can result in significant strength, balance and motor symptoms improvements in people with early to moderate Parkinson's disease[13]. Further to this, a large scale randomized controlled trial (n=231)[14] compared PwP who exercised 40 to 60 minutes, 3 times weekly to usual care for 6 months[14]. They found that an exercise program targeting balance, leg strength, and freezing of gait improved physical and psychological health[14]. Falls were reduced in people with milder disease but not in those with more severe Parkinson disease[14]. These studies show that exercise can improve muscle strength and physical function and in turn reduce the risk of developing sarcopenia and falls in those with early to moderate Parkinson's Disease.

From these studies, we can see that interventions require adherence to intensive exercise lasting over three months. It is established that non-motor features are a considerable barrier to exercise among PwP. Apathy may be defined simply as a loss of motivation, appearing as though the person is lazy or uncaring[15]. A recent meta-analysis (18 studies; n=1,144 participants)[16] would suggest that exercise alone fails to improve non-motor symptoms. However, Tennigkeit et al.[16] found when exercise is combined with behavioural strategies to help disease management, the results were more promising.

Strategies including videos, role-playing, education sessions, and self-monitoring (symptom diaries) led not only to improved mobility and QoL, but also improved self-

efficacy and depression, suggesting behavioural change (BC) approaches may help non-motor symptoms. However, it remains unknown whether these techniques further led to better exercise adherence and more physical activity, suggesting that a comprehensive review of exercise behavioural strategies is indicated.

Exercise self-efficacy is positively correlated to more exercise behaviour and adherence[17,18]. Speelman et al.[19] has shown that BC approaches (coaching, goal setting, activity monitors) are widely accepted by participants, and perceived as effective[19], with the activity monitor being identified as the most useful tool[19]. Ellis et al.[20] has shown that short daily interactions (five minutes/day) with a virtual coach is also well accepted among participants[20]. However, their effects on adherence and physical activity remains unclear.

Behavioural change interventions aim to overcome barriers to behaviour. Atkins et al's[21]. Theoretical Domains Framework (TDF), provides a structure to understanding the barriers and motivators to behaviour (in this case, exercise among PwP), and can be used to classify BC interventions and their components. This may, in turn, explain the how interventions facilitate exercise adherence and help identify the effective core components across interventions.

In short, to motivate PwP to remain active to help reduce the risks of sarcopenia, falls, and frailty, it is important to identify BC interventions that overcome barriers to exercise, to improve exercise self-efficacy and adherence, which in turn, lead to less falls, greater strength, fitness, and better quality of life (QoL). To the best of our knowledge, no previous review has explored the effects of BC interventions on exercise self-efficacy and adherence among PwP. This review aims to address this evidence by providing recommendations for self-management approaches.

Review objectives

This review aimed to synthesise the available evidence on BC interventions to improve exercise adherence among PwP.

Specifically, this review aimed to:

1. Describe the most common behaviour change interventions to improve exercise adherence
2. Map the identified intervention components to the Theoretical Domains Framework.
3. To determine the effects of the BC intervention on exercise self-efficacy, QoL, physical function, and exercise adherence.

Methods

This review was conducted guided by the Joanna Briggs Institute (JBI) Reviewer's Manual[22] and reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines[23]. The protocol was registered with PROSPERO (ID: CRD42021293057) and is published online (https://doi.org/10.12688/hrbopenres.13474.2). We included randomised and non-randomised studies to provide evidence of effect, recognising that non-randomised studies provide less robust evidence.

Eligibility Criteria

We included full-text studies reporting exercise self-efficacy, exercise uptake and adherence in PwP's and published in English. PwP diagnosed with other comorbidities (e.g. anxiety, depression, and diabetes) were included. See Table 1 for eligibility criteria.

BC interventions are defined as complex coordinated sets of activities devised to change specified behaviour patterns[24]. *BC techniques* are defined as complex, observable, and reproducible components of an intervention designed to alter behaviour[25], such as goal- setting, decision-making or problem solving. Finally, *exercise self-efficacy* was defined as an individual's confidence or belief that they can successfully engage in physical activity or exercise[26,27].

The primary outcomes of interest were exercising self-efficacy, QoL, physical function and exercise adherence and every timepoint was considered.

Database searching

The search strategy was developed by the primary author (LA) and supported by an experienced librarian (VC). A search of nine databases (Table S1) from inception to 10th September 2023 was performed (LA).

Study selection and article screening

Identified articles were uploaded to Endnote X8. Following de-duplication, titles, abstracts, and full texts were independently screened by two reviewers (LA, RMcC), using the search terms displayed in Table S1. The reference lists of the included articles and topical reviews were hand-searched. Any disagreement regarding inclusion was discussed with a third reviewer (ST).

Data extraction

One reviewer (LA) extracted the data. A second reviewer (RMcC) randomly selected four studies to verify data extraction methods. Data extracted included author, year, country, study design and size, participant characteristics, disease severity, details of the exercise and BC interventions, results, and theoretical framework used.

Risk of bias assessment

Three independent reviewers (LA, RMcC and ST) assessed the risk of bias using the Cochrane Risk of Bias Tool (Version 2)[28] for randomised controlled trials (RCTs) and the ROBINS-I tool[29] for non-randomised trials, as recommended[30]. Any ambiguity was reviewed, and a consensus was achieved.

Mapping to the Theoretical Domains Framework (TDF)

The extracted intervention components were mapped to the Theoretical Domains Framework (TDF), using Atkins

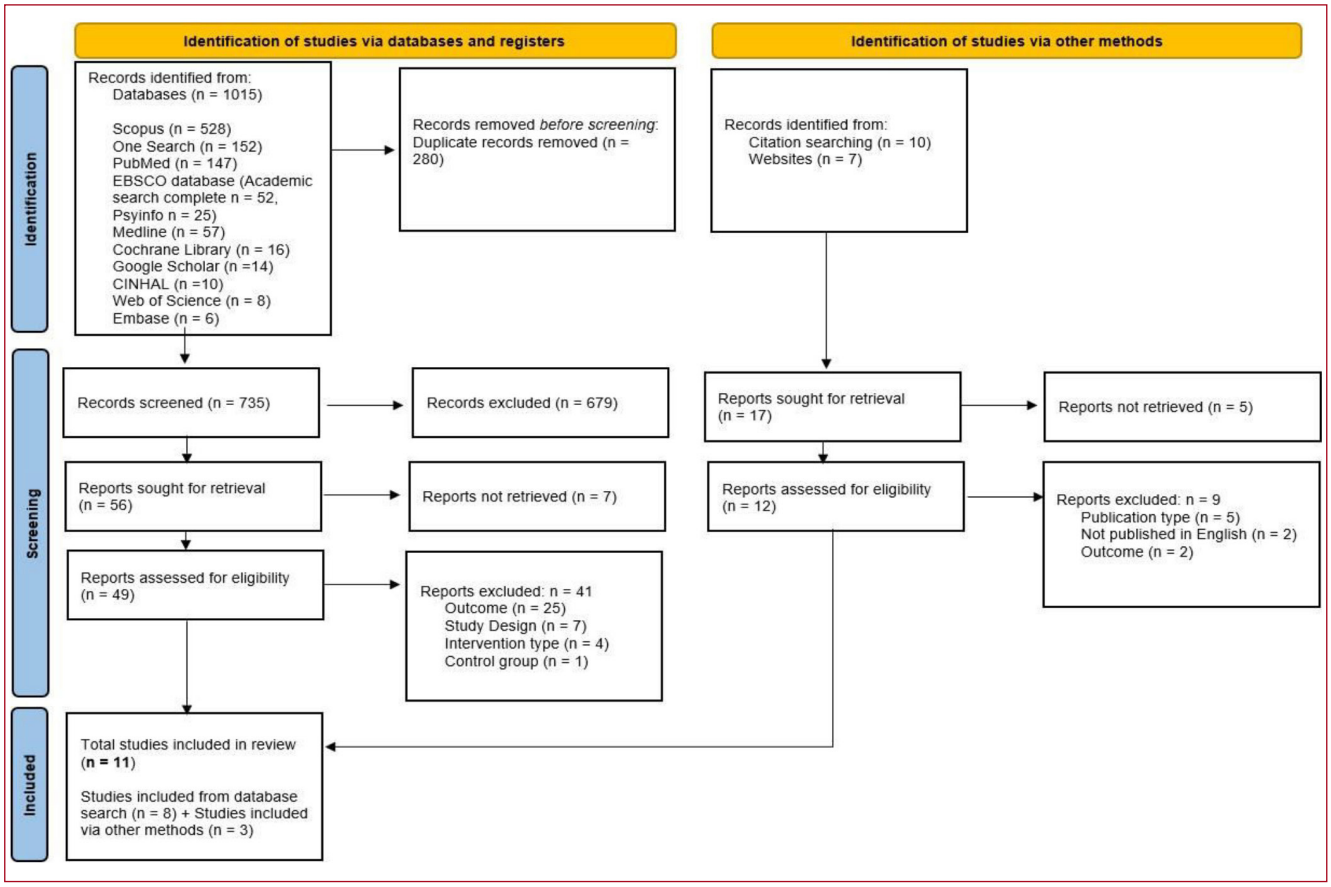

Figure 1. PRISMA flowchart.

et al.[21] for guidance. Using the coding described by Atkins et al.[21], two researchers (LA, RMC) extracted the suitable codes, and assigned them to the TDF domains. Codes were re-reviewed by three researchers (LA, RMcC and ST) to confirm final allocation.

Data synthesis

We completed a narrative synthesis to examine the effects of BC interventions. Components of the effective BC interventions were mapped to the TDF, to identify which barriers and facilitators were addressed in the effective interventions. Negative effects were also recorded. We attempted a meta-analysis, but the heterogeneity between studies led to a very small number of studies being included in each model, with low/very low certainty in the evidence.

Results

Study selection

After completing the searches, 1032 articles were identified, 61 full-text articles were reviewed and finally eleven articles (2002-2020) (n=901) were included (Figure 1). Table 2 describes the characteristics of the included studies.

Description of studies

Study Characteristics

Study quality was mixed. Included were four randomized controlled trials (Tickle-Degnen et al.[31], n=107; van Nimwegen et al.[32], n=586; Ellis et al.[33], n=51; Peteet[34], n=19), two n-RCTs (Lee et al.[35], n=42; Lai et al.[36], n=20) and five single-arm feasibility studies (Landers and Ellis[37], n=28; Long[38], n=13; Hermanns et al.[39], n=5; Ellis et al.[20], n=20; Colon- Semenza et al.[44], n=10).

Control group interventions were described as no rehabilitation[31], standard exercise intervention[32-34,36] and usual pharmacological care only[35]. Most studies were conducted in the United States of America[20,31,33,34,36-40], one in South Korea[35] and one in the Netherlands[32].

Risk of bias within studies

The outcome of the risk of bias assessment of the RCTs was mixed. Only Ellis et al.[33] was considered to have a low

Table 2. Study characteristics and description of interventions of included trials.

First Author, Publication year, Country, Study design, Participants, Sample Size	Aim	Programme Facilitator/s	Behavioural Change		Exercise Intervention	Comparator intervention	Outcome Measures
			Behavioural change framework	Mode of delivery	Intervention type, FITT, Setting		
Colón-Semenza et al.(2018)[40] USA **Feasibility study** (Mixed methods) Idiopathic Parkinson's Disease (H&Y stage 1- 3) **Total: n=10** (5 coaches; 5 mentees) Peer coaches: Age: 64.6 ± 4.04 Sex: 3/2 (M/F) Peer mentees: Age: 63.4 ± 2.06 Sex: 3/2 (M/F)	To develop a PD- specific peer coach training program and a remote peer-mentored walking program using mHealth technology with the goal of increasing physical activity in persons with PD.	Peer coaches *Training Program* 1) Peer coaches were asked to review printed and Web- based educational materials independently over a 1- to 2-week period. 2) Peer coaches participated in two,4-hour, in-person training sessions	1) Self- determination theory. 2) Social Cognitive Theory	***Multi-component Behavioural Change Components: Technology + Support Groups*** ***Peer-mentored walking program:*** 1) The peer coaches and mentees were given a wireless activity tracker (FitBit Zip). 2) Coaches were instructed on how to become friends on the Fitbit mobile app, so as to instruct mentees during their initial interaction. 3) Within 1 week after training, peer coach scheduled initial conversation focusing on establishing rapport, jointly determining the 8-week walking goal for the mentee, and developing the initial action plan. 4) Peer coach and mentee did not walk together, but in their own self-selected environment. 5) Peer pairs viewed the steps they accumulated over the week using the FitBit friends' option. This feature allows remote interaction between the peer coach and peer mentee, allowing regular feedback (ie, cheering with an emoji or instant messaging) on progress toward goals. 6) Mentees could see the coach's step counts, providing a social comparison and vicarious experiences to improve self-efficacy. ***Weekly Phone Calls:*** 1) The peer coach and mentee engaged in phone conversations weekly. 2) Peer coaches had checklists to guide peer discussions to ensure that they were adhering to the recommended techniques for peer mentoring. 3) These were: assessing the walking activity goal, progress made, problems encountered, strategies to overcome barriers, and resources available. **Frequency**: Self-selected. **Duration**: 8 weeks. **Setting**: Self-selected environment	Self-regulated exercise in self-selected environment. **Duration**: 8 weeks	No control group	1) Activity tracker. 2) Self-efficacy for Walking Duration. 3) LLFDI
Ellis et al. (2013)[20] USA **Single group pre-post study** Idiopathic Parkinson's Disease (H&Y stage 1.5-3) **Total: n=20** Age: 65.5 ± 5.6 Sex: 9/11 (M/F)	To explore the feasibility, acceptability, and preliminary evidence of the effectiveness of a virtual exercise coach to promote daily walking in community-dwelling persons with Parkinson disease	N/A	None	***Multi-component Behavioural Change Components: Technology + Support Groups*** ***Activity monitor in conjunction with Virtual Coach (focused on promoting walking):*** 1) Participants instructed to wear a pedometer and walk daily for 1 month and to interact with the virtual exercise coach for 5 mins per day. 2) Conversations with the virtual exercise coach were dialogue and other media designed to promote health behaviour change and conversational nonverbal behaviour designed to build a relationship and a therapeutic alliance. 3) A daily 5-min conversation typically was: a greeting, social chat, and well-being check-in to see whether the participant needed to progress or suspend their walking program and to provide empathic opportunities.	Patients were instructed to walk daily for 1 month (No specified exercise intervention)	No control group	1) Useability and Acceptability (Activity monitor steps). 2) Safety. 3) Efficacy (6MWT; Gait speed; Self-selected walking speed)

Table 2. *(Cont. from previous page).*

First Author, Publication year, Country, Study design, Participants, Sample Size	Aim	Programme Facilitator/s	Behavioural Change		Exercise Intervention	Comparator intervention	Outcome Measures
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				4) After this, participants plugged their pedometer into the system to upload their steps. 5) The virtual coach reviewed their progress relative to short-term and long-term goals, provided positive reinforcement if warranted, identified barriers to walking, and engaged the participant in a problem-solving discussion for any barriers identified, then negotiated a new short-term goal, if warranted. 6) The session closed with an exercise tip of the day. Each day's dialogue varied in content and structure and was augmented with additional media for participant engagement and retention. **Frequency**: Self-selected. **Duration**: 1 month. **Setting**: Self-selected environment.			
Ellis et al. (2019)[33] USA RCT Idiopathic Parkinson's Disease (H&Y stage 1-3) Total: n=51 Age: 64.1 ± 9.5 Sex: 28/23 (M/F) Intervention: 26 Age: 64.8 ± 8.5 Sex:15/11 (M/F) Control: 25 Age: 63.3 ± 10.6 Sex: 13/12 (M/F)	To explore the preliminary effectiveness, safety, and acceptability of a mobile health (mHealth)-mediated exercise program designed to promote sustained physical activity in people with PD.	A licensed physical therapist with expertise in PD to develop an individualized exercise and walking program. Exercises were adapted remotely over time by the physical therapist in response to improvements or setbacks experienced by participants	None	***Behavioural Change Component: Technology mHealth App*** The mHealth condition was used in conjunction with the individualized exercise and walking programs. It included: 1) Remote monitoring, 2) More accessible communication, 3) More frequent program adaptation by a physical therapist. 4) Incremental walking and exercise goals were entered into the mHealth app. 5) Action plans included what (which exercises, duration of walking), how (appropriate technique), when (time of day, days per week), and where (community, mall) for exercise. 6) Notifications (ie, automated prompts and reminders) were used to motivate participants 7) Exercises were adapted remotely over time by the therapist in response to improvements or setbacks. 8) Adherence and progress toward goals was graphically displayed to allow participants to track their own performance. 9) Triggered contact between the physical therapist and participants during a change in the pattern of exercise adherence (i.e., unexplained lack of engagement > 1 week), a patient-reported acute health condition or a patient-initiated question about the program. **Frequency**: Daily interaction with mHealth app. **Duration**: 12 months. **Setting**: Self-selected environment. Both exercise and control interventions of the program included standard elements designed to promote behavioural change. These included: 1) Participant goal setting, 2) Tailoring the program to participants' preferences, and 3) The provision of feedback via activity trackers.	The program was developed from a predetermined set of exercises based on the American Parkinson Disease. Association "Be Active and Beyond" program (included strengthening and stretching exercises).Walking Component: Consisted of an individualized recommended range of steps per day (eg, 5000-7500 or 7500-10,000) that was determined from each participant's baseline activity level. **Frequency:** Exercise component 5 to 7 exercises for ≥3d/wk. Walking component Individualized recommended range of steps per day (e.g.,5000-7500 or 7500-10,000). **Duration:** 12 months. **Setting:** Self-selected environment.	Stretching and strengthening exercises provided using printed photographs; walk daily using a pedometer; interact with a physical therapist at the beginning of the study only; **no use of mobile technology**	1) StepWatch Activity Monitor. 2) PDQ-39. 3) 6MWT

Table 2. *(Cont. from previous page).*

First Author, Publication year, Country, Study design, Participants, Sample Size	Aim	Programme Facilitator/s	Behavioural Change		Exercise Intervention	Comparator intervention	Outcome Measures
			Behavioural change framework	Mode of delivery	Intervention type, FITT, Setting		
Hermanns et al. (2019)[39] USA **Feasibility** pre-post-study Idiopathic Parkinson's Disease (H&Y stage 1-4) **Total: n=5** Age: 73 ± 4.95 Sex: 3/2 (M/F)	1) To assess the feasibility of an intervention that requires wearing a physical activity tracker and participating in an online support group, and 2) To examine the effect of this intervention on the self-efficacy for physical activity and QOL of older adults with PD.	Physical Therapist	Social Cognitive Theory	***Multi-component Behavioural Change Component: Technology + Support Groups*** ***Activity Tracker:*** 1) Participants were given physical activity tracker. ***Online Support:*** 1) Participants were instructed to engage in a private online support group where they would engage in education session, share what exercises or other physical activity they performed, their overall perceived health, and other PD resources with the other study participants. **Frequency**: Minimum three times per week. **Duration**: 12 weeks. **Setting**: Self-selected environment.	1) Patients were provided with an iPad. 2) Three videos were preloaded and available for viewing: warm-up and two additional videos of specific exercises for balance, rigidity, and gait. 3) Beginning with the seated warm-up video performed by therapist- included stretching. 4) Instructed to select one of the two remaining videos for large muscle exercise. **Frequency**: Three times per week. **Duration**: 12 weeks. **Setting**: Self-selected environment.	No control group	1) Physical Activity Assessment Inventory. 2) Functional Assessment of Cancer Therapy-General. 3) Physical activity tracker
Lai et al.(2020)[36] USA **Preliminary Quasi-experimental (Mixed methods)** Idiopathic Parkinson's Disease (H&Y stage 1-3) **Total: n=20** Intervention: 10 Age: 63.4 ± 10.4 Sex: 7/3 (M/F) Control: 10 Age: 70.8 ± 7.1 Sex: 7/3 (M/F)	To inform future, large-scale trials that aim to implement Internet-exercise interventions in Parkinson's disease	Physical Therapist	Social Cognitive Theory	***Behavioural Change Component: Technology*** ***Telecoach TAE group to:*** 1) Participants received one-to-one exercise training through the telehealth system. 2) The system allowed telecoaches to monitor vital signs remotely in real-time during the exercise sessions and communicate with participants through videoconferencing. 3) A telecoach accompanied and observed the participant for all of each exercise session. 4) In addition to ongoing verbal support during exercise training, participants received behavioural coaching at the initial home visit (20 min). 5) Behavioural coaching aimed to: instruct participants on proper exercise technique to increase mastery; discuss barriers or issues with the participant's ability to attend the exercise sessions; help participants set achievable goals to complete the exercise prescription; provide verbal encouragement to achieve the desired exercise workload; answer questions related to exercise and discuss the benefits of exercise. **Frequency**: 3 sessions per week. **Duration**: 8 weeks (Total: 24 sessions). **Setting**: Self-selected environment.	1) Both the TAE and SRE group received a home visit prior to starting the intervention and the same exercise prescription of combined aerobic and strength exercises. 2) Participants were told to perform moderate aerobic exercise within 40-60% of their heart rate reserve, using telehealth system & stationary recumbent cycle. 3) For strength exercises, participants used adjustable ankle weights (1-5 lb) to perform 2-3 sets of 10-20 repetitions for major lower-extremity muscle groups. 4) Participants were informed that they could independently perform 'more or less exercise' than prescribed, as long as they were connected to the telehealth system. **Frequency**: 165 minutes per week. **Duration**: 8 weeks (Total: 24 sessions). **Setting**: Self-selected environment.	***SRE group (No telecoach):*** 1) Participants independently managed their exercise training using the telehealth system. 2) The journal was used to record their progress and included written instructions on exercise techniques. 3) Participants were told that exercise data during sessions were recorded for later inspection by a telecoach, on weekly basis. 4) Participants were given the contact information of a telecoach to discuss exercise-related questions or technical issues with equipment. 5) Similar to the TAE group, SRE participants received a behaviour coaching session at initial home visit.	1) Measures of adherence: (a) the total number of exercise sessions performed, (b) time in minutes exercising per week, (c) time exercising at a moderate aerobic intensity per week, and (d) attendance. 2) Walking Capacity (walking capacity (6MWT, and comfortable and fast walking speed)

Table 2. *(Cont. from previous page).*

First Author, Publication year, Country, Study design, Participants, Sample Size	Aim	Programme Facilitator/s	Behavioural Change		Exercise Intervention	Comparator intervention	Outcome Measures
			Behavioural change framework	Mode of delivery	Intervention type, FITT, Setting		
						Frequency: 3 sessions per week. **Duration**: 8 weeks (Total: 24 sessions). **Setting**: Self-selected environment.	
Landers and Ellis (2020)[37] USA **Single-arm pilot study** People with Parkinson's disease (self-reported) who had downloaded the commercially available app **Total: n=28** Age: 62.1 ± 9.6 Sex: 6/14 (M/F) (8 unspecified)	To test the feasibility, safety, and signal of efficacy of a mobile app that facilitates exercise for people with Parkinson disease	The customized exercise regimen was constructed and developed by physical therapists	None	***Behavioural Change Component: Technology: Online Mobile Exercise App:*** 1) After registering on app and completing several self- report Likert scale questions and performance-based assessments, exercise regimen was made for participant's level of function. 2) The customized exercise regimen was constructed and developed by physical therapists. 3) The app chose the exercise program based on the primary goal (ie, mobility) and then used the responses from self-report questions and the data from performance-based tests to determine the severity of the PD. 4) From this information, the app selected exercises consistent with the primary goal and at the appropriate level of function based on one's severity of Parkinson disease. 5) At preset intervals (generally after 2 weeks), the app reassessed functional capacity (same self-report questions and performance-based measures). Type, duration, and intensity of each exercise was adjusted in the exercise regimen. **Frequency**: 150 mins per week. **Duration**: 12 weeks. **Setting**: Self-selected environment.	Aerobic, strengthening, balance, yoga based, range of motion/stretching, meditation based, and speech therapy exercises. **Frequency**: At least 150 minutes per week. **Duration**: 12 weeks. **Setting**: Self-selected environment.	No control group.	1) Feasibility. 2) Safety. 3) Efficacy (30- second STS; Timed Up and Go; PDQ-8.
Lee et al.(2019)[35] South Korea **Quasi-experimental study (With a non-equivalent control group)** Idiopathic Parkinson's Disease (H&Y stage 1-3) **Total: n=42** Intervention group: 22 Age: 62.73 ± 8.50 Sex: 13/9 (M/F) Comparison group: 20 Age: 62.20 ± 5.27 Sex: 12/8 (M/F)	To test the effects of group exercise and telephone counselling on physical and psychosocial health in people with Parkinson's disease.	Classes were supervised by three experts who were doctoral students majoring in geriatric nursing or sports medicine and who had previously participated in exercise programs for patients with chronic disease. Counselling-NR.	Social Cognitive Theory	***Behavioural Change Component: Support Groups: Motivational Telephone Counselling:*** 1) Telephone counselling was delivered to motivate continuation of exercise and obtain feedback on the group exercise program. 2) Counselling content included: (a) Have you lately experienced any health problems such as a fall or unpleasant symptoms? (b) Has any positive or pleasing change occurred since you began participating in the group exercise program? If so, what is it? (c) Has any negative or unpleasant change occurred since you began participating in the group exercise program? If so, what is it? Let's think about what we could do to solve the problem. (d) Are you willing to participate in the group exercise program consistently? If not, what is the reason for your decision? (e) Is there anything more that you want to talk about or suggest? **Frequency**: Once every 2 weeks. **Duration**: 12 weeks. **Setting**: Sporting facility.	The group program consisted of 10 minutes of warm- up (range of motion exercise and stretching were conducted for relaxation of muscles and joints), 15 minutes of aerobic exercise (line dancing), 15 minutes of resistance exercise (upper limb theraband exercises; lower limb body weight exercises), and 10 minutes of cool down (stretching). **Frequency**: Twice a week. **Duration**: 12 weeks. **Setting**: Group classes in sporting facility.	Usual Care-Pharmacological treatment from outpatient clinic.	1) The International Physical Activity Questionnaire-Short Form. 2) The Schwab and England Activities of Daily Living Scale. 3) Short Form Geriatric Depression Scale- Korean Version. 4) 30-second STS. 5) TUG. 6) Berg Balance Scale. 7) 6MWT. 8) PDQ-39.

Table 2. *(Cont. from previous page).*

First Author, Publication year, Country, Study design, Participants, Sample Size	Aim	Programme Facilitator/s	Behavioural Change		Exercise Intervention	Comparator intervention	Outcome Measures
			Behavioural change framework	Mode of delivery	Intervention type, FITT, Setting		
Long (2020)[38] USA **Single arm feasibility study** Idiopathic Parkinson's Disease (H&Y stage 1-2) **Total: n=13** Age: 61.69 ± 9.14 Sex: 9/4 (M/F)	To evaluate feasibility, acceptability and preliminary efficacy for PA levels, self- efficacy, motivation, and self-perception of performance	Occupational Therapist	1) Bandura's Self-Efficacy Theory. 2) Self-Determination Theory Further supported by The Transtheoretical Model of Behaviour Change and 3) The Transformative Exercise Framework.	***Multi-component Behavioural Change Components: Technology + Support Groups + Education + Behavioural Techniques: Activity monitor (tracking and feedback):*** a Fitbit PA monitor with online monitoring platform. ***Therapist support (emphasizing stages of change):*** 1) Participant/therapist interaction (included discussing the stages of change, motivational interviewing: positive reinforcement, goal setting). 2) Sessions that occurred over the following 14 weeks (week 1, 2, 3, 6, 10, and 14). The therapist checked-in with the participant via phone or email to provide additional support and feedback on the weeks when the participant did not have one-to-one sessions (week 4,5, 7, 8, 9, 11, 12, and 13). ***Educational workbook (emphasizing self-management strategies and self-efficacy):*** a PD-specific PA workbook (included information of physical activity and PD-specific exercise benefits, overcoming challenges, developing a physical activity plan, goals and targets, safety and monitoring and recording physical activity and progress). **Frequency**: Six one-to-one sessions. **Duration**: 14 weeks. **Setting**: Self-selected environment	No specific exercise component-Participants engaged in self-regulated exercise in self-selected environment.	No control group	1) Activity tracker. 2) Brunel lifestyle inventory Physical Activity Questionnaire. 3) The Exercise Self- Efficacy scale. The Behavioural Regulation in Exercise Questionnaire. 4) Modified Canadian Occupational Performance Measure.
Peteet (2002)[34] USA **Pilot RCT** Idiopathic Parkinson's Disease (H&Y stage 2-3) **Total: n=19** Age: 60.89 ± SD NR Sex: 12/7 (M/F) Intervention: 8 Age: 58 ± 6.59 Sex: 5/3 (M/F) Control: 11 Age: 63 ± 9.52 Sex: 7/4(M/F)	NR	Physical Therapist (exercise) Instructor (self-management program).	1) The Health Belief Model. 2) The Transtheoretical model (stages of change). 3) Social Learning theory.	***Multi-component Behavioural Change Components: Behavioural Techniques + Education: Self-management educational program:*** 1) Instructor-led group discussion of topics including exercise barriers, fall prevention, strategies for relaxation, physical activity action planning and feedback, modelling of behaviour by participants for one another, reinterpretation of symptoms by giving many possible causes for each symptom, management strategies for symptoms, and individual decision making. 2) Informal group problem solving, 3) Individualized self-management exercise plans for participants. **Frequency**: 45 mins per session, once per week. **Duration**: 6 weeks. **Setting**: Group session (setting NR).	1) Warm-up (bicycle, upper-extremity ergometer, stretching exercises to the legs and arms, and mobility exercises to the neck, trunk, aims and legs. 2) Aerobic component using theraband and/or weights for strengthening. Treadmill and overground walking with varying speeds and frequencies was used along with external visual (e.g., stripes on the floor) and auditory (e.g.,metronome or music). 3) Functional activities like turning in bed, transferring to sitting & standing, and stairs. 4) Introduction of recreational activities, such as ball games and aerobics. 5) Relaxation exercises. 6) Cool down. **Frequency**: 45 mins session, once/ week. **Duration**: 6 weeks. **Setting**: Group session (setting NR).	Control group engaged in exercise component only. Both groups participated in the same standard exercises.	1) The Physical Activity Scale for the Elderly. 2) The Self-Efficacy for Exercise scale. 3) the Geriatric Depression Scale. 4) Functional Reach Test. 5) Timed Up and Go Test. 6) Berg Balance Scale.

Table 2. *(Cont. from previous page).*

First Author, Publication year, Country, Study design, Participants, Sample Size	Aim	Programme Facilitator/s	Behavioural Change		Exercise Intervention	Comparator intervention	Outcome Measures
			Behavioural change framework	Mode of delivery	Intervention type, FITT, Setting		
Tickle-Degnen et al.(2010)[31] US **RCT** Idiopathic Parkinson's Disease (H&Y stage 2-3) **Total: n=107** Age: 66.3 ± 9.0 Sex: 72/35 (M/F) Intervention: 27 hours rehabilitation:37 Age: 67.6 ± 10.3 Sex: 26/11 (M/F) 18 hours rehabilitation:33 Age: 65.8 ± 8.3 Sex: 22/11 (M/F) Control 0 hours rehabilitation:37 Age: 65.6 ± 8.3 Sex: 24/13 (M/F)	1) To determine whether self-management rehabilitation promoted HRQOL beyond best medical therapy. 2) To determine whether rehabilitation outcomes persisted at 2 and 6 months of follow-up. 3) To determine whether rehabilitation-targeted domains of mobility, communication, and activities of daily living were more responsive to the intervention than were nontargeted areas such as emotions, stigma, social support, and cognitive ability.	A physical therapist led all sessions and an occupational therapist and speech and language therapist each participated in half of the sessions, assisted by therapy students.	1) Theory of planned behaviour. 2) Social Cognitive Theory.	**Behavioural Change Component: Education:** ***Interdisciplinary Self-management Rehabilitation: 27 hours of rehabilitation, with 18 in clinic group rehabilitation and 9 hours of rehabilitation:*** 1) Participants assigned to the 27-hour condition engaged in 4.5 hours of self-management rehabilitation per week in two 1.5-hour group clinic sessions and one 1.5-hour individual home or community session to transfer self- management skills to the locations of daily living. 2) A physical therapist led all sessions and an occupational therapist and speech and language therapist each participated in half of the sessions, assisted by therapy students. 3) Participants received manuals with detailed photographs of exercise routines. Each group clinic session involved physical exercises, speech exercises, functional training, and a discussion about self- management strategies (Barriers to exercise, communication, mobility, benefits of exercise, enhancing social communication, strategies to improve walking, mastering moving in bed, rising from chairs, coping with tremor, stiffness, self-management for life: moving forward, preventing falls, talking on the phone. strategies to improve dressing, relaxation, stress management, self- management for life: staying on track). ***18 hours of clinic group rehabilitation plus 9 hours of attention control social sessions:*** 1) Participants assigned to the 18-hour condition had 3 hours of self-management rehabilitation per week in two 1.5-hour group clinic sessions. 2) They did not receive weekly 1.5 hour of transfer-of- training session in the home or community. 3) Instead, they received weekly 1.5-hour student- facilitated social group session in the clinic, which was intended to control for the extra attention. **Duration**: 6 weeks. **Setting**: in clinic (group session), home environment (transfer training).	Motion, flexibility, and strength exercises (25 min) Active ranging/stretching to increase trunk extension/rotation. Stretching hip flexors, hamstrings and gastrocnemius, Strengthening trunk/hip postural muscles, knee and ankle extensors. Daily function training examples (15 min) Moving in bed. Rising from chair. Up and down from floor Social communication Dressing. Handwriting Swallowing. Social Communication. Gait training (10 min). Walking with external auditory cues to optimize gait pattern and Speed. **Frequency**: One a week (part of the group self- management rehabilitation sessions). **Duration**: 6 weeks. **Setting**: In clinic.	0 hours rehabilitation	PDQ-39

Table 2. *(Cont. from previous page).*

First Author, Publication year, Country, Study design, Participants, Sample Size	Aim	Programme Facilitator/s	Behavioural Change		Exercise Intervention	Comparator intervention	Outcome Measures
			Behavioural change framework	Mode of delivery	Intervention type, FITT, Setting		
van Nimwegen et al.(2013)[32] Netherlands **Multicentre RCT** Idiopathic Parkinson's Disease (H&Y stage 1- 3) **Total: n=586.** Intervention: 299 Age: 65.1 ± 7.9 Sex: 194/105 (M/F) Control: 287 Age: 65.9 ± 7.2 Sex: 188/99 (M/F	To evaluate whether a multifaceted behavioural change programme increases physical activities in patients with Parkinson's disease.	Physiotherapists	1) Social Cognitive Theory. 2) The transtheoretical model of health behaviour change.	***Multi-component Behavioural Change Components: Support Groups + Education+ Behavioural Techniques + Technology: ParkFit Activity Coach:*** 1) Physiotherapists served as personal activity coaches who guided patients towards more active lifestyle during monthly coaching sessions. 2) Physiotherapists educated patients about the beneficial effects of physical activity and about suitable activities. 3) Additionally, patients were stimulated to participate in group exercise to experience beneficial effects of physical activity and to receive social support from fellow patients. ***Education Brochure and Health Contract:*** 1) Patients received an educational workbook covering specific elements to promote a behavioural change. 2) The workbook gave information about the benefits of physical activity, the risks of a sedentary lifestyle, suitable activities for PD patients, strategies to identify and overcome barriers to engage in physical activity, setting goals and recruiting social support. 3) The workbook included a health contract (written agreement between patient and physiotherapist) to support initiating and maintaining physical activities by formulating long term activity goals. 4) A logbook was included to monitor short term goals. Patients received a bi-annual newsletter accentuating the benefits of physical activity. ***Goal setting:*** 1) During the coaching sessions patients and physiotherapists formulated activity goals. 2) These were created in order to obtain the long-term goals a formulated in the health contract. 3) During the coaching sessions patient and therapists evaluated these goals as well as the experienced barriers. 4) The formulated activity goals had to be realistic, concrete, and individualized and had to be formulated in a systematic way. ***Activity Monitor:*** 1) All patients got a personal ambulatory monitor. 2) The accelerometer showed the amount of actually delivered daily physical activity using light-emitting diodes. 3) At a personalized website, patient and coach could formulate a personal goal based on kilocalories; feedback of the monitor was directly related to this personal goal. 4) Since data of the monitor were uploaded to this website, patient and coach could monitor the individual progress. **Frequency**: NR. **Duration**: 24 weeks. **Setting**: Community Hospital.	***Physiotherapy:*** 1) The ParkFit program also included regular physiotherapy sessions. 2) Based on individual disabilities, the therapist and patient jointly formulated individually tailored treatment aims, according to the evidence-based guideline of physiotherapy for PD. **Frequency**: NR. **Duration**: 24 weeks. **Setting**: Community Hospital.	***ParkSafe:*** Regular physiotherapy aimed at promoting safety of movement. Received an education brochure (similar to ParkFit group) but provided information about benefits on physiotherapy and safety movements. **Frequency**: NR. **Duration**: 24 weeks. **Setting**: Community Hospital.	***Primary Outcome***: LAPAQ. ***Secondary Outcomes***: 1) 6MWT. 2) PDQ-39. 3) 7-day activity diary. 4) Ambulatory activity monitor.

FITT=Frequency, Intensity, Time , Type; H & Y=Hoehn and Yahr; M=Male; F=Female; RCT=Randomized control trial; PD=Parkinson's Disease; IPD=Idiopathic Parkinson's Disease; LLFDI=Late life function and Disability Instrument; mHealth=-mobile health d/wk=Days per week; ; 6MWT=6-minute walk test; PDQ-39=Parkinson's Disease Questionnaire-39; Min=Minute; N/A=Not Applicable; TAE=Telecoach-assisted exercise; SRE=Self- regulated exercise; STS=sit to stand; PDQ-8=Parkinson's Disease Questionnaire-8; TUG=Timed Up and Go; NR=Not reported; LAPAQ=LASA physical activity questionnaire.

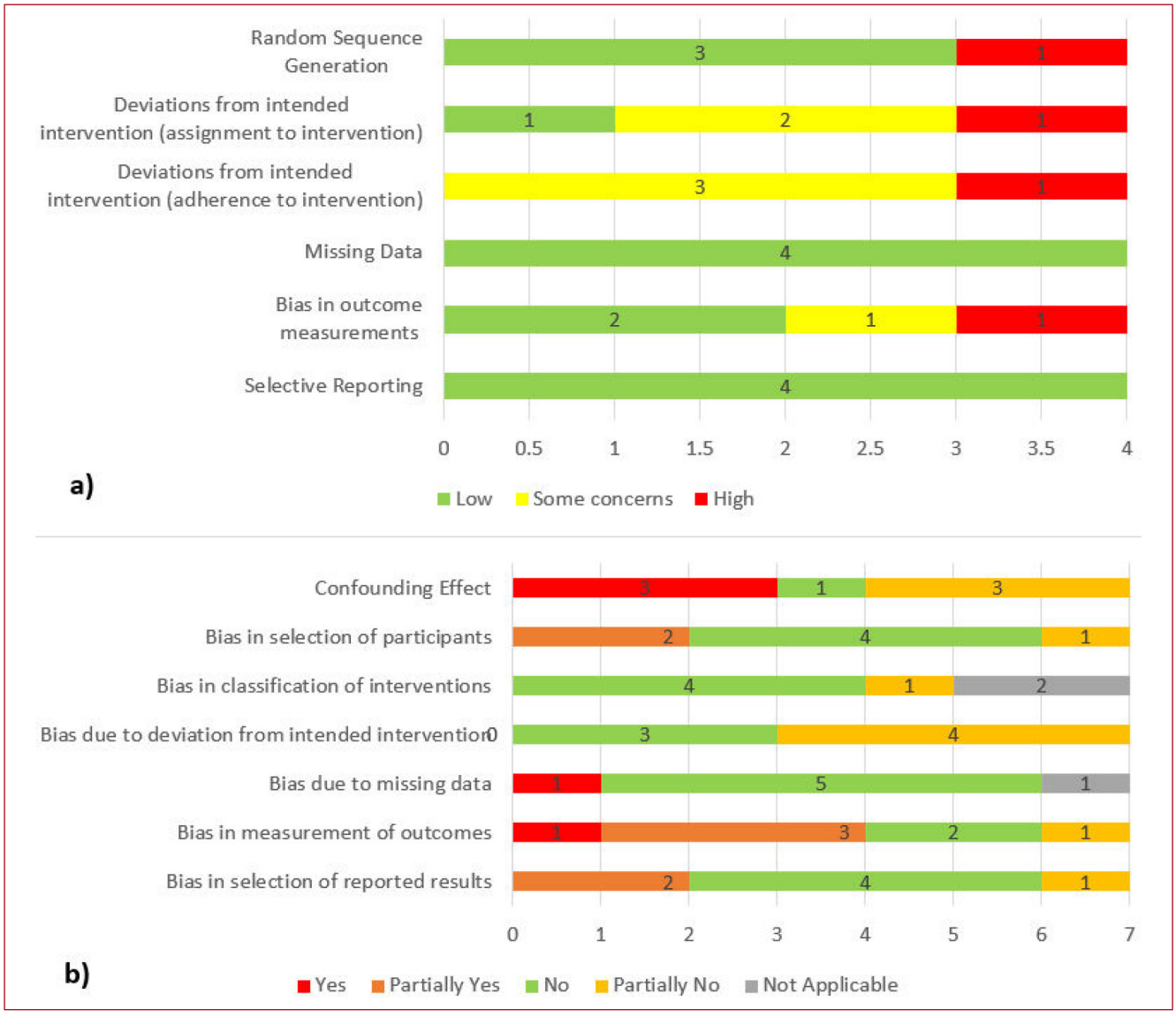

Figure 2. a) risk of bias across randomized controlled trials b) risk of bias across non- randomized studies.

risk, with the others considered moderate[31,32] or high[34], due to potential bias from deviations from the intended intervention[31,34], poor randomization[34], and lack of allocation concealment[34].

Most of the seven non-RCTS were deemed at a moderate risk of bias using the ROBINS-I tool. Potential sources included the selection criteria[39], lack of blinding[20,35,38], inability to adjust, or control for confounding variables[35,38,40] and failure to report participant withdrawal[35] (Figure 2, Table S2, Table S3).

Participants

In total, 901 participants were included (570 males, 331 females; mean weighted age 65.17 years). Sample sizes ranged from five[39] to 586 participants[32]. Nearly all used the original or modified Hoehn and Yahr (H&Y) scale to determine disease severity. Three studies[36,37,39] did not provide individual H&Y stages (n=179 participants). Most participants were Stage 2/2.5 (n=623) and only one study included patients at Stage 4[43].

Theory/Models underpinning BC interventions

Eight studies using a theory/model to underpin the BC intervention[31,32,34-36,38-40]; the Social Cognitive Theory[31,32,35,36,39,40], Transtheoretical Model of Behaviour Change[32,34,38], Self- determination Theory[38,40], and Self-Efficacy Theory[38].

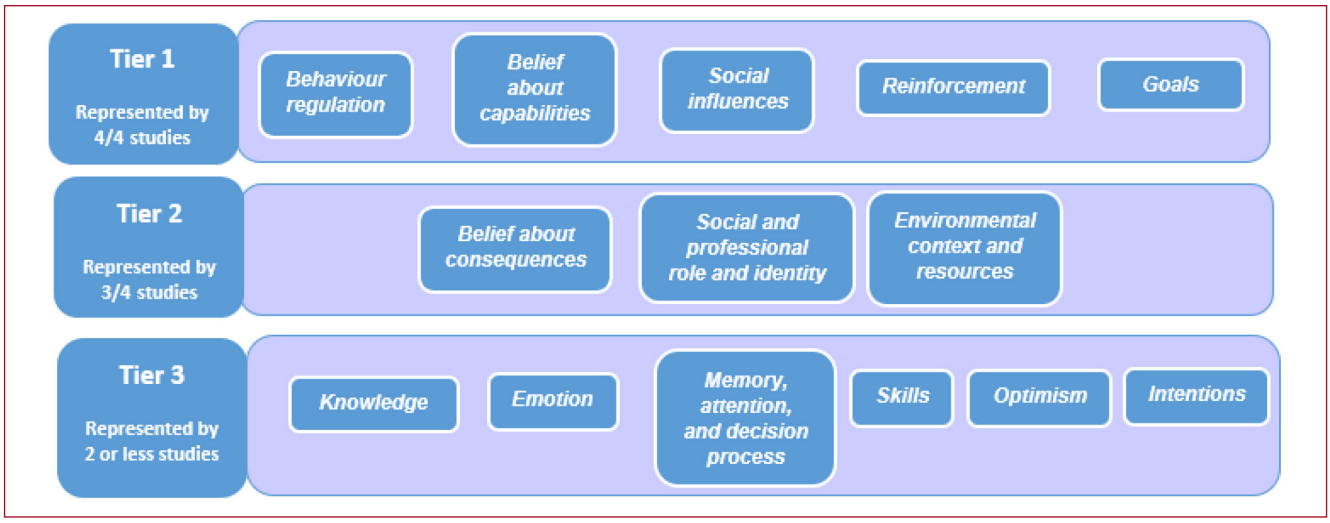

Figure 3. TDF domains used in studies detecting significant improvements.

The BC interventions mapped to the Theoretical Domains Framework (TDF)

The BC interventions consisted of education[31,32,34,38], behavioural techniques[32,34,38], technology[20,32,33,36-40] and peer/support groups[20,32,35,38-40]. Intervention duration varied greatly from 4 weeks to 12 months.

A total of 47 items from the interventions were extracted, coded, and mapped to the TDF (Table 3). Of interest, over half (57%) of the items aimed to improve intrinsic motivation (personal factors; barrier identification, goal setting, action planning), while fewer than 20% related to external motivators (social factors, activity monitors, incentives, support groups) (Table S4 and S5).

Education programmes consisted of either workbooks/brochures[32,38], or weekly lectures[31,34]. Topics included the condition and symptom management, importance of physical activity, suitable exercises including relaxation, overcoming barriers, and fall prevention[31,34] (Table 3). As anticipated, *knowledge* and *skills* domains of the TDF were addressed in all the studies utilizing education.

Behavioural techniques such as goal setting[32,38], barrier identification[32,34], cognitive restructuring[34], problem-solving[34], decision-making[34], action planning[34,38] and relaxation[34] were explored through informal group-work or workbooks[32,34]. (Table 3). Behavioural techniques mostly aimed to enhance *knowledge, beliefs about capabilities*, and promote *behaviour regulation, control environmental contexts and social influences* (Table 3 and Table S5).

Technology included activity trackers[32,38-40], pedometers[20], virtual coaches[20,36] and online exercise apps[33,37] which provided prompts and feedback to participants regarding exercise (Table 3). Technology was mainly used as an extrinsic motivator (*behaviour regulation*), with some studies incorporating intrinsic motivation strategies (*knowledge about their condition, action planning, decision making, and awareness of negative consequences*). Of note, technology addressed the same issues as the other behaviour change interventions (education, behavioural techniques, and support groups), and while it may not provide *more* than other interventions, it may be *efficient* and can be tailored to the person's needs and intrinsic motivation. Of note, technology was always managed by a trained professional or trained peer (training prior to the intervention).

Support groups were delivered either individually, through telephone peer coaching[40] or motivational counselling[35], or, through peer-group online sessions[39], or therapist-led support[32,38], and aimed to address most of the TDF domains (9/14 domains). Participants were encouraged to identify their progress, problems encountered, strategies to overcome barriers, and resources were made available (Table 3). Only Lee et al.[35] used it as a single intervention to support behaviour change (*action planning, awareness of negative consequences, barrier identification and recruitment of social supports*).

From the mapping exercise, we can see that each intervention provided elements to address most of the TDF domains. Education addressed *knowledge* and self-management skills. Behavioural techniques addressed the *intentions* of the individual, *environment context and resources and decision-making processes*. Technology addressed beliefs *about capabilities, goal setting* and *social comparisons*. Finally, support groups addressed *action planning and social influences* through peer/group support and address individual's *beliefs about consequences*.

	Education	Technology			Support groups	Multi-component					
						Behavioural Techniques +Education	Technology + support groups			Technology + Behavioural Techniques + Support groups + Education	
TDF Domain	**Tickle -Degnen et al.[31]**	**Ellis et al.[33]**	Lai et al.36	Landers and Ellis[37]	**Lee et al.[35]**	Petee[t34]	Colon -Semenza et al.[40]	Ellis et al.[20]	Hermanns et al.[39]	Long[38]	**Van Nimwegen et al.[32]**
Knowledge											
Skills											
Memory, attention and decision processes											
Behaviour regulation											
Beliefs about capabilities											
Beliefs about consequences											
Social/ professional role and identity											
Emotion											
Intentions											
Reinforcement											
Goals											
Optimism											
Environmental context resources											
Social Influences											
Total	**12/14**	**5/14**	8/14	5/14	**10/14**	11/14	7/14	11/14	6/14	11/14	**11/14**

***Bold**=Significantly positive findings for what outcomes.*

Table 3. Intervention type mapped across TDF domains.

Outcomes of the interventions

Summary of overall findings

Only four of the 11 studies detected significant changes in one or more outcomes (Ellis et al.[33], n=51; Lee et al.[35], n=42; Tickle-Degnen et al.[31], n=107; and van Nimwegen et al.[32], n=586). Improvements in QoL[31,33,35], physical function[32], and exercise adherence[32] were found. No improvements in exercise self-efficacy were detected, however only the smaller/feasibility studies measured self-efficacy, hence the effects remain unclear[34,38-40]. Finally, no negative effects were reported.

Interventions included education only (Tickle-Degnen et al.[31] (n=107)); technology only (Ellis et al.[33] (n=51)); multi-component intervention (van Nimwegen et al.[32] (n=586) and support groups only (Lee et al.[35] (n- RCT, n=42)). Only Van Nimwegen et al.[32] detected improvements in more than one outcome (physical function and exercise adherence), suggesting that a multi-component intervention encompassing education, behavioural techniques, technology and support groups could be more effective (improved QoL, physical function, and exercise adherence).

Quality of life

Using various BC interventions, three RCTs[31-33], and one n-RCT[35] reported QoL changes, using the Parkinson's disease questionnaire (PDQ-39)[31-33,35] (Table S6).

With 18-hours/27-hours of interdisciplinary self-management education (n=107), Tickle- Degnen et al.[31] detected improved QoL (54%), with some benefits persisting six months after the programme. Similarly, using a health app, Ellis et al.[33] detected better mobility-related QoL in the less-active participants, (n=51, 12-month intervention). Finally, Lee et al.[35] found 12- week telephone counselling (*support groups*, n=42) improved QoL (+15%), which further improved at 16 weeks (+21%) however this

study was non-randomised. Conversely, van Nimwegen et al.[32] (RCT, n=586, 24-week multi-component intervention) reported no changes in QoL. This robust large study suggests no additional impact on QoL with a comprehensive BC intervention, however, more large-scale studies need to re-confirm this finding.

Mapping to the TDF revealed no clear pattern. Common domains included *belief about capabilities, social influences, and behaviour regulation*, while most of the other domains were addressed by two or less studies (Table 3).

Physical function

Only two RCTs (Ellis et al.[33], n=51; van Nimwegen et al.[32], n=586) measured physical function, both using the 6MWT (Table S6). Van Nimwegen et al.[32] (24-week multi-component) found improved physical function and Ellis et al.[33] (12-month mHealth intervention) detected only within-group improvements.

Again, mapping to the TDF revealed no clear pattern. Key common domains included *belief about capabilities, goals, and social influences* (Table 3).

Exercise activity/adherence

Of three RCTs[32-34] measuring exercise uptake/adherence using activity trackers or various questionnaires, only van Nimwegen et al.[32] detected more physical activity compared to conventional physiotherapy[32] (11/14 TDF domains, Table 3).

Which TDF domains are most effective?

The TDF domains addressed in the larger adequately powered studies were grouped to identify the most effective TDF domains. To recap, Tickle-Degnen et al.[31] implemented an education intervention (12/14 TDF domains), Ellis et al.[33] utilized technology (5/14 TDF domains), van Nimwegen et al.[32] used a multi-component intervention encompassing education, behavioural techniques, technology and support groups (11/14 TDF domains) and Lee et al.[35] conducted support groups (9/14 TDF domains). Only five TDF domains were addressed by all four studies (*behaviour regulation, belief about capabilities, goals, reinforcement, and social influences*). Three further domains were addressed by only three studies[31,32,33] (*belief about consequences, social and professional role* and *identity,* and *environmental context resources*). From this, the TDF domains were categorized into three tiers (of effectiveness) based on the domains represented by these studies (Figure 3).

Therefore, the findings would suggest that Tier 1 displays the more commonly addressed TDF domains, with Tier 3 displaying the domains addressed least. While there is no strong evidence for one approach over another, the most effective studies employed a intervention addressing many TDF domains.

Discussion

People with Parkinson's have trouble sustaining exercise and reaching the recommended physical activity guidelines, increasing their risk of frailty and falls. The aims of this review were to firstly, identify BC interventions aimed to improve exercise self-efficacy and adherence, secondly, to map them to the TDF, and finally, to examine their effect on health outcomes. We identified education, behavioural techniques, technology, and support groups, either as a single or multi-component intervention, were used to address most domains of the TDF. However, the most effective interventions addressed *behaviour regulation, belief about capabilities, goals, reinforcement, and social influences*. The quality of the included studies was poor. Therefore, we can assume that the evidence of BC interventions to improve self- exercise adherence and self-efficacy is limited and of low quality, further demonstrating that the topic is relatively new and unknown.

We found the TDF gave us a good understanding of the BC interventions. The framework helped to tease apart the issues/barriers addressed by each intervention and structure our analysis accordingly. It helped to identify the importance of intrinsic factors, and which domains appeared most effective. Of note the TDF was originally aimed at healthcare providers, hence it was unclear whether PwP were aware of their "*intentions*" and "*social and professional role and identity*" (domains listed in the TDF)[21].

From the literature, multi-component interventions appear to be used commonly, and our review suggested that the multi-component intervention (van Nimwegen et al.[32] (n=586)) appears to be the most effective. In a recent review (n=24 studies), Tennigkeit et al.[16] found that uni-dimensional BC interventions often failed to address the complex cognitive- behavioural challenges with Parkinson's, while multi-component self-management programs improved health, mobility, QoL, as well as self-efficacy and depression, demonstrating effects on non-motor features. The authors did not examine exercise adherence or physical activity. It is difficult to draw conclusions from our review, we found some encouraging evidence of improved exercise adherence, but no definitive study measured exercise self-efficacy. Therefore, we conclude that effective interventions to enhance exercise self-efficacy remain unknown, a fundamental requirement for long-term exercise adherence.

Behavioural change interventions targeting intrinsic motivation

Many intrinsic methods improved outcomes, including goal setting[31-33,35], social supports[32,33,35], coping strategies31 and barrier identification[31,32,35] (Table S5). These findings concur with findings of Room et al.[41] (n=11 studies), who found that intrinsic behavioural techniques improved exercise adherence in older adults. Techniques were categorised as (1) comparison of behaviour, (2) social support, (3) identity

of goals and planning, (4) natural consequences and (5) feedback and monitoring. While the evidence was insufficient to recommend intrinsic behavioural techniques, the results are similar to ours (goal setting, social support, feedback and monitoring, identification of barriers and action planning), further strengthening the concept that intrinsic motivation is an essential aim of BC interventions.

Recognising the importance of intrinsic motivation in physical activity maintenance, Krishnamurthi et al.[42] is currently examining the differences between the ReadySteady intervention (motivational sessions, mobile app, pole striding and education), versus a pole striding and education intervention, versus education alone[42]. Some evidence exists in the older adult population. In a non-randomised trial, Azizan et al.[43] found a twofold increase in exercise self-efficacy and threefold increase in physical activity with a BC intervention (based on the Transtheoretical model of Behaviour Change) with a 24-week exercise program (n=63).

To the best of our knowledge, this is the only review exploring the effects of BC interventions on exercise self-efficacy and adherence to exercise and physical activity among PwP.

Limitations

The synthesis combined both randomised and non-randomised evidence, which come from different levels of hierarchical evidence and must be interpreted with caution. Many studies had inadequate sample sizes (n ≤ 20 were common), or poor study design (2 n-RCT, 4 feasibility studies). Most studies recruited only highly educated Caucasian individuals, and all failed to control (or failed to report control of) participants' additional exercise beyond of the intervention. Some studies identified selection bias in their recruitment process[20,33,37,39,40]. Finally, inadequate methodology reporting prevented a comprehensive assessment of the methodological quality, or when reported well, most were deemed to be a moderate risk of bias.

Conclusion

We conclude that there is insufficient high-quality evidence to recommend the most effective BC intervention to promote exercise adherence among PwP. Our analysis using the TDF has helped highlight the most effective domains to bring about change.

Future research should explore multi-component BC interventions encompassing the five most effective TDF domains (*Behavioural regulation, Belief about Capabilities, Social influences, Reinforcement* and *Goals*). Future trials should be sufficiently powered, with diverse populations recruited, and sufficient follow-up periods to indicate sustained exercise adherence.

Clinical Messages

- There is insufficient high-quality evidence to recommend the most effective BC intervention to promote exercise adherence among PwP.
- Future research should examine multi-component BC interventions encompassing the five most effective TDF domains (*Behavioural regulation, Belief about Capabilities, Social influences, Reinforcement* and *Goals*).
- We recommend that trials are sufficiently powered, diverse populations are recruited, with sufficient follow-up periods to indicated sustainable exercise adherence.

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Authors' Contributions

LA: Conceptualization, Formal Analysis, Methodology, Writing – Original Draft Preparation. ST: Conceptualization, Supervision, Writing – Review & Editing. SL: Supervision, Writing – Review & Editing. RMcC: Conceptualization, Methodology, Supervision, Writing – Review & Editing. All authors read and approved the final version of the manuscript.

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Supplementary Data

Difference between protocol and review

The following amendments were made after the publication of the review protocol.

Date: 10/09/2023

As per the protocol the database was from inception to 1st of September 2021. This is subsequently updated and searched to 10th September 2023.

Date: 15/11/2021

Amendment: The inclusion criteria outlined in the protocol stated that interventions would be included if they implemented "any form of behaviour change intervention, used in conjunction with exercise or alone". However, prior to conducting the database search this was amended to only include studies that implemented a behaviour change intervention used in conjunction with exercise.

Rationale: This amendment ensured that the search was clearly focused to answer the specific research question

Date: 20/01/2022

Amendment: The protocol stated that the findings would be mapped to the Behaviour Change Wheel (BCW) and the Theoretical Domains Framework (TDF). However, during data synthesis it was determined that the findings would only be mapped to the TDF.

Rationale: The components of the BCW are embedded within the TDF and mapping to both would not provide any additional information.

Date: 06/04/2022

Amendment: The protocol outlined that the JBI Risk of Bias tool would be used to assess the risk of bias in the included studies. However, we used the Cochrane Risk of Bias Tool (Version 2) for randomised control trials and the ROBINS-I tool for non-randomised trials.

Rationale: These tools are the preferred method of assessing risk of bias.

Date: 25/05/2022

Amendment: The protocol outlined that the proposed sensitivity analysis would include "restricting analysis to studies including a control group"; this was further refined to "restricting analysis to studies including a control group with an exercise component."

Rationale: To ensure the specific research question was answered.

Databases:
- EBSCO (Academic search complete and Psychinfo) - Medline - Cinahl - Web of Science - PubMed - Embase - Scopus - Google Scholar - Cochrane Library
Search keywords:
1. ["behavioural change intervention*" OR "behavioral change intervention*" OR "behaviour change technique*" OR "behavior change technique*" OR "cognitive behavioural therapy" OR "cognitive behavioral therapy" OR psychology OR "psychological therapy" OR "health behaviour*" OR "health behavior*"] 2. [self-efficacy OR "self efficacy" OR "physical activity self-efficacy" OR "physical activity self efficacy" OR "exercise self-efficacy" OR "exercise self efficacy" OR self-management] 3. 1 AND 2 4. ["physical activit*" OR recreation OR sport OR exercise OR training OR fitness OR "physical therap*" OR rehabilitation] 5. 3 AND 4 6. ["Parkinson's Disease" OR "Parkinsons Disease" OR "Parkinson Disease" OR Parkinson's OR Parkinson] 7. 5 AND 6

Table S1. Search strategy.

Author(s) (yr)	Random Sequence Generation	Deviations from intended intervention (assignment to intervention)	Deviations from intended intervention (adherence to intervention)	Missing Data	Bias in outcome measurements	Selective Reporting	High/ Moderate/ Low Risk
Ellis et al.(2019)[33]	Low	Low	Some concerns	Low	Low	Low	Low
Peteet (2002)[34]	High	High	High	Low	Low	Low	High
Tickle-Degnen et al.(2010)[31]	Low	Some concerns	Some concerns	Low	Some concerns	Low	Moderate
van Nimwegen et al.(2013)[32]	Low	Some concerns	Some concerns	Low	High	Low	Moderate

Table S2. Results of the RoB 2 tool[28].

Author (year)	Confounding Effect	Bias in selection of participants	Bias in classification of interventions	Bias due to deviation from intended intervention	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of reported results	Overall bias High/ Moderate/ Low Risk
Colón-Semenza et al. (2018)[40]	Y	N	NA	N	N	PN	PN	Moderate
Ellis et al. (2013)[20]	PN	PY	N	PN	N	PY	PY	Moderate
Hermanns et al. (2019)[39]	PN	PN	N	PN	NA	N	N	Low
Lai et al. (2020)[36]	PN	N	PN	N	N	N	N	Low
Landers and Ellis (2020)[37]	N	N	N	PN	N	Y	N	Moderate
Lee et al.(2019)35	Y	N	N	PN	Y	PY	PY	High
Long (2020)[38]	Y	PY	NA	N	N	PY	N	Moderate

Y=Yes; PY=Partially yes; N=No; PN=Partially No; NA=Not applicable; NI=No information.

Table S3. Results of ROBINS-I scale[29].

Table S4. TDF domains mapped for included studies.

Author (year)	Knowledge	Skills	Memory, attention and decision processes	Behaviour regulation	Beliefs about capabilities	Beliefs about consequences	Social/ professional role and identity	Emotion	Intentions	Reinforcement	Goals	Optimism	Environmental context resources	Social Influences
Colón-Semenza et al.(2018)[40] USA														
Ellis et al.(2013)[20] USA														
Ellis et al.(2019)[33] USA														
Hermanns et al.(2019)[39] USA														
Lai et al.(2020)[36] USA														
Landers and Ellis (2020)[37] USA														
Lee et al.(2019)[35] South Korea														
Long (2020)[38] USA														
Peteet (2002)[34] USA														
Tickle-Degnen et al.(2010)[31] USA														
van Nimwegen et al.(2013)[32] Netherlands														
Total	6/11	8/11	3/11	11/11	11/11	7/11	5/11	3/11	6/11	10/11	8/11	0/11	8/11	11/11

***Bold** =studies with significantly positive findings.*

Table S5. TDF domains and component constructs identified in the included studies.

TDF Domain	COMPONENT CONSTRUCTS
Knowledge	Education of: condition[34,38,39], communication[31], mobility[31], exercise and physical activity[31,32,38.]
Skills	Skill development[20,31,32,38,39], self-management skills[20,31,32,38,39], coping strategies[31,34,39], competence[36-38], transfer training[32]
Memory, attention, and decision processes	Decision making[34,35], problem solving[20,34]
Behaviour regulation habit32,35, feedback32,33,38,40	Action planning[31,34-38], activity tracking[20,32,38-40], self-monitoring[32,33,37,38], breaking
Beliefs about capabilities	Perceived competence[20,32-34,36-4-], empowerment[20,33,34,37,38,40], identification of prompts/cues for successes[35], self-confidence[20,33,34,36-38,40], self-efficacy[35,40], beliefs[31,32,36,38] pleasant change[35]
Beliefs about consequences	awareness of actions[20,31,38,40], negative consequences[31,32,35,38] , unpleasant change[35]
Social/professional role and identity	Leadership[31,34,39], Group Identity[31], Organizational commitment[31,32,35,39], Professional role[31,34,35,38,39]
Emotion	Stress management[34], relaxation[34,37]
Intentions	Promote health behaviour change[20], transtheoretical model of change[31,34,38], stages of change[38], theory of planned behaviour[31]
Reinforcement	incentives[33,40], reinforcement[20,32,33,36-39], rewards[35]
Goals	Long[20,31] and short-term goal setting[20,31,33,35,36,48,40], goal-setting[31]
Optimism	
Environmental context resources	Barrier identification[20,31,32,34-36,38,40]
Social Influences	Recruiting social supports[31], social support[20,31,32,35,37,38,40], social comparisons[31,34,40], online support group[39], online verbal support[36], feedback[34,35,38]

Table S6. Results for studies investigating quality of life and physical function outcomes.

Article	Outcomes	Conclusions
Author (year)	Outcome(s) of interest	Results
Ellis et al.(2013)[20] *Multi-component Behavioural Change Components: Technology + Support Groups*	6MWT; Gait speed; Self-selected walking speed	Walking distance improved significantly in the 6-MWT, from a mean (SD) distance of 459.5 (91.9) m at baseline to 484.1 (85.3) m after the intervention (P=0.02). Self-selected walking speed improved from a mean (SD) of 1.19 (0.2) m/sec at baseline to 1.26 (0.18) m/sec after the intervention (P=0.02). In addition, the baseline maximum walking speed improved from 1.66 (0.32) m/sec to 1.77 (0.32) m/sec after the intervention (P=0.02). On the basis of minimal clinically important differences of 50 m for the 6-MWT and 0.1 m/sec for the 10-m walk test derived from the geriatric population, the results in this study reveal a clinically meaningful change of 0.11 m/sec in the maximum walking speed. Changes of 24 m in the 6-MWT and 0.07 m/sec in the 10-m self-selected condition did not exceed the minimal clinically important difference.
Ellis et al.(2019)[33] *Behavioural Change Component: Technology*	PDQ-39 6MWT	*Quality of Life* PDQ-39 mobility domain scores for the mHealth group declined from baseline to 12 months, which reflected improved mobility (-1.7 points, 95% CI=-4.4 to 1.1). While the active control group scores increased by 2.1 points (95% CI=-0.76 to 5.0). The between-group difference did not cross the threshold level of .05 α (estimated mean change: -3.8 points, 95% CI=-7.8 to 0.2; p=0.06); however, the magnitude of the difference was clinically meaningful. **Participants with lower activity at baseline reported better mobility-related quality of life in the mHealth condition compared with the active control condition, with a statistically significant and clinically meaningful difference in the change in PDQ-39 mobility** over 12 months between groups (-8.2 points, 95% CI=-15.4 to -0.9; **p=0.03**). *Physical Function* The change in 6MWT from baseline to 12 months (3.8 m 95% CI=5.1-62.5) was statistically significant (p =0.02) and could be considered clinically meaningful for the mHealth group but not the Active control group (5.3 m, 95% CI=-25.6 to 36.2) However, the difference in the change scores between groups was not statistically significant (28.5 m, 95% CI=-14.4 to 71.5; p =0 .19). *Less active participants* There was a nonsignificant between-group difference in improved distance walked (23.4 m, 95% CI=-49.4 to 96.3; P=.51); however, within-group changes in the mHealth group were similar to those in the whole sample (29.1 m, 95% CI=-16.8 to 75.0; P=.20) although this improvement was not significant.

Table S6. *(Cont. from previous page).*

Article	Outcomes	Conclusions
Author (year)	Outcome(s) of interest	Results
Hermanns et al.(2019)[39] ***Multi-component Behavioural Change Components: Technology + Support Groups***	Functional Assessment of Cancer Therapy-General	Percentage of change findings suggested that the physical activity tracker and electronic tablet intervention did not have a significant effect on participants' QoL (percentage change: -3.18).
Lai et al.(2020)[36] ***Behavioural Change Component: Technology***	Walking Capacity	All TAE participants exhibited a small to moderate increase (range: 2-101 m) in distance achieved on the 6MWT, with a mean increase of 35 m from baseline. TAE participants also displayed improvements in comfortable walking speed and fastest walking speed with a mean change of 0.31 (0.77) m/sec and 0.16 (0.63) m/sec from baseline respectively. Whereas SRE participants appeared to have a more variable response (changes in walking distance ranged from -67 to 83 m), with a mean increase of 1.35 m from baseline. SRE displayed decreases in comfortable walking speed and fastest walking speed with a mean change of -0.11 (0.67) m/sec and -0.002 (0.41) m/sec from baseline respectively.
Landers and Ellis (2020)[37] ***Behavioural Change Component: Technology***	PDQ-8 30-second STS Timed Up and Go	*Quality of Life* The PDQ-8 improved from the baseline, mean 6.8 (SD 5.0), to the 8-week measurement, mean 4.1 (SD 5.0; P= 0.01; Hedges g=0.53; 95% CI 0.14-0.94). At the 8-week point, 6/28 (21%) improved beyond the MDC on the PDQ- 8. The results of the ANOVAs (baseline, 8-week, and 12-week measurements) suggest that there were no additional improvements from the 8-week to the 12-week measurement points for the PDQ-8 (P=0.94). There were no statistically significant interactions for the factorial ANOVAs to test dosing effect: STS (P=0.39), TUG (P=0.41), and PDQ-8 (P=0.86). Likewise, there were no statistically significant correlations for the average time of app exercise usage and change scores on the STS (r=-0.148, P=0.45), TUG (r=0.113, p=0.57), and PDQ-8 (r=-0.017, P=0.93). *Physical Function* There was a statistically significant improvement at both 8 and 12 weeks. The STS improved from the baseline, mean 11.6 (SD 4.0), to the 8-week measurement, mean 14.3 (SD 4.7; p=0.01; Hedges g= 0.59; 95% CI 0.16-1.04). At the 8-week point, 15/28 (54%) improved beyond the MDC on the STS. The TUG improved from the baseline, mean 11.2 (SD 3.9), to the 8-week measurement, mean 8.5 (SD 2.6; P<0.001; Hedges g=.80; 95% CI 0.46-1.18). At the 8-week point, 8/28 (29%) improved beyond the MDC on the TUG. The results of the ANOVAs (baseline, 8-week, and 12-week measurements) suggest that there were no additional improvements from the 8-week to the 12-week measurement points for the STS (P > 0.99), TUG (P > 0.99),
Lee et al.(2019)[35] ***Behavioural Change Component: Support Groups***	PDQ-39 30-second STS TUG Berg Balance Scale 6MWT	*Quality of Life* The intervention group displayed overall improvements health-related QoL from baseline (38.75 (20.28)) to postintervention (32.63 (17.99)) to 16-week follow-up (30.45 (14.52)). While the control group displayed poorer QoL from baseline (26.72 (13.47)) to postintervention (32.55 (19.84)) to 16-week follow-up (30.11 (16.47)). **There was a significant difference found between the groups for overall health related QoL (p=0.012)** and the subscales of stigma (p=0.023), cognition (p=0.028), communication (p=0.014) and social support (p=0.003) *Activities of Daily Living* The intervention group displayed improvement in ADLs from baseline (76.36 (23.21)) to postintervention (81.58 (13.02)) to 16-week follow-up (82.63 (14.85)). The control group displayed a smaller improvement from baseline (80.00 (14.91)) to postintervention (84.67 (15.52)) with a small decline from postintervention to 16-week follow-up (82.94 (10.47)). There were no significant differences found between the groups (p=0.406) *Functional Fitness* The intervention group displayed improvements in leg strength (baseline: 12.48 (2.98); postintervention 13.67 (2.57); 16-week follow-up 13.28 (2.95)), mobility (baseline: 9.44 (1.52); postintervention 8.08 (1.66); 16-week follow-up 8.27 (1.85)), balance (baseline: 52.32(2.77); post intervention 53.63 (3.00); 16-week follow up 53.63 (2.69)) and cardiopulmonary endurance (baseline: 398.04 (75.81); postintervention 427.05 (82.98); 16-week follow-up 434.34 (82.52)) from baseline to 16-week follow-up. While the control group also displayed improvements in leg strength (baseline: 11.28 (3.30); postintervention 12.27 (3.65); 16-week follow-up 15.44 (2.56)), mobility (baseline: 9.41 (2.83); postintervention 8.75 (2.02); 16-week follow-up 6.95 (1.56)), balance (baseline: 51.89 (3.40); postintervention 52.87 (4.42); 16-week follow-up 54.12 (2.26)) and cardiopulmonary endurance (baseline: 401.69 (72.24); postintervention 433.89 (82.12); 16-week follow-up 460.15 (72.55)) from baseline to 16-week follow-up. There was no significant differences found between the groups for any of these variables (Leg strength p=0.874 , mobility p=0.541 , balance p=0.699 and cardiopulmonary fitness p= 0.258)
Peteet (2002)[34] ***Behavioural Change Components: Behavioural Techniques and Education***	Functional Reach Test Timed Up and Go Test Berg Balance Scale	*Physical Function* Both experimental and control groups did not demonstrate a statistically significant change between the two groups in either the Timed Up and Go test (p=0. 126) or the Functional Reach test (p= 0.135).

Table S6. *(Cont. from previous page).*

Article	Outcomes	Conclusions
Author (year)	Outcome(s) of interest	Results
Tickle-Degnen et al. (2010)[31] Behavioural Change Component: Education	PDQ-39	***Quality of Life*** Those who overall HRQOL scores improved when receiving rehabilitation (18 or 27 hours) were compared with those whose scores improved when receiving no intervention (0 hours). A decrease of at least 5.39 points on the summery index (a reduction in problems) was used as the criterion for clinically relevant improvement. Rates of improvement were greater for rehabilitation versus no rehabilitation at post and 6 months follow-up in particular, with a smaller difference at 2 months. **At immediately post-test**, 54% of participants in rehabilitation were improved versus 18% receiving no rehabilitation. The difference of these two rates is 36%, the absolute benefit increases due to rehabilitation (95% CI 5 20- 53%; **p<0.0001**)). At 2 months follow-up, 34% of participants in rehabilitation were improved versus 20% of those who did not receive rehabilitation (p=0.11). **At 6 months**, 38% who received rehabilitation were improved versus 10% of those who received no rehabilitation (**p<0.001**).
van Nimwegen et al. (2013)[32] *Multi-component Behavioural Change Components: Technology + Behavioural Techniques + Education + Support Groups*	PDQ-39 6MWT	*Quality of Life* Quality of life did not differ between the groups (adjusted group difference -0.9 points, 95% CI -2.1 to 0.3; p =0.14) *Physical Function* ParkFit patients increased their **physical function** compared with controls (**6MWT** adjusted group difference 4.8 m, 95% CI 0.1 to 9.6; **p=0.05**).

*SD=standard deviation; PD=Parkinson's Disease; 6MWT=6-minute walk test; PDQ-39=Parkinson's Disease Questionnaire-39; PDQ-8=Parkinson's Disease Questionnaire-8; 95% CI=95% Confidence Interval; NR=Not reported; STS=sit to stand; QoL=Quality of life; HRQoL=Health-related quality of life; EQ-5D=European Quality of Life Five Dimension; TAE=Telecoach-assisted exercise; SRE=Self- regulated exercise; MDC=Minimal Detectable Change; TUG=Timed Up and Go; ADLs =Activities of Daily Living; M=Mean; m/sec=metre per second; s=seconds; ns=Non-significant, **Bold**=studies with significantly positive findings.*