

1 **The effectiveness of interventions and intervention components for increasing physical activity**
2 **and reducing sedentary behaviour in people with persistent musculoskeletal pain: a systematic**
3 **review and meta-analysis**

4 Gregory Booth ^{a,b}, Ana Howarth ^b, Brendon Stubbs ^{c,d}, Michael Ussher ^{b,e}

5

6 Therapies Department, Royal National Orthopaedic Hospital NHS Trust ^a

7 Population Health Research Institute, St. George's, University of London ^b

8 South London and Maudsley NHS Foundation Trust ^c

9

10 Institute of Psychiatry, Psychology and Neuroscience, King's College London ^d

11

12 Institute of Social Marketing and Health, University of Stirling ^e

13

14

15 **Corresponding author:**

16 Mr Gregory Booth

17 Mailing address: Therapies Department, Royal National Orthopaedic Hospital, Brockley Hill,
18 Stanmore, Middlesex, HA7 4LP, United Kingdom

19 Tel: 020 8909 5820

20 Email address: Gregory.booth@nhs.net

21

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6 Brendon Stubbs has published a book on exercise and mental illness and is on the Editorial board of
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12

13 Conflicts of interest

14 The authors declare no conflicts of interest.

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21 **Abstract**

22 This systematic review and meta-analysis investigated the effectiveness of physical activity (PA) and
23 sedentary behaviour (SB) interventions on PA and SB levels in people with persistent
24 musculoskeletal pain. We explored the effectiveness of behaviour change techniques (BCTs), the use
25 of behaviour change theory and non-PA/SB outcomes. Randomised controlled trials of PA or SB
26 interventions for people with persistent musculoskeletal pain were eligible. Twenty-three studies

1 were included. Quality of evidence was assessed using the GRADE approach. Meta-analysis
2 demonstrated a small effect for PA post-intervention (Hedge's $g = 0.321$, CI 0.136 to 0.507, $p =$
3 0.001, very low-quality evidence). There was no effect for longer-term follow-up PA (low quality
4 evidence) or SB outcomes (very low-quality evidence). There was a small effect for studies with low
5 risk-of-bias at longer-term follow-up PA. Self-report PA outcomes, PA and education interventions,
6 non-self-selected PA, a combination of supervised and unsupervised PA and a combination of
7 individual and group-based interventions had larger effects. Heterogeneity was moderate to
8 considerable. Risk-of-bias, assessed using Cochrane risk-of-bias tool (version two), was generally low.
9 Five promising BCTs were identified: 'adding objects to the environment', 'goal setting (outcome)',
10 'action planning', 'monitoring outcome(s) of behaviour by others without feedback' and 'feedback
11 on outcome(s) of behaviour'. In conclusion, there is evidence for a modest benefit for PA
12 interventions immediately post-intervention, however the quality of evidence is very low. There was
13 no evidence for longer-term follow-up PA or SB. Higher quality studies of PA and SB interventions
14 that use objective measures are needed. PROSPERO registration: CRD42020180260.

15

16 **Perspective**

17 This review investigated the effects of physical activity and sedentary behaviour interventions on
18 physical activity and sedentary behaviour levels in people with persistent musculoskeletal pain.
19 Current evidence shows a modest benefit for interventions on physical activity post-intervention but
20 not at longer-term follow-up or on sedentary behaviour at any time-point, however quality of
21 evidence is low to very low.

22

23 **Keywords:** systematic review, meta-analysis, physical activity, sedentary behaviour, persistent
24 musculoskeletal pain

1 **1. Introduction**

2 Persistent musculoskeletal pain conditions are some of the leading causes of disability worldwide.⁹⁷

3 Low back and neck pain are reported to be the leading causes of disability and ‘other
4 musculoskeletal disorders’ are eighth on the list.⁹⁷ Persistent musculoskeletal pain is defined as pain
5 lasting longer than three months that is experienced in bones, joints, muscles, tendons and other
6 soft tissues.⁷⁴ The terms ‘persistent’ and ‘chronic’ pain are used interchangeably in the literature; in
7 this study, the term persistent is used throughout.

8 Persistent musculoskeletal pain affects people’s ability to do physical activities such as walking and
9 household chores, and commonly affects sleep, relationships and work.¹⁴ Higher walking disability is
10 associated with greater risk of death in people with osteoarthritis.⁶⁸ People with persistent
11 musculoskeletal pain also often have co-morbidities, including psychological problems,^{85, 92}
12 cardiovascular disease⁹² and obesity.²⁰

13 The World Health Organization define physical activity (PA) as “any bodily movement produced by
14 skeletal muscles that requires energy expenditure.” This “includes exercise as well as other activities
15 which involve bodily movement and are done as part of playing, working, active transportation,
16 house chores and recreational activities.”⁷¹ Exercise is defined as “a subcategory of physical activity
17 that is planned, structured, repetitive, and purposeful in the sense that the improvement or
18 maintenance of one or more components of physical fitness is the objective.”⁷¹ Low back pain and
19 osteoarthritis are two of the most common, most costly and most debilitating persistent
20 musculoskeletal pain conditions. However, people with persistent low back pain are less active than
21 matched healthy controls⁸² and those with the condition that have higher disability are more likely
22 to have lower PA levels.⁵⁴ Similarly, only small to moderate numbers of people with hip and knee
23 osteoarthritis meet PA guidelines.⁹⁹

24

1 PA is safe for people with persistent musculoskeletal pain³⁵ and can be effective at improving
2 physical function and quality of life.^{34, 35, 69, 89} PA is associated with reduced premature mortality,²⁹
3 and is effective in reducing the impact of numerous associated health problems common in people
4 with persistent musculoskeletal pain.^{52, 86, 88} PA is recommended in national guidelines for
5 management of osteoarthritis,^{66, 78} low back pain and sciatica.^{67, 77} PA promotion and exercise
6 therapy are also recommended as part of first line treatment for low back pain.³³ National public
7 health campaigns have recommended reducing sedentary behaviour (SB) to improve the
8 management of long-term health conditions, such as persistent musculoskeletal pain.⁷⁵

9 Recent systematic reviews and meta-analyses on PA interventions in people with persistent
10 musculoskeletal pain all have limitations.^{28, 55, 70} One review⁵⁵ performed their meta-analysis defining
11 their follow-up period from post-randomisation, rather than from post-intervention. The length of
12 PA interventions varies greatly and therefore, what is considered long-term follow-up may coincide
13 with still being in the intervention period, meaning this approach does not provide accurate
14 estimates of immediate post-intervention effects and longer-term maintenance effects. Another
15 review²⁸ found a small effect at medium-term follow-up and no effect at long-term follow-up, but
16 did not do an immediate post-intervention analysis. This is important for comparing post-
17 intervention with longer-term follow-up effects. One review⁷⁰ only included objective PA outcomes,
18 however, many studies include only self-report measures and such measures also compliment
19 objective data, therefore excluding these measures reduced the scope of the review. Another review
20 separated their self-report and objective results and did not calculate a combined pooled effect.⁵⁵
21 These reviews were also limited by including preliminary/pilot studies with small sample sizes, which
22 may alter the precision of results.^{55, 70}

23 To our knowledge, no systematic reviews or meta-analyses in people with persistent
24 musculoskeletal pain have examined the effects on PA levels according to the nature of the
25 intervention, including the mode of PA, or intervention characteristics such as setting of PA or

1 method of intervention delivery, and this may be important due to the large variation in ways of
2 performing PA. Moreover, we are not aware of any reviews examining the effects of interventions
3 aimed at reducing sedentary behaviour (SB) in people with persistent musculoskeletal pain.

4 Behaviour change techniques (BCTs) are the components of interventions directly affecting
5 behaviour; the 'active ingredients'.⁶⁰ Identification of effective BCTs within interventions can allow
6 identification of potentially important intervention components that help bring about behaviour
7 change.⁶⁰ Rigorous testing of behaviour change theory can help inform intervention design, as well
8 as provide explanations for why they may or may not be effective.^{59, 80} Therefore, theories are
9 fundamental in behaviour change intervention design.⁵⁹ To our knowledge no reviews have explored
10 the use of behaviour change theory in interventions aimed at increasing PA or reducing SB in people
11 with persistent musculoskeletal pain.

12 An updated review is needed, which overcomes the above limitations of previous reviews,
13 comparing post-intervention and longer-term follow-up outcomes in full randomised controlled
14 trials (RCTs), that includes self-report and objective PA measures. Therefore, we aimed to provide an
15 up-to-date review on the effect of PA interventions on PA levels in people with persistent
16 musculoskeletal pain. Additionally, we reviewed interventions for reducing SB in this population. We
17 also explored the effects of risk-of-bias, outcome measure type, nature of the intervention, type and
18 setting of PA and method of intervention delivery. We explored any associations between number of
19 behaviour change techniques (BCTs, i.e., intervention contents⁶⁰) and effect sizes and explored
20 potential effectiveness of specific BCTs, as well as identifying the use of theory in the interventions.
21 Lastly, we reviewed findings for non-PA/SB health-related outcomes.

22

23 **2. Methods**

1 This review is reported consistent with the Preferred Reporting Items for Systematic Reviews and
2 Meta-Analyses (PRISMA) statement⁶² (see supplementary material) and is registered with the
3 International Prospective Register of Systematic Reviews (PROSPERO: CRD42020180260).

4 *2.1 Search Strategy*

5 Search terms were derived from knowledge of the research area and by reviewing the search
6 strategies in similar reviews, and were agreed by two authors (GB, MU). Specific RCT search filters
7 were included in the search strategy.^{21, 53} A search of MEDLINE, Embase, CINAHL, SportDiscus,
8 PsycINFO, PEDro and CENTRAL electronic databases was initially performed on 28/05/20 and
9 29/05/20 and was updated on 24/06/2021. Databases were searched from inception until the date
10 of the search (see supplementary material for MEDLINE search strategy). This search strategy was
11 adapted for the other databases, with consistent search terms throughout. The reference lists of
12 similar systematic reviews and meta-analyses were also searched to identify relevant studies.

13 *2.2 Selection of studies*

14 *2.2.1 Screening*

15 Search results were exported into Endnote⁹³ and duplicates removed. Results were imported into
16 Rayyan QCRI software⁷² for title and abstract screening. One author (GB) screened all titles and
17 abstracts independently against the eligibility criteria. Two authors (MU, AH) independently
18 screened 50% each of the titles and abstracts. Conflicts were resolved by discussion. Of the
19 remaining articles, full texts were retrieved and reviewed, and three authors (GB, MU, AH) finalised
20 the articles via consensus.

21 *2.2.2 Eligibility criteria*

22 Eligible studies were those published in English language in peer-reviewed journals. We included
23 RCTs or cluster-RCTs. We excluded quasi-RCTs and preliminary/pilot studies.

1 The population of interest was adults (aged ≥ 18 years) with persistent musculoskeletal pain (i.e.,
2 pain lasting ≥ 3 months, experienced in bones, joints, muscles, tendons and other soft tissues.⁷⁴) We
3 only included those with persistent spinal pain (including lumbar, thoracic and cervical) and
4 persistent peripheral joint pain (upper and lower limbs). We included participants with multiple pain
5 sites. Participants that had undergone surgery but met the inclusion criteria of adults with PMP were
6 included, but those awaiting surgery were excluded, due to the likelihood of uncertain and varied
7 long-term management.

8 We excluded studies of patients with non-musculoskeletal pain or cancer-related pain, and those
9 with rheumatological conditions such as fibromyalgia or rheumatoid arthritis as these are distinct
10 conditions.⁴⁵

11 We included studies of any interventions aimed at increasing PA levels or adherence to PA, or
12 studies seeking to reduce SB. We used the World Health Organization's definition of PA: "any bodily
13 movement produced by skeletal muscles that requires energy expenditure." which "includes
14 exercise as well as other activities which involve bodily movement and are done as part of playing,
15 working, active transportation, house chores and recreational activities".¹⁰⁰ We defined SB as: "any
16 waking behaviour characterized by an energy expenditure ≤ 1.5 metabolic equivalents (METs), while
17 in a sitting, reclining or lying posture".^{65,95} Interventions of any duration and with any length of
18 follow-up were included. Multi-component interventions where all the components were aimed at
19 increasing PA or reducing SB were included. We excluded multi-component interventions with
20 elements aimed at changing behaviours other than PA or SB (e.g., diet), or that included medical
21 interventions (e.g., injections). We excluded site-specific exercises (e.g., neck exercises) unless aimed
22 at increasing overall PA levels or reducing SB. We included studies with all types of control group and
23 studies with multiple intervention arms.

24

1 Our co-primary outcomes of interest were objective or self-report measures of PA or SB (e.g.
2 accelerometry). All measures were included that measured PA levels, PA adherence or SB levels. If
3 studies included both objective and self-report measures, the objective measure was included in the
4 meta-analysis. For studies that used multiple self-report or objective measures, we included the
5 main outcome in the original study. If the main outcome was not reported, we used the outcome
6 that was more commonly used to measure PA/SB.

7

8 *2.3 Data extraction*

9 One author (GB) independently extracted data for all included studies. Two authors (MU, AH)
10 checked the accuracy of data extraction (50% of studies each), with ambiguities resolved by
11 discussion.

12 Extracted data included: study and participant characteristics, intervention and control
13 characteristics, PA settings, methods of PA delivery and providers. BCTs were coded from
14 intervention and control using the BCT Taxonomy version one (BCTTv1).⁶⁰ A coding system was
15 developed, with 'confident' meaning we were fully confident that the BCT was present, or
16 'tentative', meaning there was uncertainty. One author (GB) has received formal training in using
17 BCTTv1 (<http://www.bct-taxonomy.com/>). The other authors (MU, AH) involved in coding are
18 experienced with using the taxonomy. Behaviour change theories were classed as being used in an
19 intervention when the theory used was explicitly stated in the article or intervention description.
20 Use of theories was coded as 'informed by theory', 'applied theory', 'testing theory' or 'building or
21 creating theory'.⁷³ For primary outcomes, we extracted mean values and standard deviations (SD)
22 from each study at post-intervention and longer-term follow-up time points, where available. Post-
23 intervention outcomes were defined as outcomes that were collected immediately after the
24 intervention period ended. Longer-term follow-up outcomes were defined as the longest follow-up
25 time-point of any study that collected outcomes beyond immediate post-intervention. Where this

1 data was unavailable, we emailed study authors requesting the data. For non-PA/SB health-related
2 outcomes (e.g., pain), we recorded which were significant and which were not significant.

3

4 *2.4 Assessment of risk-of-bias*

5 Risk-of-bias was assessed in each included study using version 2 of the Cochrane risk-of-bias
6 assessment tool for randomised trials⁹¹ and additional considerations were used for cluster-
7 randomised trials.³⁰ Risk-of-bias domains included bias arising from: the randomisation process
8 (including addition of bias arising from the timing of identification and recruitment of participants in
9 relation to timing of randomisation in cluster-randomised trials), deviations from intended
10 interventions, missing outcome data, measurement of the outcome, and selection of results. For
11 each study, each domain was judged as being either 'low risk-of-bias', having 'some concerns' or
12 being 'high risk-of-bias'. Studies were judged as low risk-of-bias if all domains were judged as 'low
13 risk-of-bias', as 'some concerns' if one or more domains were judged as 'some concerns' and high
14 risk-of-bias if one or more domains were as judged as 'high risk-of-bias'.

15 For the studies with self-report outcomes, we assessed these as low risk-of-bias in the measurement
16 of the outcome domain if the outcome was validated. If we could not find evidence of the outcomes
17 being validated, we assessed this as 'some concerns'.

18 Risk-of-bias assessments were conducted independently by one author (GB), and two authors (MU,
19 AH) independently assessed 50% each of the studies. Disagreements were resolved by discussion.

20

21 *2.5 Data synthesis and analysis*

22 *2.5.1 Meta-analysis, subgroup-analysis and meta-regression*

1 Meta-analyses were performed using Comprehensive Meta-analysis software Version 3.¹² For all
2 meta-analyses and subgroup analyses we used the random-effects model, due to suspected
3 heterogeneity. For our primary meta-analyses, we calculated the effect sizes using Hedge's *g* and
4 95% confidence intervals (CIs) for PA and SB outcomes immediately post-intervention and at longer-
5 term follow-up. The Hedge's *g* effect sizes were interpreted as: small = 0.2, medium = 0.5 and large =
6 0.8. We conducted a sensitivity analysis including studies only of low risk-of-bias. We conducted pre-
7 planned subgroup analyses on PA outcomes for: outcome measure type (self-report versus
8 objective), PA type (self-selected, non-self-selected, combination), PA setting (supervised,
9 unsupervised, combination) and intervention delivery method (individual, group-based,
10 combination). For the study with two intervention arms,¹⁰ we split the control group sample in half
11 whilst keeping the same mean and standard deviation to ensure these participants were not double
12 counted in the meta-analysis.

13 Statistical heterogeneity was assessed using Cochran's *Q* and the *I*² test³⁷. *I*² values of above 80%
14 were assessed as considerable, between 60% and 80% were assessed as substantial, between 40%
15 and 60% as moderate and below 40% as unimportant.²³ Publication bias was assessed by inspecting
16 funnel plots and using the Begg-Mazumbar Kendall's tau⁵ and Egger test.²⁷ We conducted a trim and
17 fill adjusted analyses²⁵ to calculate a new effect size after 'trimming' the funnel plot of small studies
18 and then estimating the number of missing studies by 'filling' the funnel plot with the omitted and
19 estimated missing studies around the new effect size. We calculated the fail-safe number of negative
20 studies that would be required to nullify (make $p \geq 0.05$) the effect.⁸¹ We performed a meta-
21 regression to identify potential moderators of PA levels. The potential moderators were number of
22 BCTs ('confident' only) present in the interventions and number of treatment sessions.

23 *2.5.2 Behaviour change components*

24 We narratively synthesised behaviour change theory use in terms of how many studies used
25 behaviour change theory, extent of theory use⁷³ and theories used.

1 We calculated the number of BCTs used across intervention and control groups and recorded the
2 number of times each BCT was coded. We identified BCTs for which there was evidence of
3 effectiveness.⁵⁸ We considered that interventions showed evidence of effectiveness when there
4 were statistically significant differences ($p < 0.05$) in PA or sedentary levels between trial groups at
5 either point measured in our meta-analyses. An “effectiveness percentage”, a measure to reflect
6 potential effectiveness, was calculated as the number of times a BCT had been a component of an
7 effective intervention, divided by the total number of interventions in which the BCT had been a
8 component. Effective percentages were calculated only for BCTs used in two or more
9 interventions.³²

10 *2.5.3 Secondary outcomes*

11 Due to many different non-PA/SB health-related outcomes, we categorised these outcomes (e.g.,
12 related to pain, function, psychological) and identified statistically significant and non-significant
13 findings. We calculated the number of times each outcome category was reported and how often
14 they were statistically significant or non-significant at either post-intervention or at their longest
15 follow-up, if they reported further follow-up time points. We then calculated the percentage that
16 each outcome category demonstrated statistically significant results.

17

18 *2.6 Quality of evidence*

19 The Grading of Recommendations, Assessment, Development and Evaluation (GRADE)¹ was used to
20 evaluate the quality of the evidence for our primary outcomes. GRADE enables a judgement of high,
21 moderate, low or very low for each outcome, across five domains: risk-of-bias, indirectness of
22 evidence, inconsistency of results, imprecision of effect size and publication bias.

23

24 *2.7 Deviations from registered protocol*

1 See supplementary material for details of deviations from the protocol, reasons for these deviations
2 and the effect on the results. None of the deviations had a significant effect on the results.

3

4

5 **3. Results**

6 *3.1 Study selection*

7 The search yielded 30,551 results, and 18,570 remained after removing duplicates. Eighty-six articles
8 remained after title and abstract screening. A further 57 articles were excluded after reviewing the
9 full texts (see figure 1 for the PRISMA flow diagram). Of the remaining 29 studies, eight authors were
10 contacted for further PA outcome data; two supplied the data^{9, 10} and six not providing data were
11 excluded.^{6, 15, 36, 42, 44, 79} Thus, 23 studies were included.^{2-4, 7, 9, 10, 13, 18, 19, 31, 38, 39, 43, 46, 48, 51, 57, 64, 76, 84, 87, 98,}

12 ¹⁰³

13

14 *3.2 Characteristics of included studies*

15 Table 1 summarises the characteristics of the included studies. Twenty studies were RCTs and three
16 were cluster-RCTs. Year of publication ranged from 2006 to 2021. Twenty-two studies had PA
17 interventions and one aimed at reducing SB.

18 *3.2.1 Participants characteristics*

19 The 23 studies included 4,012 participants; 2103 were in the intervention groups and 2487 (65.3%)
20 were female. Mean age was 61.38 years (range 46 to 85). Seven studies included participants with
21 persistent low back pain,^{3, 4, 48, 51, 57, 84, 87} eight had participants with knee osteoarthritis,^{2, 7, 9, 19, 31, 38, 64,}
22 ⁹⁸ one included participants with hip osteoarthritis,¹⁰ five included both knee and hip
23 osteoarthritis,^{13, 39, 43, 46, 76} one included chronic musculoskeletal pain but did not specify the location

1 or origin,¹⁸ and one included lower limb osteoarthritis (hip, knee, ankle or foot).¹⁰³ Four studies^{2, 3, 43,}
2 ⁴⁸ with 575 participants reported ethnicity, and 422 (73.39%) were Caucasian. Employment was
3 reported in nine studies;^{7, 10, 38, 48, 57, 64, 87, 98, 103} the mean percentage employed was 53.9% (range
4 15.8% to 91%). Six studies reported co-morbidities,^{10, 18, 19, 38, 43, 64} with cardiovascular disease, lung
5 diseases, orthopaedic problems, cancer, diabetes, hypertension and mental health conditions being
6 reported in at least two studies. Ethnicity, employment and co-morbidities are not reported in table
7 1 due to the low number of studies reporting this information.

8 *3.2.2 Intervention characteristics*

9 See table 1 for details of the intervention aimed at reducing SB.³ There were 23 interventions in 22
10 studies of PA interventions; one study had two intervention arms.¹⁰ Interventions varied from four
11 weeks⁸⁷ to 24 months.² Two interventions were solely web-based.^{13, 48} Eighteen interventions
12 consisted of non-self-selected PA, with 11 of these consisting of exercise,^{2, 4, 7, 9, 10, 19, 31, 39, 57, 64, 103}
13 three of walking,^{10, 48, 51} three combining exercise and walking^{43, 87, 98} and one offering exercise and
14 functional activities.⁷⁶ Three interventions combined self-selected and non-self-selected PA; the non-
15 self-selected component was physiotherapy prescribed exercise.^{18, 38, 46} Two interventions offered
16 self-selected PA only.^{13, 84}

17 Interventions provided: counselling/coaching with PA,^{2, 4, 7, 9, 18, 48, 84, 103} education with PA^{13, 19, 43, 46, 51,}
18 ^{57, 76} and education and counselling with PA.^{10, 31, 38, 64, 87} Two interventions provided PA only.^{39, 98}

19 Interventions offered: only supervised PA,^{4, 9, 31, 57} only unsupervised PA^{3, 13, 38, 48, 51, 64, 84} and combined
20 supervised and unsupervised PA.^{2, 7, 10, 18, 19, 39, 43, 46, 76, 87, 98, 103} Interventions were delivered

21 individually,^{3, 4, 7, 9, 13, 18, 38, 46, 48, 51, 64, 76} group-based^{39, 57, 87} and combined individual and group.^{2, 10, 19, 31,}

22 ^{43, 84, 98, 103} The number of interactive sessions (excluding online) was reported in 20 studies, ranging

23 from two to 54 sessions. Of five studies including online components, one had nine modules,¹³ one

24 had 11 modules,⁴⁶ one had weekly engagement⁴⁸ and two provided unlimited access to resources.^{64,}

25 ⁸⁴

1 *3.2.3 Control group characteristics*

2 Two control groups received no intervention,^{3,13} four had the same or similar PA as the intervention
3 group with less or without the additional behavioural component,^{2,7,9,103} three received a similar
4 behavioural component with different PA,^{31,51,64} seven had a minimal or less intense PA-based
5 intervention,^{10,19,39,43,57,64,84} one had the same self-management component but a different PA
6 component³¹ and seven received usual care.^{4,18,38,46,48,76,98}

7 One study was a three arm RCT, with the intervention arms consisting of Nordic walking and
8 strength training and the control group consisting of home exercise.¹⁰ We determined the home
9 exercise group as the control group as this group was designated as the control by the study authors.
10 The control group received a much less intensive intervention (table 1).

11

12 *3.2.4 Physical activity and sedentary behaviour outcomes*

13 Seventeen studies had only self-reported PA outcomes,^{2-4,9,10,18,19,38,39,43,51,57,64,76,84,87,103} three only
14 objective outcomes^{31,48,98} and three had a combination of self-report and objective.^{7,13,46}

15 Twelve different PA self-report measures were used. Six of the measures were used more than once;
16 Physical Activity Scale for the Elderly (PASE) was used six times, a Numerical Rating Scale (NRS) for
17 exercise adherence was used four times, and the Global Physical Activity Questionnaire (GPAQ),
18 International Physical Activity Questionnaire (IPAQ), Freiburg Questionnaire and Short Questionnaire
19 to Assess Health-Enhancing PA (SQUASH) were each used twice. For objective PA outcomes,
20 accelerometers were used five times and pedometers were used in one study. One study used the
21 Global Physical Activity Questionnaire for measuring SB³ and this was the only self-report outcome
22 used for SB. Accelerometers were used in three studies to objectively measure SB.^{13,46,98}

23 Four studies measured outcomes of specific intensities of PA. One measured minutes per week
24 doing moderate to vigorous PA,³ one measured minutes per day doing moderate to vigorous PA,⁴⁶

1 one measured days per week doing 30 minutes or more of moderate to vigorous PA⁷⁶ and one
2 measured minutes per day doing three or more MET-minutes of PA.³¹

3 *3.3 Risk-of-bias assessment*

4 Risk-of-bias is displayed in figure 2. Eighteen studies were assessed as low risk-of-bias. Five had
5 ‘some concerns’; three of these used unvalidated NRS PA outcome measures,^{2, 9, 19} one used an
6 activity diary,⁴ and one lacked detail of the randomisation process and of baseline data for each
7 study group.¹⁰³ The latter study also had ‘some concerns’ as there was no information about
8 whether there were any deviations from the intended intervention. No studies were judged as being
9 at high risk-of-bias.

10

11 *3.4 Meta-analysis*

12 Twenty-one post-intervention PA outcomes from 19 studies were included in our meta-analysis; one
13 study contained two intervention arms,¹⁰ and we included two outcome measures for one study as
14 they reported longer-term outcomes for self-report outcomes, but only post-intervention outcomes
15 for objective outcomes.⁷ Pooled data from these 21 outcomes showed a small effect in favour of the
16 interventions (Hedge’s $g = 0.321$, CI 0.136 to 0.507, $p = 0.001$, very low certainty evidence) (Figure 3),
17 with considerable heterogeneity ($Q = 117.2834$ $p = 0.008$, $I^2 = 83\%$). In the funnel plot there was
18 asymmetry, with one study far to the right (see supplementary material). However, neither Begg and
19 Mazumdar’s rank correlation test ($\tau = 0.27619$, $p = 0.08$) nor Egger’s regression test (intercept =
20 1.996, $p = 0.261$) were significant, demonstrating no evidence of publication bias. Pooled data from
21 the 12 studies presenting longer-term PA outcomes showed no effect (Hedge’s $g = 0.197$, CI 0.061 to
22 0.332, $p = 0.005$, low certainty evidence) (Figure 4), with moderate heterogeneity ($Q = 26.85459$ $p =$
23 0.005, $I^2 = 59\%$). Again, there was evidence of funnel plot asymmetry, with one study far to the right

1 (see supplementary material). Begg and Mazumdar's rank correlation ($\tau = 0.12121$, $p = 0.58$) and
2 Egger's regression (intercept = 0.167, $p = 0.947$) tests were not significant.

3 Meta-analysis for post-intervention SB outcomes, with three studies, was not significant (Hedge's $g =$
4 -0.203 , CI -0.702 to 0.295 , $P = 0.424$, very low certainty evidence) (Figure 5) and there was no
5 evidence of heterogeneity ($Q = 5.55$ $P = 0.062$, $I^2 = 63.97\%$). There was no effect for longer-term
6 follow-up SB outcomes in two studies (Hedge's $g = 0.011$ CI -0.183 to 0.204 , $P = 0.914$, very low
7 certainty evidence) (Figure 6), nor was there significant heterogeneity ($Q = 0.379$ $P = 0.538$, $I^2 = 0\%$).
8 Table 2 presents all meta-analyses. Due to the small number of studies in both SB analyses, we did
9 not test for publication bias. See table 3 for GRADE ratings and justification for ratings.

10 *3.4.1 Sensitivity analysis*

11 There was a marginally smaller effect for studies with low risk-of-bias at post-intervention for PA
12 (Hedge's $g = 0.257$, CI 0.115 to 0.399 , $p < 0.001$), with substantial heterogeneity ($Q = 42.305$ $p <$
13 0.001 , $I^2 = 64.54\%$). There was a small effect size for PA at longer-term follow-up for studies with low
14 risk-of-bias (Hedge's $g = 0.202$, CI 0.045 to 0.360 , $p = 0.012$), and heterogeneity was substantial ($Q =$
15 26.71611 $p = 0.002$, $I^2 = 66.31\%$). We did not perform a sensitivity analysis for SB outcomes as all
16 studies were judged as low risk-of-bias.

17 *3.4.2 Subgroup analysis*

18 Subgroup analysis was performed only for post-intervention PA outcomes (see table 2), as there
19 were insufficient studies for longer-term follow-up outcomes. Studies containing only self-report
20 outcomes had a larger but still small effect size (Hedge's $g = 0.350$, CI 0.113 to 0.586 , $p = 0.004$);
21 interventions consisting of PA and education showed the highest effect size, which was a medium
22 effect (Hedge's $g = 0.749$, CI 0.003 to 1.495 , $p = 0.049$); non-self-selected PA was the only type of PA
23 that showed any effect (Hedge's $g = 0.384$, CI 0.158 to 0.610 , $p = 0.001$); a combination of supervised
24 and unsupervised PA showed the largest effect size, although this remained small (Hedge's $g =$

1 0.447, CI 0.130 to 0.764, $p = 0.006$) and a combination of individual and group-based intervention
2 delivery methods showed the highest effect size, although this also remained small (Hedge's $g =$
3 0.491, CI 0.054 to 0.927, $p = 0.028$).

4 *3.4.3 Adjustment for publication bias and fail-safe number of studies*

5 Several analyses were adjusted for publication bias (see table 2). The majority of the adjusted
6 analyses originally underestimated the effect sizes. For our main meta-analysis, the effect remained
7 small after adjustment for post-intervention PA outcomes and increased to a small effect for longer-
8 term follow-up PA outcomes. Post-intervention SB was unchanged after adjustment and longest
9 follow-up for SB had too few studies to be adjusted. The fail-safe number of studies needed to nullify
10 the effect was high for post-intervention PA outcomes ($N = 302$).

11 *3.4.4 Meta-regression for physical activity outcomes*

12 The number of sessions did not moderate the effect size of interventions at post-intervention ($\beta =$
13 0.0216, CI -0.0520 to 0.0952, $p = 0.57$, $R^2 = 0.00$) or at longer-term follow-up ($\beta = 0.0267$, CI -0.0126
14 to 0.0659, $p = 0.18$, $R^2 = 0.12$). A summary of the meta-regression outcomes is presented in table 4.
15 The meta-regression outcomes for number of BCTs is described in section 3.5.

16

17 *3.5 Behaviour Change Techniques*

18 None of the studies referred to the intervention contents as BCTs or referred to the BCT taxonomy
19 (BCTT), so all interventions were coded using the BCT Taxonomy version one⁶⁰ to extract BCTs.

20 A total of 219 BCTs was delivered to PA and SB intervention and control groups; 177 were delivered
21 to the intervention groups only. In the interventions, there were 31 different BCTs from 13 BCT
22 clusters. Most BCTs were in the 'Goals and planning' ($n=33$) and 'Feedback and monitoring' ($n=34$)

1 clusters. The number of BCTs identified for each intervention (PA and SB) ranged from three¹³ to
2 fourteen,⁴³ with an average of seven BCTs.

3 The majority of BCTs were present more than once in interventions, however, 10 BCTs were only
4 present once: 'behavioural contract', 'social support (emotional)', 'salience of consequences',
5 'monitoring of emotional consequences', 'pros and cons', 'non-specific reward', 'social reward',
6 'pharmacological support', 'reduce negative emotions' and 'body changes'.

7 Among six studies in the meta-analyses showing effectiveness for PA outcomes,^{7, 19, 38, 43, 76, 98} the BCT
8 'credible source' was present in all six interventions; 'instruction on how to perform a behaviour'
9 and 'self-monitoring of behaviour' were present in five interventions; 'problem solving', 'action
10 planning' and 'demonstration of the behaviour' were present in four of the interventions; 'goal
11 setting (behaviour)' and 'behavioural practice/rehearsal' were present in three interventions and
12 'feedback on behaviour' and 'graded tasks' were present in two of the interventions. Several BCTs
13 were present only once in the effective interventions (table 5).

14 BCT effectiveness percentages are presented in table 5. Of the BCTs that were components of two or
15 more PA interventions, one BCT had an effectiveness percentage of 67%: 'adding objects to the
16 environment' and four had effectiveness percentages of 50%: 'goal setting (outcome)', 'action
17 planning', 'monitoring outcome(s) of behaviour by others without feedback' and 'feedback on
18 outcome(s) of behaviour'. One BCT had a percentage of 0%: 'Monitoring of behaviour by others
19 without feedback' (See supplementary material for BCTs).

20 One study focused on reducing SB, demonstrated post-intervention effectiveness³ and included the
21 BCTs of: 'goal setting (behaviour)', 'behavioural contract', 'social support (unspecified)', 'information
22 about health consequences', 'prompts/cues', 'credible source' and 'adding objects to the
23 environment'.

1 Meta-regression for number of BCTs did not moderate the intervention effect at immediate post-
2 intervention ($\beta = -0.0031$, CI -0.0155 to 0.0092, $p = 0.62$, $R^2 = 0.00$) or at longer-term follow-up ($\beta =$
3 0.0095 , CI -0.0060 to 0.0249, $p = 0.2304$, $R^2 = 0.07$).

4 Study protocols were available for eight trials;^{8, 17, 40, 41, 47, 49, 63, 83} however, the highest number of
5 BCTs was present in a trial without an available protocol.⁴³

6 Forty-four BCTs were coded as 'tentative'; 39 of these were in the interventions. We only included
7 BCTs in this analysis that were coded as 'confident'.

8

9 *3.6 Use of theory*

10 Twelve studies explicitly identified using at least one behaviour change theory. The majority used
11 one theory,^{4, 19, 43, 46, 48, 57, 76, 84, 87} two used two theories^{18, 64} and one used three theories.² Among
12 these studies, three were judged as being informed by theory,^{18, 46, 84} five as applying theory,^{2, 4, 48, 57,}
13 ⁷⁶ three as testing theory^{19, 43, 87} and one study built/ created theory⁶⁴ (see table 6). Social Cognitive
14 Theory and the Transtheoretical Model were used three times each and were the most used
15 theories. Self-efficacy Theory, the Health Action Process Approach and Operant Conditioning were
16 used in two studies. Goal Setting Theory the Rubicon Model of Action Phases, the Capability-
17 Opportunity-Motivation-Behaviour model and Theoretical Domains Framework were each used in
18 one study.

19 Three of the six effective studies used theory. One study tested the Transtheoretical Model,¹⁹ one
20 tested Social Cognitive Theory⁴³ and one applied operant conditioning.⁷⁶

21

22 *3.7 Health-related (secondary) outcomes*

1 One study did not have any outcome measures besides PA.⁷⁶ Two studies did not report between
2 group differences in secondary outcomes.^{31, 103} Of the twenty studies reporting between-group
3 results for health-related outcomes, other than PA/SB, thirteen showed between group statistical
4 significance in at least one outcome.^{3, 4, 7, 10, 13, 18, 19, 38, 39, 43, 57, 64, 98}

5 Due to large variation in the outcome measures we grouped them into seven categories: pain,
6 function, psychological, quality of life, physical/functional performance, cardiovascular health/risk
7 factors and medication use. Table 7 displays the studies that had significant outcomes in each
8 category. Functional outcomes (self-report measures of physical function or disability) were the
9 most common, being measured in 18 studies. Psychological outcomes were significant at either
10 post-intervention, longer-term follow-up, or at both time-points in 58.3% of the studies where they
11 were measured; the highest of all outcome categories that were measured in two or more studies
12 (for details of outcomes see supplementary material).

13

14 **4. Discussion**

15 To our knowledge, this is the first systematic review and meta-analysis to evaluate immediate post-
16 intervention and longer-term follow-up for both PA and SB in full RCTs in people with persistent
17 musculoskeletal pain. For post-intervention PA, our meta-analysis of 21 outcomes showed a small
18 effect in favour of the interventions (Hedge's $g = 0.321$, CI 0.136 to 0.507, $p = 0.001$, very low
19 certainty evidence). Meta-analysis of twelve PA outcomes for longer-term follow-up showed no
20 effect (Hedge's $g = 0.197$, CI 0.061 to 0.332, $p = 0.005$, low certainty evidence). Few studies reported
21 SB outcomes and our meta-analysis of three outcomes for post-intervention and two for longer-term
22 follow-up showed no significant effect, with evidence rated as very low quality. Due to the quality of
23 evidence being very low or low, these results need to be interpreted with caution as the real effect
24 of PA and SB interventions could be different. Risk-of-bias was generally low for PA outcomes and
25 our sensitivity analysis including outcomes with low risk-of-bias only slightly reduced the effect size

1 for post-intervention PA. However, the effect size of our sensitivity analysis for PA at longer-term
2 follow-up increased to demonstrate a small effect. All studies including SB outcomes were judged as
3 low risk-of-bias.

4 This is the first systematic review and meta-analysis to investigate differences between self-selected
5 PA, non-self-selected PA and combinations of the two. Non-self-selected PA was the only PA type
6 that showed any effect. To our knowledge, this is also the only study to perform subgroup analysis of
7 PA outcomes by the nature of the interventions, the setting of PA and the method of intervention
8 delivery in this population. From our analysis, it appears that interventions that combine PA with
9 education are more effective than those that combine PA with counselling/coaching, those
10 combining PA with education and counselling and those with PA only. It also seems that
11 interventions combining supervised and unsupervised PA are more effective than supervised and
12 unsupervised alone, and those combining individual and group-based interventions are more
13 effective than those that are solely individual or group-based immediately post-intervention,
14 although the effect sizes remain small. Our analysis demonstrated a slightly higher effect size for
15 self-report outcomes only and showed no effect for objective outcomes only. Therefore, the
16 absolute magnitude of effect is likely to be smaller than the results shown in our main meta-analysis.
17 Lastly, to our knowledge this is the first study to do a thorough analysis of the impact of publication
18 bias on PA levels in people with persistent musculoskeletal pain. Our findings show that most of our
19 adjusted analyses originally underestimated the effect sizes. Meta-regression demonstrated that the
20 number of sessions did not moderate the effect size for post-intervention or longer-term follow-up
21 PA outcomes.

22 We performed an in-depth analysis of BCTs in the PA interventions by using an established
23 taxonomy⁶⁰ and method for estimating effectiveness.⁵⁸ There was substantial variation across
24 studies in which BCTs were included; we identified only three BCTs that were present in at least half
25 of the included studies. We found six BCTs that were present in more than half of the six studies

1 showing effectiveness for PA outcomes, however, only one of these had an effectiveness percentage
2 of 50%: 'action planning'. The other BCTs with effectiveness percentages of 50%, were 'goal setting
3 (outcome)', 'monitoring outcome(s) of behaviour by others without feedback' and 'feedback on
4 outcome(s) of behaviour'. The BCT 'adding objects to the environment' had an effectiveness
5 percentage of 67%, the highest in our study. An effectiveness percentage of 50% or above suggests
6 potential effectiveness, however, we cannot confidently conclude that they are likely to contribute
7 to a more effective intervention. Meta-regression showed that the number of BCTs did not
8 moderate the PA effect size at post-intervention or longer-term follow-up. We identified seven BCTs
9 in the one intervention that was aimed at reducing SB; a study that demonstrated effectiveness at
10 reducing SB.³

11 Ours is the first systematic review to examine the use of theory in PA and SB interventions for
12 people with persistent musculoskeletal pain and we judged use of theory using a common system.⁷³
13 The one study aiming to reduce SB was not theoretically based.³ Twelve of the 22 PA studies
14 reported using a theoretical foundation for their interventions.^{2, 4, 18, 19, 43, 46, 48, 57, 76, 84} Most of these
15 studies only applied theory in their intervention design.^{2, 4, 48, 57, 76} Three tested theory^{19, 43, 87} and one
16 built/created theory,⁶⁴ although this study did not demonstrate effectiveness for increasing PA
17 levels. Evidently, more theoretically based intervention studies are needed, especially studies which
18 test and develop theory.

19 Studies reported a broad range of non-PA/SB health-related outcomes. The most commonly
20 reported outcomes were in the function and pain categories. Psychological was the only outcome
21 category where more than 50% of the studies with these outcomes showed any significant between-
22 group changes, aside from cardiovascular health and risk factors which were only reported in one
23 study.

24 Several findings from our meta-analysis are comparable with similar previous reviews. Our results
25 demonstrated a small effect for PA outcomes immediately post-intervention but no effect at longer-

1 term follow-up. However, our sensitivity analysis including studies with low risk-of-bias only showed
2 a small effect for PA at longer-term follow-up, suggesting higher quality studies show results more in
3 favour of longer-term outcomes. Other studies of PA for people with persistent musculoskeletal pain
4 have examined differences in effects at different follow-up points. One systematic review and meta-
5 analysis reported a small significant effect at medium-term follow-up but no effect at long-term
6 follow-up²⁸ and another found no effect when using longest follow-up measures.¹⁰² Together, these
7 findings suggest the need to improve maintenance of PA after the intervention period.

8 Consistent with our findings, previous reviews also reported no significant effects for objectively
9 measured PA at any time point.^{55, 70} Also in line with our findings, one review⁵⁵ reported much lower
10 numbers of studies with objective outcomes compared with self-report, and their effects are also
11 higher for self-report. This is shared with another review¹⁰² which did not perform meta-analysis for
12 objective outcomes due to insufficient studies. Discrepancies between self-report and objective
13 measures of PA and SB have also been reported in a large population-based epidemiological study;
14 with participants reporting less sedentary time and higher levels of vigorous PA by self-report
15 compared with accelerometry.²⁶ It appears that self-report measures consistently overestimate PA
16 levels compared with objective measures. More studies are needed which use objective measures of
17 PA and SB, thereby overcoming the issues of recall and reporting bias with self-report.⁹⁶

18 Our risk-of-bias assessments were considerably different to similar systematic reviews and meta-
19 analyses.^{55, 102} Studies included in these reviews were mostly assessed as having bias due to lack of
20 blinding⁵⁵ and incomplete outcome data.¹⁰² A likely explanation for the differences in risk-of-bias
21 assessments is that we used the most recent version of Cochrane risk-of-bias tool (RoB2), which
22 recognises that unblinded trials and missing outcome data do not always lead to bias and
23 judgements are dependent on context.⁹¹ For example, it is often not possible to blind participants to
24 their intervention in PA trials, but these trials could still be of high scientific quality. In these
25 circumstances, the latest risk-of-bias tool allows a judgement of low risk-of-bias, whereas the

1 original Cochrane risk-of-bias tool would automatically have led to unblinded trials being judged as
2 high risk-of-bias.⁹¹ Furthermore, if the reasons for missing outcome data are unrelated to the
3 outcome being assessed (e.g. failure of a measuring device), then risk-of-bias can be assessed as low
4 using the latest risk-of-bias tool.⁹¹ The original Cochrane risk-of-bias tool would have led to these
5 situations being judged as high risk-of-bias.

6 We coded 31 different BCTs across all PA interventions included in our study. This is similar to
7 another similar review that reported 28 different BCTs in effective interventions and 31 in ineffective
8 interventions.⁵⁵ In contrast, another similar review²⁸ coded 43 different BCTs across all interventions.
9 The BCTs 'instruction on how to perform a behaviour' and 'behavioural practice/rehearsal' were two
10 of the most common BCTs in our review. This is consistent with other PA/exercise reviews of studies
11 of people with persistent musculoskeletal pain.^{11, 28, 55, 56, 101} These BCTs were also two of the most
12 common in the effective studies in our review. However, 'instruction on how to perform a
13 behaviour' had an effectiveness percentage of only 25% and 'behavioural practice/rehearsal' had an
14 effectiveness percentage of only 30%; suggesting that despite being often present in interventions,
15 they may not be essential components.

16 We found the BCT 'action planning' to have one of the highest effectiveness percentages (50%). This
17 BCT was also found to have the highest short-term effectiveness in a review of PA promotion for
18 lower limb osteoarthritis.¹⁰¹ In our study, the BCTs 'goal setting (outcome)', 'monitoring outcome(s)
19 of behaviour by others without feedback' and 'feedback on outcome(s) of behaviour' also had
20 effectiveness percentages of 50%. 'Goal setting (outcome)' and 'monitoring outcome(s) of behaviour
21 by others without feedback' were only present in four interventions and 'feedback on outcome(s) of
22 behaviour' was only present in two interventions in our review. The BCT with the highest
23 effectiveness percentage in our study, 'adding objects to the environment' (67%), was present in just
24 three interventions. These BCTs are also not reported as common BCTs in other similar reviews.
25 Perhaps these BCTs warrant further investigation, particularly as goal setting and environmental

1 changes are associated with behavioural maintenance.⁵⁰ Furthermore, only one BCT associated with
2 behavioural maintenance; 'self-monitoring of behaviour',⁵⁰ was used in more than half of the
3 included interventions.

4

5 *4.1 strengths and limitations*

6 This review has many strengths. The protocol was prospectively registered on the PROSPERO
7 database, we followed the PRISMA guidelines⁶² and multiple authors were involved in each stage of
8 the review. The use of the most recent Cochrane risk-of-bias tool is considered a strength due its
9 comprehensiveness, despite the tool showing low interrater reliability and challenges in its
10 application.⁶¹ These issues were mitigated by all the authors discussing application of the tool prior
11 to using it, using the detailed guide accompanying the tool and discussing any disagreements to
12 reach consensus.⁶¹ We used the established GRADE criteria to assess the quality of evidence. In
13 addition to standard meta-analysis techniques, we assessed the impact of publication bias and
14 performed adjusted analyses; the first study of PA interventions in this population to do this. This is
15 the first systematic review and meta-analysis to investigate differences in the nature of
16 interventions and between a number of intervention components: the type of PA, setting of PA and
17 method of delivery. Additionally, our in-depth analysis of BCTs allowed greater exploration of the
18 active components in interventions. This study also provides unique insights into the use of theory in
19 interventions and non-PA/SB health-related outcomes. We only included full RCTs and the majority
20 of studies in our review were low risk-of-bias.

21 We encountered substantial heterogeneity in the interventions and control groups. This is common
22 in both persistent pain and PA literature and is expected considering health behaviour change
23 interventions are often complex.⁶⁰ We followed the Cochrane reviewer's handbook to attempt to
24 disentangle this by conducting meta-regression analyses and subgroup analyses. However, the
25 variation in control group characteristics may have significant influence on results as an intervention

1 compared with an active control may show a smaller between group difference than an intervention
2 compared with an inactive control. Moreover, such variations in the nature, length and intensity of
3 interventions are likely to have influenced the results. This leads to uncertainty in study outcomes.
4 Length of follow-up also varied widely between studies. The outcome measures used, and type of
5 data derived from each outcome also varied greatly. Although the validity of the outcome measures
6 used was generally a strength, more standardisation and consistency, with use of objective
7 measures, would strengthen confidence in the meta-analysis findings. The type of PA may also have
8 considerable impact on the level of change detectable by certain outcome measures. For example,
9 accelerometry and outcomes measuring steps/day are likely to detect greater changes in PA in
10 walking interventions compared with strength-based interventions. This further leads to uncertainty
11 in the absolute effect of interventions.

12

13 Another limitation is the small number of studies in several of our subgroup analyses. There was only
14 one study with solely self-selected PA and three with a combination of self-selected and non-self-
15 selected PA. Considering activities that are enjoyable, that resemble individual's values and that are
16 personally relevant are more likely to result in maintenance of behaviour,⁵⁰ it seems important that
17 the choice of PA be driven by the participant.

18 Only three of the studies included power calculations and reported adequate power for PA
19 outcomes.^{2, 4, 84} Therefore, we cannot be sure if these studies were adequately powered to detect PA
20 outcomes and the results of this review should be interpreted with caution.

21 Several studies reported outcomes for SB, but the presence of only one study specifically aimed at
22 reducing SB is a concern considering the health detriments of sitting are independent of moderate to
23 vigorous PA.⁹⁰ This study was also limited by using only a self-report measure and having no follow-
24 up beyond the intervention period. With only one SB study we were unable to analyse potential
25 effectiveness of the BCTs for this outcome.

1 The key aim of our study was to analyse PA and SB outcomes. A secondary aim was to investigate
2 changes in non-PA/SB health-related outcomes. As this was a secondary aim, we did not perform
3 meta-analysis to quantitatively synthesise these outcomes. This limits the inferences we can make
4 from this data; specifically, we cannot assess the clinical relevance of these outcomes. Nonetheless,
5 it enabled us to highlight the most reported type of outcomes and how often these outcomes
6 demonstrated statistically significant results.

7 Lastly, we were unable to include all the identified relevant studies as our requests to obtain
8 additional data from six authors were unsuccessful. The inclusion of these studies could have
9 affected the results of this review.

10 *4.2 Implications for clinical practice*

11 Due to the heterogeneity of outcome measures and types of data collected, we were only able to
12 pool the PA and SB outcome data using the Hedge's g effect estimate. Therefore, we were unable to
13 determine the overall magnitude of change in PA levels and cannot infer clinical relevance of these
14 outcomes. In one of the studies showing statistically effective outcomes,⁷⁶ their intervention group
15 showed mean longer-term PA levels above 150 minutes/week of moderate to vigorous PA,
16 demonstrating health-enhancing levels of PA.¹⁶ For people with lower extremity joint problems, 45
17 mins of moderate to vigorous PA is the minimum threshold to improve low function or sustain high
18 function.²⁴ Three or more days a week of moderate or greater PA is recommended to enhance
19 function and reduce falls in older adults (≥ 65 years).¹⁶ This study included participants with knee and
20 hip osteoarthritis with a mean age of 65 years and reported a mean of five days doing ≥ 30 mins
21 moderate to vigorous PA in their intervention group at longer-term follow-up.⁷⁶ However, they did
22 not report functional outcomes so we cannot determine if their changes in PA led to clinically
23 relevant functional gains.

24 Another study reporting statistically effective increases in PA also reported mean PA levels of more
25 than 150 minutes/week in their intervention group.⁴³ However, this study only reported significant

1 functional improvements at post-intervention and not at longer-term follow-up. This study did not
2 report intensity of PA, so it is possible that PA intensity was insufficient to sustain gains. Neither of
3 these studies measured PA objectively, so it is possible their effect estimates may be overestimated.

4 We were unable to determine the clinical relevance of the other studies demonstrating statistical
5 effectiveness^{7, 19, 38, 98} due to the outcomes not translating to measurable PA levels or lacking
6 estimated minimal clinically important differences. To our knowledge, the PA levels required to
7 affect non-PA/SB outcomes, other than function, are not reported in people with persistent
8 musculoskeletal pain.

9 Our BCT effectiveness percentages are based on statistical significance. Therefore, we cannot
10 determine whether these BCTs are likely to lead to clinically effective outcomes.

11

12 *4.3 Implications for future research*

13 It is clear that there is a need for higher quality studies of interventions aimed at increasing PA and
14 reducing SB. Future research might benefit from adopting similar interventions that have been
15 demonstrated to be effective to enable better comparisons of their effectiveness. Trials need to be
16 adequately powered to detect changes in PA/SB and need longer-term follow-ups beyond the
17 intervention period. Intervention descriptions need to have sufficient detail for interventions to be
18 replicated,²² and the active components (e.g., BCTs) easily identified. This will allow better
19 investigation of potential mechanisms of action. We recommend that future research prioritises
20 using objective device-based PA/SB measures and report this in minutes per intensity level so this
21 can be compared in line with recommended guidelines such as the recent World Health Organization
22 guidelines. This would help clinical translation of research findings. Researchers should target PA
23 that is chosen by the participant in line with their values and what they enjoy. Identifying and/or
24 developing theory is a key step in developing complex interventions,²² and interventions would likely

1 benefit from better applying and building theory. Researchers should focus on incorporating BCTs or
2 strategies that focus specifically on maintenance of behaviour, as well as initial change.

3 We utilised a pre-registered definition of persistent musculoskeletal pain.^{74, 94} Similar to other
4 reviews^{28, 45, 55, 102} we did not include cancer and rheumatic pain as this would have further increased
5 heterogeneity in the samples. Thus, we recommend that future research is needed to explore this
6 issue in these specialist populations.

7 Finally, future research should identify the level of PA that is required to meaningfully affect broader
8 health outcomes in people with persistent musculoskeletal pain.

9

10

11 **5. Conclusion**

12 Increasing PA and reducing SB is challenging but essential for people with persistent musculoskeletal
13 pain due to the multitude of health benefits. Evidence suggests that interventions have a small
14 effect on PA levels immediately post-intervention but no effect at longer-term follow-up and no
15 effect on SB levels at any time point. However, these findings should be interpreted with caution and
16 clinical relevance of these effects could not be determined. Our findings suggest that PA combined
17 with education, combinations of supervised and unsupervised PA, and combinations of individual
18 and group-based interventions may be most beneficial. We identified several BCTs that may be of
19 benefit and warrant further exploration of their effectiveness. Despite the risk-of-bias being
20 generally low across studies, the quality of evidence is either low or very low. Higher quality studies
21 of theoretically-based interventions that target PA and SB, and that are well reported are needed in
22 order to be able to confidently guide clinical practice.

23

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2 Stubbs finalised the design and protocol. G. Booth conducted the search. G. Booth, A. Howarth and
3 M. Ussher completed the screening and study selection, data extraction and risk-of-bias
4 assessments. G. Booth and B. Stubbs conducted the data analysis, which was reviewed and
5 confirmed by A. Howarth and M. Ussher. G. Booth and M. Ussher performed the GRADE
6 assessments. All authors contributed to interpretation of the results. G. Booth wrote each version of
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10

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38 Figure Legend:

39 Figure 1: PRISMA Flow Diagram

40 Figure 2: Risk-of-bias assessments

41 Figure 3: Meta-analysis of post-intervention physical activity outcomes

42 Figure 4: Meta-analysis of longer-term follow-up physical activity outcomes

43 Figure 5: Meta-analysis of post-intervention sedentary behaviour outcomes

44 Figure 6: Meta-analysis of longer-term follow-up sedentary behaviour outcomes

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1 Table legend:

2 Table 1: Study, participant and intervention characteristics

3 Table 2: Main meta-analysis and subgroup analysis

4 Table 3: Summary of findings and quality of evidence (GRADE)

5 Table 4: Meta-regression

6 Table 5: Behaviour change techniques effectiveness percentages

7 Table 6: Behaviour change theory in studies

8 Table 7: Studies with significant health-related outcomes other than physical activity/sedentary
9 behaviour

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Table 1: Study, participant and intervention characteristics

First author/ Year	Study Design	Number of participants	Age (years) mean (SD)	Female (no./%)	Conditions (No./%)	Intervention description	Control description	Baseline physical activity levels: Mean (SD)	Physical activity/ Sedentary behaviour outcomes	Longest follow-up
Baker 2020	RCT	<u>Total:</u> 104 <u>Intervention:</u> 52 <u>Control:</u> 52	<u>Total:</u> 65.2 <u>Intervention:</u> 65.8 (6.6) <u>Control:</u> 64.5 (8.3)	<u>Total:</u> 85 (81.7%) <u>Intervention:</u> 42 (80.8%) <u>Control:</u> 43 (82.7%)	Knee OA <u>Total:</u> Knee OA N=94 (90.4%) Knee replacement N=10 (9.6%) <u>Intervention:</u> Knee OA N=48 (92.3%) Knee replacement N=4 (7.7%) <u>Control:</u> Knee OA N=46 (88.5%) Knee replacement N=6 (11.5%)	<u>Duration:</u> 24 months <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Resistive strength training + Computer-based telephone counselling <u>Method of delivery:</u> Individual + group-based <u>Setting of PA:</u> Supervised + unsupervised <u>Dose:</u> 54 sessions	<u>Duration:</u> 24 months <u>Description:</u> Resistive strength training + reminder text message	N/A	<u>PA:</u> Exercise adherence NRS	0
Barone Gibbs 2017	RCT	<u>Total:</u> 27 <u>Intervention:</u> 13 <u>Control:</u> 14	<u>Total:</u> 51.5 <u>Intervention:</u> 52 (9) <u>Control:</u> 51 (13)	<u>Total:</u> 21 (77.8%) <u>Intervention:</u> 11 (85%) <u>Control:</u> 10 (71%)	PLBP	<u>Duration:</u> 6 months <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Behavioural counselling, Sit-stand desk attachment, activity prompter + pain self-management <u>Method of delivery:</u> Individual <u>Setting of PA:</u> Unsupervised <u>Dose:</u> 7 sessions	<u>Duration:</u> 6 months <u>Description:</u> No intervention	<u>Overall:</u> Min/week: 191 <u>Intervention:</u> Min/week: 190 (163) <u>Control:</u> Min/week: 191 (175)	<u>PA:</u> Min/week doing MVPA (GPAQ) SB: Hour/day sitting (GPAQ)	0
Basler 2007	RCT	<u>Total:</u> 170 <u>Intervention:</u> 86 <u>Control:</u> 84	<u>Total:</u> 70.3 (4.4) <u>Intervention:</u> 70.09 (4.19) <u>Control:</u> 70.56 (4.55)	<u>Total:</u> 109 (64%) <u>Intervention:</u> 54 (62.8%) <u>Control:</u> 55 (65.5%)	PLBP	<u>Duration:</u> 5 weeks <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> 10 mins counselling + physiotherapy (including exercise) <u>Method of delivery:</u> Individual <u>Setting of PA:</u> Supervised	<u>Duration:</u> 5 weeks <u>Description:</u> Physiotherapy treatment + placebo ultrasound	<u>Overall:</u> Min/day: 15 <u>Intervention:</u> Min/day: 15.98 <u>Control:</u> Min/day: 14.11	<u>PA:</u> Min/day (7-day activity diary)	5 months

						<u>Dose:</u> 20 sessions				
Bennell 2014	RCT	<u>Total:</u> 78 <u>Intervention:</u> 40 <u>Control:</u> 38	<u>Total:</u> 62.1 (6.9) <u>Intervention:</u> 60.5 (6.6) <u>Control:</u> 63.7 (7)	<u>Total:</u> 42 (53.8%) <u>Intervention:</u> 24 (60%) <u>Control:</u> 18 (47%)	Knee OA	<u>Duration:</u> 16 weeks <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Prescribed HEP + 2 physiotherapy booster sessions <u>Method of delivery:</u> Individual <u>Setting of PA:</u> Supervised <u>Dose:</u> 2 sessions	<u>Duration:</u> 0 weeks <u>Description:</u> Advice to do HEP	N/A	<u>PA:</u> Exercise adherence NRS	8 weeks
Bennell 2017	RCT	<u>Total:</u> 168 <u>Intervention:</u> 84 <u>Control:</u> 84	<u>Total:</u> 62.25 <u>Intervention:</u> 61.1 (6.9) <u>Control:</u> 63.4 (7.8)	<u>Total:</u> 106 (63%) <u>Intervention:</u> 57 (68%) <u>Control:</u> 49 (58%)	Knee OA	<u>Duration:</u> 6 months <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Physiotherapy exercise prescription + concurrent telephone coaching <u>Method of delivery:</u> Individual <u>Setting of PA:</u> Supervised + unsupervised <u>Dose:</u> 11 sessions	<u>Duration:</u> 6 months <u>Description:</u> Physiotherapy exercise prescription	<u>Overall:</u> Step/day: 7998 <u>Intervention:</u> Step/day: 8116 <u>Control:</u> Step/day: 7879	<u>PA:</u> PASE AAS Step/day (7-day Accelerometry) Exercise adherence NRS	<u>PASE:</u> 12 months Step/day (7-day Accelerometry): 0
Bieler 2017 (Strength training)	RCT	<u>Total:</u> 152 <u>Intervention:</u> 50 <u>Control:</u> 52	<u>Total:</u> 69.6 <u>Intervention:</u> 69.6 (5.4) <u>Control:</u> 69.3 (6.4)	<u>Total:</u> 103 (67.8%) <u>Intervention:</u> 34 (68%) <u>Control:</u> 36 (69%)	Hip OA	<u>Duration:</u> 12 months <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Progressive strength training, PA/OA education + PA counselling <u>Method of delivery:</u> Individual + group-based <u>Setting of PA:</u> Supervised + unsupervised <u>Dose:</u>	<u>Duration:</u> 0 months <u>Description:</u> 1 session: Advised to do home exercises as per Danish Arthritis Association	<u>Overall:</u> PASE: 122 <u>Intervention:</u> PASE: 140 (64.7) <u>Control:</u> PASE: 119 (55.2)	<u>PA:</u> PASE VPA (0-5 Likert scale) CCHS	0

						53 sessions				
Bieler 2017 (Nordic walking)	RCT	<u>Total:</u> 152 <u>Intervention:</u> 50 <u>Control:</u> 52	<u>Total:</u> 69.6 <u>Intervention:</u> 70 (6.3) <u>Control:</u> 69.3 (6.4)	<u>Total:</u> 103 (67.8%) <u>Intervention:</u> 33 (66%) <u>Control:</u> 36 (69%)	Hip OA	<u>Duration:</u> 12 months <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Nordic walking, PA/OA education + PA counselling <u>Method of delivery:</u> Individual + group-based <u>Setting of PA:</u> Supervised + unsupervised <u>Dose:</u> 53 sessions	<u>Duration:</u> 0 months <u>Description:</u> 1 session: Advised to do home exercises as per Danish Arthritis Association	<u>Overall:</u> PASE: 122 <u>Intervention:</u> PASE: 107 (47.3) <u>Control:</u> PASE: 119 55.2)	<u>PA:</u> PASE VPA (0-5 Likert scale) CCHS	0
Bossen 2013	RCT	<u>Total:</u> 199 <u>Intervention:</u> 100 <u>Control:</u> 99	<u>Total:</u> 62 (5.7) <u>Intervention:</u> 61 (5.9) <u>Control:</u> 63 (5.4)	<u>Total:</u> 129 (64.8%) <u>Intervention:</u> 60 (60%) <u>Control:</u> 69 (69.7%)	<u>Overall:</u> Knee OA N=127 (63.8%) Hip OA N=41 (20.6%) Knee and hip OA N=31 (15.6%) <u>Intervention:</u> Knee OA N=67 (67%) Hip OA N=21 (21%) Knee and Hip OA N=12 (12%) <u>Control:</u> Knee OA N=60 (60.6%) Hip OA N=20 (20.2%) Knee and hip OA N=19 (19.2%)	<u>Duration:</u> 9 weeks <u>Type of PA:</u> Self-selected <u>Specific activities:</u> 'Join2move': modular web-based focused on time-contingent gradual PA increase <u>Method of delivery:</u> Individual <u>Setting of PA:</u> Unsupervised <u>Dose:</u> 9 modules	<u>Duration:</u> N/A <u>Specific Description:</u> Waiting list	<u>Overall:</u> Min/day: 382 <u>Intervention:</u> Min/day: 369 <u>Control:</u> Min/day: 395	<u>PA:</u> PASE Min/day (accelerometry) <u>SB:</u> Min/day (accelerometry)	10 months
Cederbom 2019	RCT	<u>Total:</u> 105 <u>Intervention:</u> 52 <u>Control:</u> 53	<u>Total:</u> 85 (6.1) <u>Intervention:</u> 85.2 (5.6) <u>Control:</u> 85.4 (6.7)	<u>Total:</u> 91 (87.6%) <u>Intervention:</u> 48 (92.3%) <u>Control:</u> 49 (93%)	Chronic MSK pain (unspecified location)	<u>Duration:</u> 12 weeks <u>Type of PA:</u> Self-selected and non-self-selected <u>Specific activities:</u> In-person physiotherapy + supportive telephone call <u>Method of delivery:</u> Individual <u>Setting of PA:</u>	<u>Duration:</u> 10 weeks <u>Description:</u> Standard care	<u>Overall:</u> Grimby-Frandin: 2.4 <u>Intervention:</u> Grimby-Frandin: 2.4 (0.7) <u>Control:</u> Grimby-Frandin: 2.4 (0.8)	<u>PA:</u> Grimby-Frandin Scale	12 weeks

						Supervise + unsupervised <u>Dose:</u> 10 sessions				
Chen 2020	Cluster-RCT	<u>Total:</u> 161 <u>Intervention:</u> 89 <u>Control:</u> 72	<u>Total:</u> 68.9 (7.35) <u>Intervention:</u> 67.09 (7.7) <u>Control:</u> 68.71 (6.69)	<u>Total:</u> 149 (92.5) <u>Intervention:</u> 81 (91%) <u>Control:</u> 68 (94.4%)	<u>Overall</u> Knee OA: Unilateral N=80 (49.7%) Knee OA Bilateral N=81 (50.3%) <u>Intervention:</u> Knee OA: Unilateral N=47 (62.8%) Bilateral N=42 (47.2%) <u>Control:</u> Knee OA Unilateral N=33 (45.8%) Bilateral N=39 (54.2%)	<u>Duration:</u> 24 weeks <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Balance, strengthening and range of movement exercises; group education, education handouts, TTM stage-based advice <u>Method of delivery:</u> Individual + group-based <u>Setting of PA:</u> Supervised + unsupervised <u>Dose:</u> 9 sessions	<u>Duration:</u> 12 weeks <u>Description:</u> HEP including intermittent review sessions	N/A	<u>PA:</u> Exercise adherence NRS	0
Farr 2010	RCT	<u>Total:</u> 171 <u>Intervention:</u> 114 <u>Control:</u> 57	<u>Total:</u> 55.1 (7.1) <u>Intervention:</u> 54.7 (7.3) <u>Control:</u> 55.8 (6.1)	<u>Total:</u> 128 (74%) <u>Intervention:</u> 87 (76%) <u>Control:</u> 41 (72%)	Knee OA	<u>Duration:</u> 9 months <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Resistance training, classroom-based self-management advice + telephone programme to reinforce skills <u>Method of delivery:</u> Individual and group-based <u>Setting of PA:</u> Supervised <u>Dose:</u> 36 sessions	<u>Duration:</u> 9 months <u>Description:</u> Classroom-based self-management advice + telephone programme to reinforce skills	<u>Overall:</u> Min/day: 25.8 <u>Intervention:</u> Min/day: 27.4 (19.4) <u>Control:</u> 24.2 (19.3)	<u>PA:</u> Min/day (≥ 3 METs) (accelerometry)	0
Hinman 2007	RCT	<u>Total:</u> 71 <u>Intervention:</u> 36 <u>Control:</u> 35	<u>Total:</u> 62.4 <u>Intervention:</u> 63.3 (9.5) <u>Control:</u> 61.5 (7.8)	<u>Total:</u> 48 (67.6%) <u>Intervention:</u> 24 (67%) <u>Control:</u> 24 (69%)	<u>Overall:</u> Knee OA N=55 (77%) Hip OA N=16 (23%) <u>Intervention:</u> Knee OA N=31 (86%) Hip OA N=5 (14%) <u>Control:</u>	<u>Duration:</u> 6 weeks <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Aquatic physiotherapy, written handouts + information on local pools <u>Method of delivery:</u>	<u>Duration:</u> 0 weeks <u>Description:</u> Advice to continue with normal activities	<u>Overall:</u> PASE: 159 <u>Intervention:</u> PASE: 165 (80) <u>Control:</u> PASE: 153 (79)	<u>PA:</u> PASE	0

					Knee OA N=24 (69%) Hip OA N=11 (31%)	Group-based <u>Setting of PA:</u> Supervised + unsupervised <u>Dose:</u> 12 sessions				
Hinman 2020	RCT	<u>Total:</u> 175 <u>Intervention:</u> 88 <u>Control:</u> 87	<u>Total:</u> 62.5 <u>Intervention:</u> 62.4 (9.1) <u>Control:</u> 62.5 (8.1)	<u>Total:</u> 110 (63%) <u>Intervention:</u> 55 (63%) <u>Control:</u> 55 (63%)	Knee OA	<u>Duration:</u> 6 months <u>Type of PA:</u> Self-selected and non-self-selected <u>Specific activities:</u> Strengthening exercises, general PA (unspecified) and support with developing an action plan delivered via phone consultations with physical therapists. Also received existing care from the Musculoskeletal Help Line in Victoria, Australia, and website with exercise videos. <u>Method of delivery:</u> Individual <u>Setting of PA:</u> Unsupervised <u>Dose:</u> 7 sessions	<u>Duration:</u> 1 session <u>Description:</u> Existing care from the Musculoskeletal Help Line in Victoria, Australia. Provides information on OA, treatments, self-management strategies, navigation of care pathways and linkages to community services	<u>Overall:</u> PASE: 167 <u>Intervention:</u> PASE: 170 (91) <u>Control:</u> PASE: 163 (81)	<u>PA:</u> PASE	6 months
Hughes 2006	RCT	<u>Total:</u> 215 <u>Intervention:</u> 115 <u>Control:</u> 100	<u>Total:</u> 73.4 <u>Intervention:</u> 73.3 <u>Control:</u> 73.4	<u>Total:</u> 179 (83.3%) <u>Intervention:</u> 93 (80.6%) <u>Control:</u> 86 (85.9%)	Knee or hip OA (participant numbers unspecified)	<u>Duration:</u> 8 weeks <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Walking, strengthening exercises + education <u>Method of delivery:</u> Individual + group-based <u>Setting of PA:</u> Supervised + unsupervised <u>Dose:</u> 24 sessions	<u>Duration:</u> 0 weeks <u>Description:</u> Given Arthritis Helpbook, list of exercise programmes in the community + self-care materials/ handouts	<u>Overall:</u> Min/week: 128.91 <u>Intervention:</u> Min/week: 135.27 (145.11) <u>Control:</u> Min/week: 122.55 (128.05)	<u>PA:</u> Min/week exercising (self-report)	10 months

Kloek 2018	Cluster-RCT	<u>Total:</u> 208 <u>Intervention:</u> 109 <u>Control:</u> 99	<u>Total:</u> 63.1 <u>Intervention:</u> 63.8 (8.5) <u>Control:</u> 62.3 (8.9)	<u>Total:</u> 141 (67.8%) <u>Intervention:</u> 74 (67.9%) <u>Control:</u> 67 (67.7%)	<u>Overall:</u> Knee OA N=138 (66.3%) Hip OA N=38 (18.3%) Knee and hip OA N=32 (15.4%) <u>Intervention:</u> Knee OA N=71 (65.1%) Hip OA N=21 (19.3%) Knee and Hip OA N=17 (15.6) <u>Control:</u> Knee OA N=67 (67.6%) Hip OA N=17 (17.2%) Knee and hip OA N=15 (15.2%)	<u>Duration:</u> 12 weeks <u>Type of PA:</u> Self-selected + non-self-selected <u>Specific activities:</u> Physiotherapy prescribed exercise, self-selected PA + online E-exercise graded activity modules <u>Method of delivery:</u> Individual <u>Setting of PA:</u> Supervised + unsupervised <u>Dose:</u> 5 in-person 11 online modules	<u>Duration:</u> Not reported <u>Description:</u> Usual care	<u>Overall:</u> Min/day MVPA (accelerometry): 23.9 <u>Intervention:</u> Min/day MVPA (accelerometry): 25.2 (23.1) <u>Control:</u> Min/day MVPA (accelerometry): 22.5 (21.8)	<u>PA:</u> Min/day doing MVPA (SQUASH) Min/day doing MVPA (accelerometry) <u>SB:</u> Min/day (accelerometry)	9 months
Krein 2013	RCT	<u>Total:</u> 229 <u>Intervention:</u> 111 <u>Control:</u> 118	<u>Total:</u> 51.6 <u>Intervention:</u> 51.2 (12.5) <u>Control:</u> 51.9 (12.8)	<u>Total:</u> 28 (12.2%) <u>Intervention:</u> 12 (11%) <u>Control:</u> 16 (14%)	PLBP	<u>Duration:</u> 12 months <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Walking-based, internet-based providing goal setting and feedback on pedometer data + e-community with fellow participants <u>Method of delivery:</u> Individual <u>Setting of PA:</u> Unsupervised <u>Dose:</u> N/A	<u>Duration:</u> N/A <u>Description:</u> Enhanced usual care – usual care + use of pedometer	<u>Overall:</u> Step/day: 4407.4 <u>Intervention:</u> Step/day: 4492.9 (2749.9) <u>Control:</u> Step/day: 4321.9 (2285.4)	<u>PA:</u> Step/day (pedometer)	0
Lang 2021	RCT	<u>Total:</u> 174 <u>Intervention:</u> 117 <u>Control:</u> 57	<u>Total:</u> 46 (16.5) <u>Intervention:</u> 47.1 (16.1) <u>Control:</u> 43.7 (17.2)	<u>Total:</u> 104 (60.1%) <u>Intervention:</u> 67 (57.8%) <u>Control:</u> 37 (64.9%)	PLBP	<u>Duration:</u> 12 weeks <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Personalised pedometer driven walking programme and a standard package of education about PA. <u>Method of delivery:</u> Individual <u>Setting of PA:</u> Unsupervised <u>Dose:</u> 13 sessions	<u>Duration:</u> 1 week <u>Description:</u> Standard package of education about PA.	<u>Overall:</u> MET-min/week: 3046 (3910.9) <u>Intervention:</u> MET-min/week: 2836.3 (3501.5) <u>Control:</u> MET-min/week: 3461 (4623.1)	<u>PA:</u> MET-min/week (IPAQ)	9 months

Meng 2011	RCT	<u>Total:</u> 360 <u>Intervention:</u> 187 <u>Control:</u> 173	<u>Total:</u> 49.9 (7.6) <u>Intervention:</u> 50.2 (7.6) <u>Control:</u> 49.5 (7.7)	<u>Total:</u> 231 (64.2%) <u>Intervention:</u> 122 (65.2%) <u>Control:</u> 109 (63%)	PLBP	<u>Duration:</u> Not reported <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> New back school with education and exercise practice <u>Method of delivery:</u> Group-based <u>Setting of PA:</u> Supervised <u>Dose:</u> 7 sessions	<u>Duration:</u> Not reported <u>Description:</u> Traditional back school (usual care) – 1 less session than intervention group	<u>Overall:</u> Hour/week: 7.05 <u>Intervention:</u> Hour/week: 7.33 (4.85) <u>Control:</u> Hour/week: 6.76 (4.27)	<u>PA:</u> Hour/week (Freiburg Questionnaire on Physical Activity)	12 months (from baseline)
Nelligan 2021	RCT	<u>Total:</u> 206 <u>Intervention:</u> 103 <u>Control:</u> 103	<u>Total:</u> 60 (8.4) <u>Intervention:</u> 60.3 (8.2) <u>Control:</u> 59 (8.5)	<u>Total:</u> 126 (61%) <u>Intervention:</u> 60 (58%) <u>Control:</u> 66 (64%)	Knee OA	<u>Duration:</u> 24 weeks <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Home-based lower limb strengthening exercise programme, general PA (unspecified) and education accessed on a website, and automated text message support <u>Method of delivery:</u> Individual <u>Setting of PA:</u> Unsupervised <u>Dose:</u> 17 sessions	<u>Duration:</u> <u>Description:</u> Education via a website about PA for people with OA	<u>Overall:</u> PASE: 141.45 <u>Intervention:</u> PASE: 146.9 (71.7) <u>Control:</u> PASE: 136 (68.2)	<u>PA:</u> PASE	0
Pisters 2010	Cluster-RCT	<u>Total:</u> 200 <u>Intervention:</u> 97 <u>Control:</u> 103	<u>Total:</u> 65 <u>Intervention:</u> 65 (7) <u>Control:</u> 65 (8)	<u>Total:</u> 154 (77%) <u>Intervention:</u> 73 (75%) <u>Control:</u> 81 (79%)	<u>Overall:</u> Knee OA N=130 (65%) Hip OA N=50 (25%) Knee and hip OA N=20 (10%) <u>Intervention:</u> Knee OA N=67 (69%) Hip OA N=22 (23%) Knee and Hip OA N=8 (8%) <u>Control:</u> Knee OA N=63 (61%) Hip OA N=28 (27%)	<u>Duration:</u> 55 weeks <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Exercise and functional activities, behavioural graded activity programme – time + booster sessions to foster integration into daily lives <u>Method of delivery:</u> Individual <u>Setting of PA:</u> Supervised + unsupervised	<u>Duration:</u> 12 weeks <u>Description:</u> Usual care	<u>Overall:</u> Day/week ≥30 mins MVPA: 4.3 <u>Intervention:</u> Day/week ≥30 mins MVPA: 4.6 (2.7) <u>Control:</u> Day/week ≥30 mins MVPA: 3.9 (2.9)	<u>PA:</u> Day/week performing ≥30 mins MVPA (SQUASH)	10 weeks

					Knee and hip OA N=12 (12%)	<u>Dose:</u> 25 sessions				
Schaller 2017	RCT	<u>Total:</u> 412 <u>Intervention:</u> 201 <u>Control:</u> 211	<u>Total:</u> 50.4 <u>Intervention:</u> 49.7 (8.3) <u>Control:</u> 51.1 (7.8)	<u>Total:</u> 126 (30.6%) <u>Intervention:</u> 58 (28.9%) <u>Control:</u> 68 (32.2%)	PLBP	<u>Duration:</u> 12 months <u>Type of PA:</u> Self-selected <u>Specific activities:</u> 'Movement coaching': Multi-level including In-person group sessions, telephone aftercare + online resources platform <u>Method of delivery:</u> Individual + group-based <u>Setting of PA:</u> Unsupervised <u>Dose:</u> 5 sessions	<u>Duration:</u> 3 weeks <u>Description:</u> Two PA education lectures	<u>Overall:</u> MET-min/week: 7260 <u>Intervention:</u> MET-min/week: 7654 (8527) <u>Control:</u> MET-min/week: 6865 (8779)	<u>PA:</u> MET-min/week (GPAQ)	0
Semrau 2021	RCT	<u>Total:</u> 361 <u>Intervention:</u> 176 <u>Control:</u> 175	<u>Total:</u> 51 (7.4) <u>Intervention:</u> 51.24 (7.4) <u>Control:</u> 51 (7.4)	<u>Total:</u> 257 (79%) <u>Intervention:</u> 124 (75.8%) <u>Control:</u> 133 (81.7%)	PLBP	<u>Duration:</u> 4 weeks <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Biopsychosocial rehabilitation programme for PLBP and Behaviour Exercise Therapy for promotion of PA behaviour. Included a range of exercise types (e.g. mobility, strengthening, walking) <u>Method of delivery:</u> Group-based <u>Setting of PA:</u> Combination <u>Dose:</u> 32 sessions	<u>Duration:</u> 4 weeks <u>Description:</u> Biopsychosocial rehabilitation programme for PLBP and Standard Exercise Therapy	<u>Overall:</u> Hour/week: 7.28 <u>Intervention:</u> Hour/week: 6.73 (7.47) <u>Control:</u> 7.82 (10.63)	<u>PA:</u> Hour/week (Freiburg Questionnaire on Physical Activity)	11 months
Wallis 2017	RCT	<u>Total:</u> 46 <u>Intervention:</u> 23	<u>Total:</u> 67.5 <u>Intervention:</u> 68 (8)	<u>Total:</u> 20 (43.5%) <u>Intervention:</u> 9 (39%)	<u>Overall</u> Knee OA: Unilateral N=20 (43.5%) Bilateral N=26 (56.5%)	<u>Duration:</u> 12 weeks <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u>	<u>Duration:</u> N/A <u>Description:</u> Usual care	<u>Overall:</u> Min/day walking: 76 <u>Intervention:</u>	<u>PA:</u> Step/day (accelerometry)	0

		<u>Control:</u> 23	<u>Control</u> 67 (7)	<u>Control:</u> 11 (48%)	<u>Intervention:</u> Knee OA: Unilateral N=9 (39%) Bilateral N=14 (61%) <u>Control:</u> Knee OA Unilateral N=11 (48%) Bilateral N=12 (52%)	Community-based walking programme, physiotherapy + usual care <u>Method of delivery:</u> Individual + group-based <u>Setting of PA:</u> Supervised + unsupervised <u>Dose:</u> Not reported		Min/day walking: 85 (40) <u>Control:</u> Min/day walking: 67 (28)	Min/day walking (accelerometry) SB: Hour/day sitting or lying (accelerometry)	
Zacharia 2018	RCT	<u>Total:</u> 20 <u>Intervention:</u> 10 <u>Control:</u> 10	<u>Total:</u> 57 (4.1) <u>Intervention:</u> Not reported <u>Control:</u> Not reported	Not reported	Lower limb OA (hip, knee, ankle or feet) (participant numbers unspecified)	<u>Duration:</u> 12 weeks <u>Type of PA:</u> Non-self-selected <u>Specific activities:</u> Yoga programme + relapse prevent programme – emails and phone calls <u>Method of delivery:</u> Individual + group-based <u>Setting of PA:</u> Supervised + unsupervised <u>Dose:</u> 20 sessions	<u>Duration:</u> 8 weeks <u>Description:</u> Yoga programme	<u>Overall:</u> MET-min/week: 3295.1 <u>Intervention:</u> MET-min/week: 3094.3 (1696.9) <u>Control:</u> MET-min/week: 3495.9 (2023.7)	<u>PA:</u> MET-min/week (IPAQ)	0
<p>Key: AAS = Active Australia Survey; CCHS = Copenhagen City Heart Study; CV = cardiovascular; GPAQ = Global Physical Activity Questionnaire; HEP = Home exercise programme; IPAQ = International Physical Activity Questionnaire; MET = Metabolic Equivalents; MVPA = moderate-vigorous physical activity; NRS = Numerical Rating Scale; OA = osteoarthritis; PA = physical activity; PASE = Physical Activity Scale for the Elderly; PLBP = persistent low back pain; RCT = randomised controlled trial; SB = sedentary behaviour; SD = standard deviation; SQUASH = Short Questionnaire to Assess Health-Enhancing Physical Activity; TTM = Transtheoretical model; VPA = Vigorous physical activity</p> <p>Bold outcomes = used in meta-analyses</p> <p>Longest follow-up time = time since end of intervention, 0 = no other follow-up except immediate post-intervention</p>										

Table 2: Main meta-analysis and subgroup meta-analysis

Analysis	Number of trials/ outcomes	Meta-analysis			Heterogeneity I ²	Trim and fill effect size (95% CI) [adjusted studies]	Classic fail-safe N
		Hedge's g	95% CI	p-value			
Meta-analysis							
Intervention vs control PA outcomes post- intervention	21	0.321	0.136 – 0.507	0.001	82.947	0.456 (0.274 – 0.637) [6]	302
Intervention vs control PA outcomes longer-term follow-up	12	0.197	0.061 – 0.332	0.005	59.039	0.242 (0.110 – 0.373) [2]	49
Intervention vs control SB outcomes post- intervention	3	-0.203	-0.702 – 0.295	0.424	63.965	Unchanged	0
Intervention vs control SB outcomes longer-term follow-up	2	0.011	-0.183 – 0.204	0.914	0	NA	NA
Subgroup analysis – PA outcomes							
Low risk of bias							
Post-intervention	16	0.257	0.115 – 0.399	0.000	64.543	0.363 (0.208 – 0.518) [4]	124
Longer-term follow-up	10	0.202	0.045 – 0.360	0.012	66.312	0.227 (0.073 – 0.381) [1]	38
Outcome measure type (post-intervention)							
Self-report	16	0.350	0.113 – 0.586	0.004	85.344	0.490 (0.271 – 0.708) [5]	208
Objective	5	0.191	-0.039 – 0.420	0.103	60.362	Unchanged	4
Nature of the intervention (post-intervention)							
PA + counselling/coaching	9	0.121	-0.007 – 0.249	0.064	28.274	-0.020 (-0.172 – 0.132) [4]	4
PA + education	4	0.749	0.003 – 1.495	0.049	95.535	Unchanged	77
PA + education + counselling	6	0.216	0.064 – 0.369	0.006	0	Unchanged	6
PA only	2	0.586	-0.016 – 1.188	0.056	60.369	NA	NA
Type of PA (post-intervention)							
Self-selected	1	-0.057	-0.250 – 0.135	0.560	NA	NA	NA
Non-self-selected	17	0.384	0.158 – 0.610	0.001	83.452	0.495 (0.284 – 0.706) [4]	273
Self-selected and non-self- selected	3	0.118	-0.061 – 0.298	0.196	0	-0.002 (-0.183 – 0.180) [2]	0
Setting of PA (post-intervention)							
Supervised	3	0.262	0.061 – 0.464	0.011	0	Unchanged	2

Unsupervised	6	0.069	-0.051 – 0.188	0.261	3.216	0.007 (-0.121 – 0.125) [3]	0
Supervised and unsupervised	12	0.447	0.130 – 0.764	0.006	87.809	0.600 (0.310 – 0.901) [3]	180
Method of delivery (post-intervention)							
Individual	11	0.177	0.079 – 0.276	0.000	0	0.104 (0.008 – 0.199) [4]	9
Group-based	1	0.309	-0.154 – 0.772	0.190	NA	NA	NA
Individual and group-based	9	0.491	0.054 – 0.927	0.028	92.159	0.668 (0.223 – 1.113) [2]	115
Key: CI = confidence interval; NA = not applicable;							

Table 3: Summary of findings and quality of evidence (GRADE)

Outcome	No. of participants (studies)	Hedge's g effect size (95% CI)	Quality of the evidence (GRADE)
Physical activity post-intervention	3,008 (21)	0.321 (0.136 to 0.507)	⊕○○○ VERY LOW ¹² Due to inconsistency and imprecision
Physical activity longer-term follow-up	2,152 (12)	0.197 (0.061 to 0.332)	⊕⊕○○ LOW ¹³ Due to inconsistency and imprecision
Sedentary behaviour post-intervention	280 (3)	-0.203 (-0.702 to 0.295)	⊕○○○ VERY LOW ¹⁴⁵ Due to indirectness, inconsistency and imprecision
Sedentary behaviour longest follow-up	407 (2)	0.011 (-0.183 to 0.204)	⊕○○○ VERY LOW ⁴⁵ Due to indirectness and imprecision

Key: CI = confidence interval; ES = effect size; PA = physical activity; ROB = Risk-of-bias; SB = sedentary behaviour

GRADE Working Group grades of evidence

High quality: Further research is very unlikely to change our confidence in the estimate of effect

Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate

Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.

Very low quality: We are very uncertain about the estimate.

Footnotes/reasons for downgrading

¹ Downgraded by one level for inconsistency due to high ($\geq 50\%$ I²) heterogeneity

² Downgraded by two levels for imprecision due to the lower CI including no effect, presence of small studies and the ES was derived from four studies of which one had concerns over ROB, and one was a small study

³ Downgraded by one for imprecision as lower CI includes no effect and the ES derived from three studies

⁴ Downgraded by one for indirectness as >50% studies are not aimed at reducing SB

⁵ Downgraded by two for imprecision as CI included no effect

Table 4: Meta-regression of moderators of physical activity outcomes

Moderator	Number of trials	β	95% CI	p-value	R ²
Number of BCTs					
Post-intervention	21	0.0216	-0.0520 – 0.0952	0.5650	0.00
Longer-term follow-up	12	0.0267	-0.0126 – 0.0659	0.1828	0.12
Number of sessions					
Post-intervention	19	-0.0031	-0.0155 – 0.0092	0.6178	0.00
Longer-term follow-up	11	0.0095	-0.0060 – 0.0249	0.2304	0.07
Key: β = beta coefficient; BCT = behaviour change technique; CI = confidence interval					

Table 5: Frequency and effectiveness percentages for behaviour change techniques used in physical activity interventions

BCT number	BCT label	Number of interventions present in	Effective interventions present in	Effectiveness percentages (physical activity)	Number of controls present in
1.1	Goal setting (behaviour)	9	3	33%	1
1.2	Problem solving	9	3	33%	2
1.3	Goal setting (outcome)	4	2	50%	1
1.4	Action planning	8	4	50%	0
1.5	Review behaviour goal(s)	2	1	NA	0
1.8	Behavioural contract	1	1	NA	0
2.1	Monitoring of behaviour by others without feedback	2	0	0%	1
2.2	Feedback on behaviour	6	2	33%	1
2.3	Self-monitoring of behaviour	14	5	36%	2
2.4	Self-monitoring of outcome(s) of behaviour	6	1	17%	0
2.5	Monitoring outcome(s) of behaviour by others without feedback	4	2	50%	1
2.7	Feedback on outcome(s) of behaviour	2	1	50%	0
3.1	Social support (unspecified)	10	1	10%	1
3.3	Social support (emotional)	1	0	NA	0
4.1	Instruction on how to perform a behaviour	20	5	25%	11
5.1	Information about health consequences	10	1	10%	8
5.2	Salience of consequences	1	1	NA	

5.4	Monitoring of emotional consequences	1	0	NA	
6.1	Demonstration of the behaviour	11	4	37%	3
7.1	Prompts/cues	3	1	33%	2
8.1	Behavioural practice/rehearsal	10	3	30%	4
8.7	Graded tasks	6	2	33%	0
9.1	Credible source	19	6	32%	12
9.2	Pros and cons	1	0	NA	
10.3	Non-specific reward	1	0	NA	0
10.4	Social reward	1	1	NA	0
11.1	Pharmacological support	1	0	NA	1
11.2	Reduce negative emotions	1	0	NA	1
12.5	Adding objects to the environment	3	2	67%	0
12.6	Body changes	1	0	NA	0
13.2	Framing/reframing	2	0	0%	1

Key: BCT = behaviour change technique; NA = not applicable; PA = physical activity

Table 6: Behaviour change theory in studies

Study	Theory and use
Baker 2020	Social Cognitive Theory (2 – applied theory) Self-efficacy theory (2 – applied theory) Transtheoretical Model (2 – applied theory)
Basler 2007	Transtheoretical Model (2 – applied theory)
Cederbom 2019	Operant Conditioning (1 – Informed by theory) Self-efficacy theory (1 – informed by theory)
Chen 2020 (effective)	Transtheoretical Model (3 – tested theory)
Hughes 2006 (effective)	Social Cognitive Theory (3 – tested theory)
Kloek 2018	Goal Setting Theory (1 – informed by theory)
Krein 2013	Social Cognitive Theory (2 – applied theory)
Meng 2011	Health Action Process Approach (2 – applied theory)
Nelligan 2021	Capability-Opportunity-Motivation-Behaviour model and Theoretical Domains Framework (4 – building or creating theory)
Pisters 2010 (effective)	Operant conditioning (2 – applied theory)
Schaller 2017	Rubicon Model of Action Phases (1 – informed by theory)
Semrau 2021	Health Action Process Approach (3 – tested theory)

Table 7: Studies with significant health-related outcomes other than physical activity/sedentary behaviour

Outcome measure category	Number of studies assessing	Studies with Significant outcomes (p<0.05)
Pain	16	Total: 5 (31.25%) Study name (measurement point): <ul style="list-style-type: none"> - Cederbom 2019 (post-intervention and longest follow-up) - Chen 2020 (post-intervention) - Hinman 2007 (post-intervention) - Hinman 2020 (post-intervention) - Nelligan 2021 (post-intervention)
Function	18	Total: 9 (50%) Study name (measurement point): <ul style="list-style-type: none"> - Barone Gibbs 2018 (post-intervention) - Basler 2007 (longest follow-up) - Bennell 2017 (post-intervention and longest follow-up) - Cederbom 2019 (post-intervention) - Chen 2020 (post-intervention) - Hinman 2007 (post-intervention) - Hinman 2020 (post-intervention) - Hughes 2006 (post-intervention) - Nelligan 2021 (post-intervention)
Psychological	12	Total: 7 (58.3%) Study name (measurement point): <ul style="list-style-type: none"> - Bieler 2017 (post-intervention - NW group) - Bossen 2013 (longest follow-up) - Chen 2020 (post-intervention) - Hinman 2020 (post-intervention and longest follow-up) - Hughes 2006 (post-intervention and longest follow-up) - Meng 2011 (longest follow-up) - Nelligan (post-intervention)
Quality of life (QOL)	12	Total: 4 (33.33%) Study name (measurement point): <ul style="list-style-type: none"> - Bieler 2017 (post-intervention) - Cederbom 2019 (post-intervention) - Hinman 2007 (post-intervention) - Nelligan 2021 (post-intervention)
Physical/functional performance	9	Total: 4 (44%) Study name (measurement point): <ul style="list-style-type: none"> - Bieler 2017 (post-intervention) - Chen 2020 (post-intervention) - Hinman 2007 (post-intervention) - Wallis 2017 (post-intervention)
Cardiovascular health and risk factors	1	Total: 1 (100%) Study name (measurement point): <ul style="list-style-type: none"> - Wallis 2017 (post-intervention)
Medication use	1	Total: 0 (0%)

Figure 1: PRISMA diagram

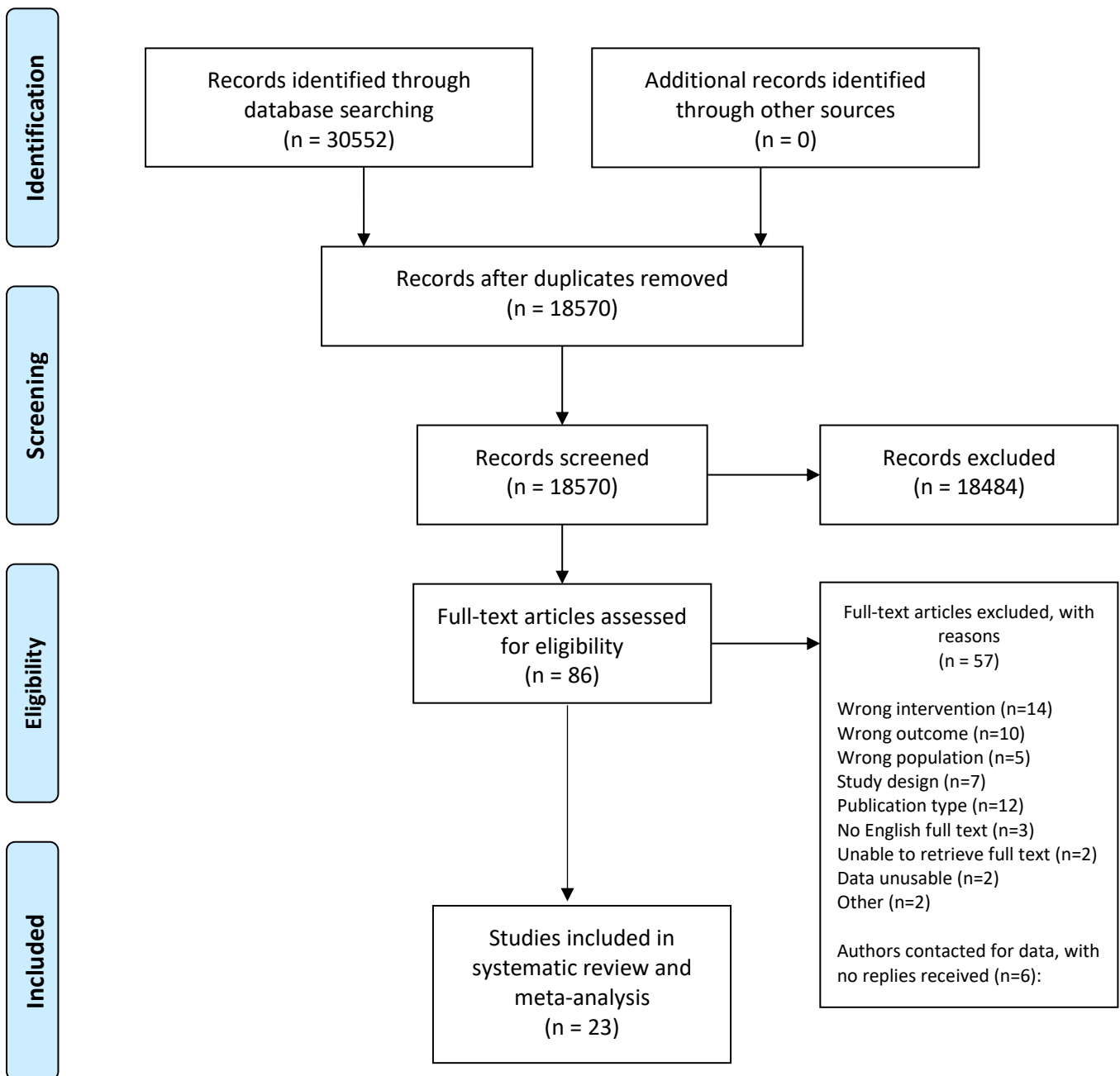


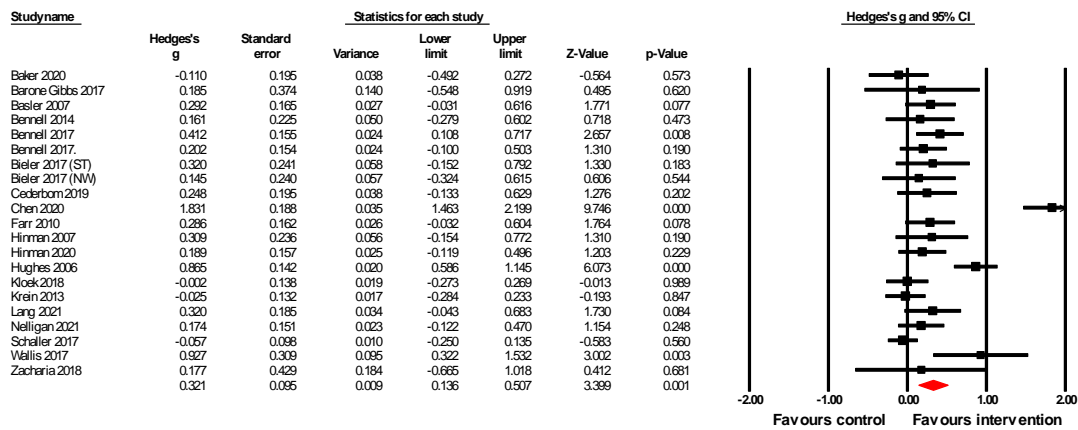
Figure 2: risk-of-bias in individual studies

Study ID	Randomization process	Deviations from intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall bias
RCTs						
Baker 2020	+	+	+	?	+	?
Barone Gibbs 2018	+	+	+	+	+	+
Basler 2007	+	+	+	?	+	?
Bennell 2014	+	+	+	?	+	?
Bennell 2017	+	+	+	+	+	+
Bieler 2017	+	+	+	+	+	+
Bossen 2013	+	+	+	+	+	+
Cederbom 2019	+	+	+	+	+	+
Farr 2010	+	+	+	+	+	+
Hinman 2007	+	+	+	+	+	+
Hinman 2020	+	+	+	+	+	+
Hughes 2006	+	+	+	+	+	+
Krein 2013	+	+	+	+	+	+
Lang 2021	+	+	+	+	+	+
Meng 2011	+	+	+	+	+	+
Nelligan 2021	+	+	+	+	+	+
Schaller 2017	+	+	+	+	+	+
Semrau 2021	+	+	+	+	+	+
Wallis 2017	+	+	+	+	+	+
Zacharia 2018	?	?	+	+	+	?
Cluster-RCTs						
Chen 2020	+	+	+	?	+	?
Kloek 2018	+	+	+	+	+	+
Pisters 2010	+	+	+	+	+	+

+ Low risk
? Some concerns
- High risk

Figure 3: Meta-analysis of post-intervention physical activity outcomes

Meta analysis: Physical activity post intervention



Bennell 2017: top = PASE; bottom = accelerometry. Bieler 2017: ST = strength training; NW = Nordic walking. CI = confidence interval

Figure 4: Meta-analysis of longer-term follow-up physical activity outcomes

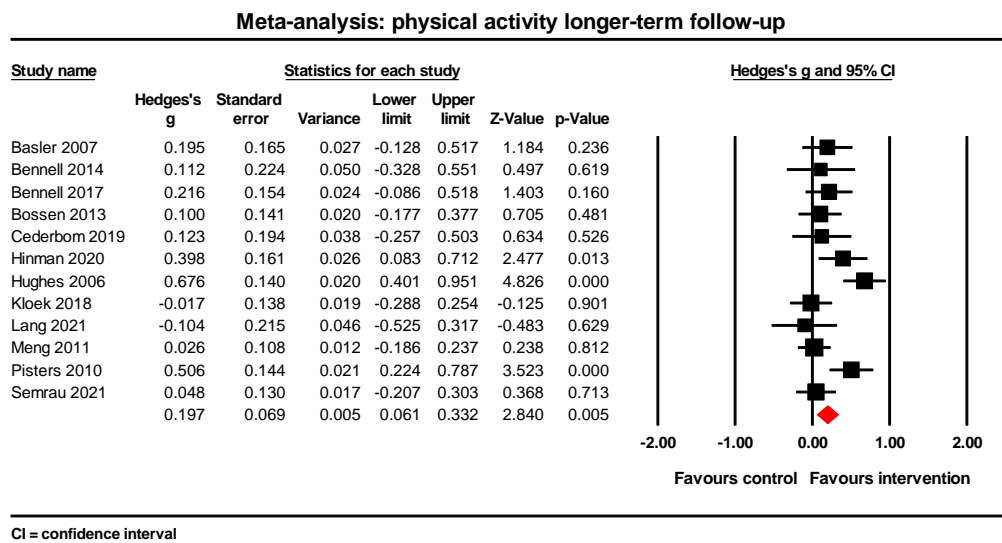


Figure 5: Meta-analysis of post-intervention sedentary behaviour outcomes

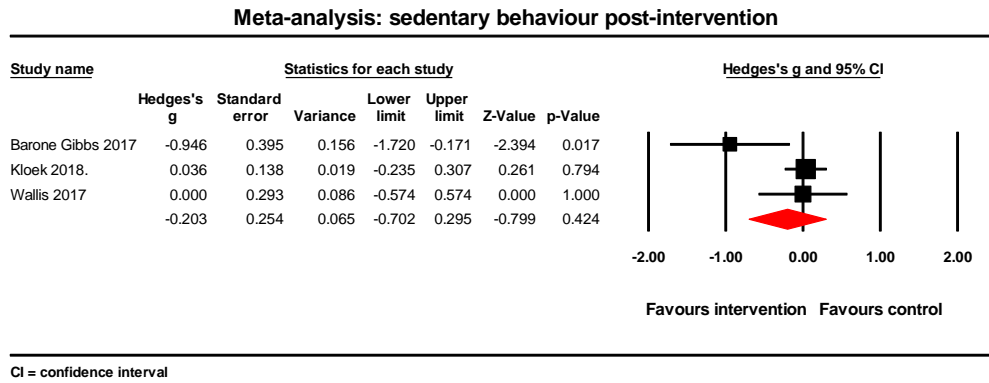
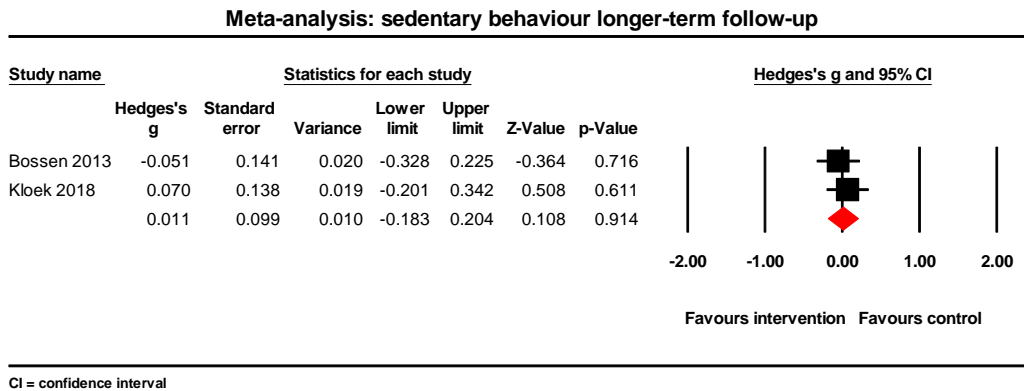


Figure 6: Meta-analysis of longer-term follow-up sedentary behaviour outcomes



Supplementary Material

MEDLINE (Via Ovid) search strategy

Population:

1. Chronic pain/
2. Persistent pain/
3. 1 or 2
4. exp Arthralgia/
5. Joint pain
6. Musculoskeletal pain/
7. Arthralgia
8. Musculoskeletal pain
9. Joint diseases
10. exp osteoarthritis
11. osteoarthritis
12. exp back pain
13. back pain
14. low back pain
15. lumbago
16. lumbar pain
17. ((neck or cervical or thoracic or spin* or lumbar or low* back or shoulder or elbow or hand or hip or knee or foot or musculoskeletal or joint) adj3 pain)
18. non-specific low* back pain
19. neck pain
20. 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19

Intervention

21. (Physical* adj2 activit*)
22. (Leisure adj1 activit*)
23. (physical adj1 (fitness or training))
24. exp Exercise
25. exercise*
26. (strength* adj1 (exercis* or training))
27. (aerobic adj1 (exercis* or training or fitness))
28. exp exercise therapy
29. Stretching
30. exp Walking
31. walking
32. "Activities of daily living"
33. Activit* of daily living
34. Self-management
35. (Sedentary or inactive* (behavio?r or lifestyle))

36. (physical* inactivit*)

37. (sitting adj1 time)

38. 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 1 or 32 or 33 or 34 or 35 or 36
or 37

Study type: RCTs filter

39. clinical trial, phase iii.sh

40. (phase 3 or phase3 or phase iii or p3 or piii).ti,ab,kw.

41. randomized controlled trial.pt

42. controlled clinical trial.pt

43. randomized.ab

44. placebo.ab

45. clinical trials as topic.sh

46. randomly.ab

47. trial.ti

48. 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47

49. 3 or 20

50. 38 and 49

51. 48 and 50

Tables:**Behaviour change techniques in each study**

Study	BCTs in intervention	BCTs in control
Baker 2020	1.1, 1.2, 2.1, 2.3, 2.5, 3.1, 4.1, 9.1	7.1, 9.1
Barone Gibbs 2018	1.1, 1.8, 3.1, 5.1, 7.1, 9.1, 12.5	No BCT
Basler 2007	3.1, 4.1, 5.1, 8.1, 9.1	4.1, 8.1, 9.1
Bennell 2014	1.1, 1.2, 2.1, 2.2, 4.1, 9.1	1.1, 2.1, 4.1, 9.1
Bennell 2017	1.1, 1.2, 1.5, 2.3, 2.5, 4.1, 6.1, 8.1, 9.1	1.2, 2.3, 2.5, 4.1, 6.1, 8.1, 9.1
Bieler 2017	ST: 1.4, 2.4, 4.1, 9.1 NW: 1.4, 2.4, 4.1, 8.1, 9.1	4.1, 9.1
Bossen 2013	7.1, 8.7, 10.3	No BCT
Cederbom 2019	1.1, 1.2, 1.4, 4.1, 5.1, 8.7, 9.1	5.1, 7.1, 9.1
Chen 2020	1.4, 2.2, 4.1, 5.1, 6.1, 8.1, 9.1	1.4, 2.2, 4.1, 8.1
Farr 2010	1.2, 2.3, 2.4, 2.5, 3.1, 4.1, 5.1, 6.1, 8.1, 9.1, 11.2, 12.5	1.2, 3.1, 4.1, 5.1, 9.1, 11.2
Hinman 2007	2.3, 2.4, 3.1, 4.1, 9.1, 12.6	No BCT
Hinman 2020	1.3, 1.4, 2.3, 2.5, 4.1, 5.2, 6.1, 9.1, 12.5	5.1
Hughes 2006	1.2, 1.3, 1.4, 1.8, 2.2, 2.3, 2.4, 2.7, 4.1, 6.1, 8.1, 8.7, 9.1, 12.5	4.1
Kloek 2018	1.3, 2.2, 2.3, 3.1, 4.1, 5.1, 6.1, 8.1, 8.7	No BCT
Krein 2013	1.1, 2.2, 2.3, 3.1, 3.3, 4.1, 5.1, 6.1, 8.7, 13.2	No BCT
Lang 2021	1.1, 1.5, 2.3, 4.1, 5.1, 9.1, 11.1, 13.2	5.1, 9.1, 11.1, 13.2
Meng 2011	4.1, 6.1, 8.1, 9.1	4.1, 9.1
Nelligan 2021	2.3, 3.1, 4.1, 6.1, 7.1, 9.1	5.1, 9.1
Pisters 2010	1.1, 1.2, 2.3, 4.1, 8.7, 9.1, 10.4	4.1
Schaller 2017	1.2, 3.1, 5.1, 9.1	5.1, 9.1
Semrau 2021	1.2, 1.3, 1.4, 1.7, 2.2, 2.3, 2.4, 2.7, 5.1, 5.4, 6.1, 8.1, 9.2	4.1, 5.1, 6.1
Wallis 2017	1.1, 1.4, 2.3, 3.1, 7.1, 9.1	No BCT
Zacharia 2018	1.1, 2.3, 3.1, 4.1, 5.1, 6.1, 8.1, 9.1	2.3, 4.1, 5.1, 6.1, 8.1, 9.1

Taxonomy numbers: 1.1: Goal setting (behaviour); 1.2: problem solving; 1.3: goal setting (outcome); 1.4: action planning; 1.5: review behaviour goal(s); 1.7: review outcome goal(s); 1.8: behavioural contract; 2.1: monitoring of behaviour by others without feedback; 2.2: feedback on behaviour; 2.3: self-monitoring of behaviour; 2.4: self-monitoring of outcome(s) of behaviour; 2.5: monitoring outcome(s) of behaviour by others without feedback; 2.7: feedback on outcome(s) of behaviour; 3.1: social support (unspecified); 3.3: social support (emotional); 4.1: instruction on how to perform a behaviour; 5.1: information about health consequences; 5.2: salience of consequences; 5.4: monitoring of emotional consequences; 6.1: demonstration of behaviour; 7.1: prompts/cues; 8.1: behavioural practice/rehearsal; 8.7: graded tasks; 9.1: credible source; 9.2: pros and cons; 10.3: non-specific reward; 10.4: social reward; 11.1: pharmacological support; 11.2: reduce negative emotions; 12.5: adding objects to the environment; 12.6: body changes; 13.2: framing/reframing
Key: BCT = behaviour change technique

Health-related (secondary) outcomes in each study

Study	Significant outcomes (Time point)	Non-significant outcomes
Baker 2020	No significant outcomes	WOMAC Timed Up and Go test Repeated chair stand Stair climb Strength - Quadriceps Strength – hamstrings
Barone Gibbs 2018	ODI (post-intervention)	Pain VAS 50-foot walk test Repeated sit-to-stand test Timed Up and Go test Unloaded/loaded reach test
Basler 2007	HFAQ (Longest follow-up)	Spine range of movement – ultrasound topometry
Bennell 2014	No significant outcomes	Pain VAS WOMAC function
Bennell 2017	GROC function (Immediate Post-intervention and longest follow-up)	WOMAC Pain NRS – overall Pain NRS – walking AQoL II GROC pain
Bieler 2017	Timed stair climbing test (post-intervention) NW-control 8-foot Up and Go test (post-intervention) NW-control MOS (post-intervention) NW-control 6-minute walk test (post-intervention) NW-control Task-specific self-efficacy (post-intervention) NW-control SF-36 role-physical (post-intervention) NW-control and ST-control SF-36 vitality (post-intervention) NW-control SF-36 mental health (post-intervention) NW-control	WOMAC Task specific self-efficacy (ST-control) ASES SF-36 other scales and other interventions Chair stand performance Timed stair climbing test (ST-control) 8-foot Up and Go test (ST-control) MOS (ST-control) 6-minute walk test (ST-control) SF-36 (other subscales and groups)
Bossen 2013	ASES other symptoms (longest follow-up) HADS anxiety (Longest follow-up)	HOOS/KOOS Pain NRS Tiredness NRS Multi-dimensional Health Locus of Control Scale HADS depression
Cederbom 2019	BPI pain (post-intervention and longest follow-up) BPI disability (post-intervention) SF-12 physical (post-intervention) SF-12 mental (post-intervention)	BPI disability (longest follow-up) SPPB Catastrophizing thoughts 2 item Falls Efficacy Scale - International SF-12 physical (longest follow-up) SF-12 mental (longest follow-up)
Chen 2020	Exercise self-efficacy scale (post-intervention) Decisional Balance Scale for Exercise (post-intervention) WOMAC pain (post-intervention) WOMAC stiffness (post-intervention) Five Time Sit to Stand Test (post-intervention) Timed Up and Go test (post-intervention)	None not significant
Farr 2010	Muscle strength upper and lower body (post-intervention) – RT groups only – no between group difference measured	WOMAC pain
Hinman 2007	Pain VAS – movement (post-intervention) WOMAC (post-intervention) AQoL (post-intervention) Strength – hip abductors (post-intervention) 6-minute walk test (post-intervention)	Strength – quadriceps Timed Up and Go test Step test

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Hinman 2020	WOMAC function (post-intervention) WOMAC pain (post-intervention) Pain on walking NRS (post-intervention) ASES pain (post-intervention and longest follow-up)	Pain NRS ASES function Brief Fear of Movement Scale AQoL 2 WOMAC function (longest follow-up) WOMAC pain (longest follow-up) Pain on walking (longest follow-up)
Hughes 2006	Lorig Self-Efficacy Scale (post-intervention and longest follow-up) WOMAC stiffness (post-intervention)	McAuley Barriers and Time Exercise Adherence Efficacy Scales Timed stand 6-minute distance walk WOMAC function WOMAC pain WOMAC stiffness (longest follow-up) Geri-AIMS pain scale
Kloek 2018	No significant outcomes	HOOS/KOOS Timed Up and Go test Pain NRS Tiredness NRS ASES
Krein 2013	No significant outcomes	RMDQ MOS pain-related functional interference score Pain NRS Exercise Self-Regulatory Efficacy Scale FABQ PA subscale
Lang 2021	No significant outcomes	ODI FABQ Back condition Beliefs Questionnaire Physical Activity Self-Efficacy Scale EQ-5D-5L
Meng 2011	GPMQ - Action-orientated coping (longest follow-up) - Cognitive restructuring (longest follow-up) - Mental distraction (longest follow-up)	Back posture habits Back exercises GPMQ - Subjective coping competence - Counter activities - Relaxation
Nelligan 2021	Pain NRS (post-intervention) WOMAC function (post-intervention) KOOS pain (post-intervention) KOOS sport and recreation (post-intervention) AQoL (post-intervention) ASES pain (post-intervention)	ASES function Self-efficacy exercise
Pisters 2010	No other outcomes	No other outcomes
Schaller 2017	No significant outcomes	SF-36 pain
Semrau 2021	No significant outcomes	HFAQ Pain NRS SF-12 Patient Health Questionnaire – Depression General Anxiety Disorder Perceived Stress Scale Tampa Scale of Kinesiophobia
Wallis 2017	40m walk test (post-intervention) Odds of lowering of systolic blood pressure below 140mmHg (post-intervention)	Pain NRS Cardiovascular risk factors - Blood pressure - Body mass index - Waist circumference - Fasting glucose levels - Cholesterol - Triglycerides WOMAC 30 second chair stand test EQ-5D EQ-VAS Medication use
Zacharia 2018	Between group difference not reported	Between group difference not reported
<p>Key: ASES = Arthritis Self-Efficacy Scale; AQoL = Assessment of Quality of Life; BPI = Brief Pain Inventory; EQ = EuroQol; FABQ = Fear Avoidance Beliefs Questionnaire; GERI-AIMS = Arthritis Impact Measurement Scales for the elderly; GPMQ = German Pain Management Questionnaire; GROC = Global Rating Of Change; HADS = Hospital Anxiety and Depression Scale; HFAQ = Hanover Functional Ability Questionnaire; HOOS = Hip disability and Osteoarthritis Outcome Score; KOOS = Knee injury and Osteoarthritis Outcome Score; MOS = Medical Outcomes Study; NRS = Numeric Rating Scale; ODI = Oswestry Disability Index; RMDQ = Roland Morris Disability</p>		

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Questionnaire; SF = Short-Form; SPPB = Short Physical Performance Battery; VAS = Visual Analogue Scale; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index

Bold study name = significant (p < 0.05) for PA or sedentary behaviour outcomes at immediate post-intervention and/or longer-term follow-up

Health-related outcomes in each category and studies with significant results in each category

Outcome measure category	Outcome measures included in category	N studies assessing	Studies with Significant outcomes (p<0.05)
Pain	WOMAC pain Pain VAS Pain NRS GROC pain BPI HOOS/KOOS pain Gerii-AIMS pain scale	16	Total: 5 (31.25%) Study name (measurement point): - Cederbom 2019 (post-intervention and longest follow-up) - Chen 2020 (post-intervention) - Hinman 2007 (post-intervention) - Hinman 2020 (post-intervention) - Nelligan 2021 (post-intervention)
Function	ODI WOMAC function WOMAC stiffness HFAQ GROC function HOOS/KOOS function HOOS/KOOS other symptoms RMDQ BPI disability Tiredness NRS	18	Total: 9 (50%) Study name (measurement point): - Barone Gibbs 2018 (post-intervention) - Basler 2007 (longest follow-up) - Bennell 2017 (post-intervention and longest follow-up) - Cederbom 2019 (post-intervention) - Chen 2020 (post-intervention) - Hinman 2007 (post-intervention) - Hinman 2020 (post-intervention) - Hughes 2006 (post-intervention) - Nelligan 2021 (post-intervention)
Psychological	Task specific self-efficacy ASES Multi-dimensional Health Locus of Control Scale Catastrophizing thoughts 2 item Falls Efficacy Scale - International Exercise self-efficacy scale Decisional Balance Scale for Exercise Lorig Self-Efficacy Scale McAuley Barriers and Time Exercise Adherence Efficacy Scales Exercise Self-Regulatory Efficacy Scale FABQ Brief Fear of Movement Scale GPMQ Back posture habits Back exercises HADS anxiety HADS depression Back condition Beliefs Questionnaire Physical Activity Self-Efficacy Scale Self-efficacy exercise Patient Health Questionnaire – Depression General Anxiety Disorder Perceived Stress Scale Tampa Scale of Kinesiophobia	12	Total: 7 (58.3%) Study name (measurement point): - Bieler 2017 (post-intervention - NW group) - Bossen 2013 (longest follow-up) - Chen 2020 (post-intervention) - Hinman 2020 (post-intervention and longest follow-up) - Hughes 2006 (post-intervention and longest follow-up) - Meng 2011 (longest follow-up) - Nelligan (post-intervention)
Quality of life (QOL)	SF-36 SF-12 HOOS/KOOS QOL AQoL AQoL II EQ-5D EQ-VAS MOS	12	Total: 4 (33.33%) Study name (measurement point): - Bieler 2017 (post-intervention) - Cederbom 2019 (post-intervention) - Hinman 2007 (post-intervention) - Nelligan 2021 (post-intervention)
Physical/functional performance	Timed Up and Go Repeated chair stand/repeated sit-to-stand Stair climb Quadriceps strength Hamstring strength 50-foot walk test	9	Total: 4 (44%) Study name (measurement point): - Bieler 2017 (post-intervention) - Chen 2020 (post-intervention) - Hinman 2007 (post-intervention) - Wallis 2017 (post-intervention)

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	Unloaded/loaded reach test Spine range of movement (ultrasound topometry) 8-foot up and go test 6-minute walk test Five Time Sit-to-Stand Test Step test Hip abductor strength Time stand 40m walk test SPPB		
Cardiovascular health and risk factors	Blood pressure Body mass index Waist circumference Fasting glucose level Cholesterol Triglycerides	1	Total: 1 (100%) Study name (measurement point): - Wallis 2017 (post-intervention)
Medication use	Medication use	1	Total: 0 (0%)

Key: ASES = Arthritis Self-Efficacy Scale; AQoL = Assessment of Quality of Life; BPI = Brief Pain Inventory; EQ = EuroQol; FABQ = Fear Avoidance Beliefs Questionnaire; GERI-AIMS = Arthritis Impact Measurement Scales for the elderly; GPMQ = German Pain Management Questionnaire; GROC = Global Rating Of Change; HADS = Hospital Anxiety and Depression Scale; HFAQ = Hanover Functional Ability Questionnaire; HOOS = Hip disability and Osteoarthritis Outcome Score; KOOS = Knee injury and Osteoarthritis Outcome Score; MOS = Medical Outcomes Study; NRS = Numeric Rating Scale; ODI = Oswestry Disability Index; RMDQ = Roland Morris Disability Questionnaire; SF = Short-Form; SPPB = Short Physical Performance Battery; VAS = Visual Analogue Scale; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index.
Bold study name = significant ($p < 0.05$) for PA or sedentary behaviour outcomes at immediate post-intervention and/or longest follow-up.

Deviations from protocol

Deviation from protocol	Reason why change made	Effect on results
Hedge's g effect measure used instead of Cohen's d	Hedge's g removes small sample bias that occurs with Cohen's d. Due to some studies having small sample sizes, Hedge's g was the preferred effect estimate	Using Hedge's g may have slightly reduced the effect estimate due to removal of small sample bias https://www.meta-analysis.com/downloads/Meta-analysis%20Effect%20sizes%20based%20on%20means.pdf
Search did not include clinic trials registries	It was unnecessary to search the clinical trials registries as CENTRAL includes records from clinicaltrials.gov and WHO's International Clinical Trials Registry Platform.	No effect
Moderators for meta-regression were not specified a-priori	We decided after data extraction to perform meta-regressions on number of BCTs and number of sessions in the interventions due to the large variations in these numbers. We wanted to assess whether higher numbers of these moderated the effect sizes	No effect – provided additional results, but did not effect main study results
Report which BCTs were used to support behaviour change at different time-points	Most included studies did not alter their BCTs used for different time-points e.g. they did not use different BCTs for PA uptake or PA	Unable to determine which BCTs might have been more helpful to facilitate initial uptake of PA/reduction of SB and which may have been more helpful in supporting maintenance.

	<p>maintenance, so we would not have been able to make meaningful conclusions from this approach. We opted to analyse BCTs for their presence at any time-point in the intervention.</p>	
<p>Did not do a subgroup analysis for different locations of pain</p>	<p>Due to heterogeneity in the interventions, we did not feel this would have been a meaningful subgroup.</p>	<p>No effect</p>
<p>Did a subgroup analysis with variations of the nature of interventions</p>	<p>Due to variations in interventions, we did an additional subgroup analysis grouping interventions into PA + counselling/coaching, PA + education, PA + education and counselling, and PA only.</p>	<p>No effect on main results. Provides additional insight into what interventions may be more effective.</p>

Figures:

Figure: PA post-intervention funnel plot

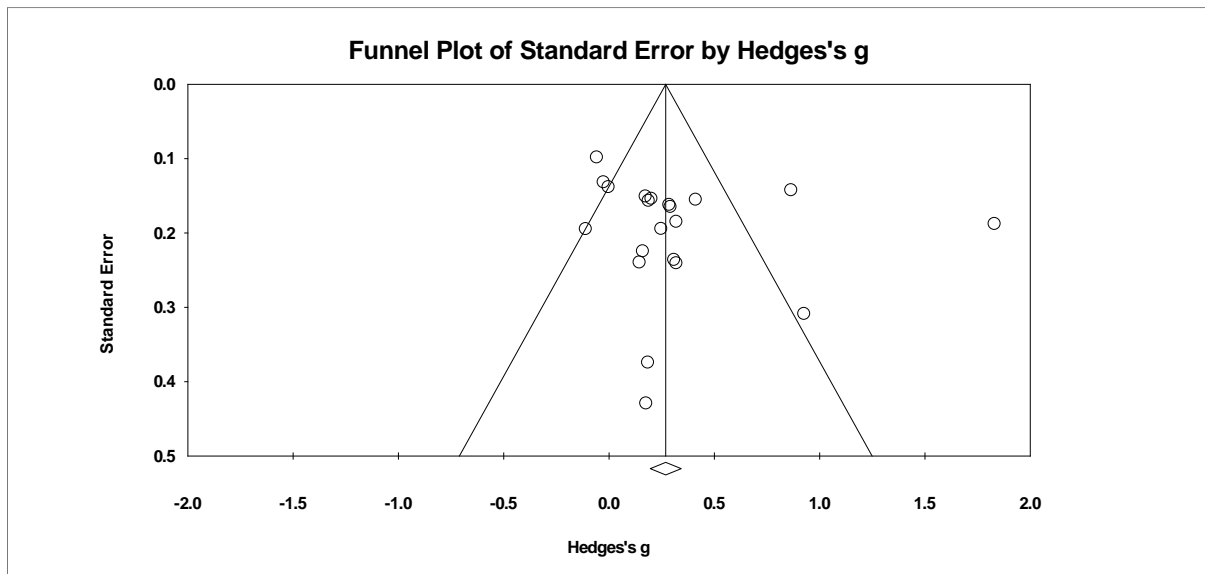
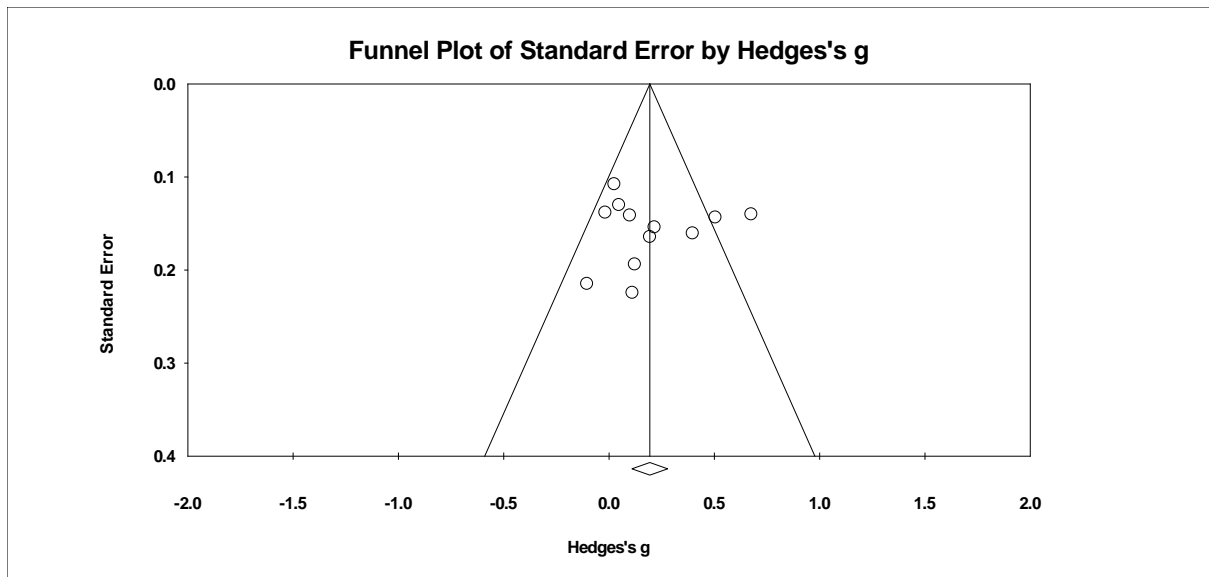


Figure: PA longest follow-up funnel plot



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Data used for meta-analysis

Study name	Outcome	Time point	Intervention mean	Intervention SD	Intervention sample size	Control mean	Control SD	Control sample size	Effect direction	ROB Assessment	Subgroup: Setting of PA	Subgroup: Method of delivery	Subgroup: Modes of PA	Subgroup: Nature of the intervention	No. of BCTs (intervention) confident & tentative	No. of BCTs (intervention) confident only	No. of sessions in intervention
Baker 2020	Exercise adherence	Post-intervention (24 months)	3.63	3.34	52	4.01	3.52	52	Negative	Some concerns	Combination	Combination	Non self-selected	PA + counselling/coa	10	8	54
Barone Gibbs 2017	Min/week MVPA	Post-intervention (6 months)	264	182	13	229	184	14	Positive	Low	Unsupervised	Individual	Non self-selected	PA + education + cou	8	7	7
Basler 2007	Min/day PA (7-day)	Post-intervention (5 weeks)	29.24	14.6	75	24.7	16.3	72	Positive	Some concerns	Supervised	Individual	Non self-selected	PA + counselling/coa	5	5	20
Basler 2007	Min/day PA (7-day)	Longest F/U (6 months)	29.63	24.2	75	25.3	19.7	72	Positive	Some concerns	Supervised	Individual	Non self-selected	PA + counselling/coa	5	5	20
Bennell 2014	Exercise adherence	Post-intervention (16 weeks)	6.8	4.1	40	6.1	4.5	38	Positive	Some concerns	Supervised	Individual	Non self-selected	PA + counselling/coa	7	6	2
Bennell 2014	Exercise adherence	Longest F/U (24 weeks)	5.7	3.6	40	5.3	3.5	38	Positive	Some concerns	Supervised	Individual	Non self-selected	PA + counselling/coa	7	6	2
Bennell 2017	PASE	Post-intervention (6 months)	189	85	84	158	63	84	Positive	Low	Combination	Individual	Non self-selected	PA + counselling/coa	11	9	11
Bennell 2017	PASE	Longest F/U (18 months)	180	94	84	162	70	84	Positive	Low	Combination	Individual	Non self-selected	PA + counselling/coa	11	9	11
Bennell 2017	Step/day (Accelerometer)	Post-intervention (6 months)	9148	3178	84	8504	3180	84	Positive	Low	Combination	Individual	Non self-selected	PA + counselling/coa	11	9	11
Bieler 2017 (ST)	PASE	Post-intervention (12 months)	148.3	69	50	126.6	63.1	26	Positive	Low	Combination	Combination	Non self-selected	PA + education + cou	8	4	53
Bieler 2017 (NW)	PASE	Post-intervention (12 months)	134	42.5	50	126.6	63.1	26	Positive	Low	Combination	Combination	Non self-selected	PA + education + cou	10	5	53
Bossen 2013	Min/day doing PA	Longest F/U (12 months)	361	227	100	338	233	99	Positive	Low	Unsupervised	Individual	Self-selected	PA + education	7	3	NA
Cederbom 2019	Grimby-Frandin Scale	Post-intervention (12 weeks)	2.7	0.8	52	2.5	0.8	53	Positive	Low	Combination	Individual	Combination	PA + counselling/coa	9	7	10
Cederbom 2019	Grimby-Frandin Scale	Longest F/U (24 weeks)	2.6	0.7	52	2.5	0.9	53	Positive	Low	Combination	Individual	Combination	PA + counselling/coa	9	7	10
Chen 2020	Exercise adherence	Post-intervention (24 weeks)	7.58	1.29	89	5	1.53	72	Positive	Some concerns	Combination	Combination	Non self-selected	PA + education	18	7	9
Farr 2010	Min/day doing MVPA	Post-intervention (9 months)	30.1	18.3	114	24.8	18.7	57	Positive	Low	Supervised	Combination	Non self-selected	PA + education + cou	12	12	36
Hinman 2007	PASE	Post-intervention (6 weeks)	165	70	36	142	77	35	Positive	Low	Combination	Group-based	Non self-selected	PA only	6	6	12
Hinman 2020	PASE	Post-intervention (6 months)	190	91	82	172	99	80	Positive	Low	Unsupervised	Individual	Combination	PA + education + cou	11	9	7
Hinman 2020	PASE	Longest F/U (12 months)	193	115	82	152	87	75	Positive	Low	Unsupervised	Individual	Combination	PA + education + cou	11	9	7
Hughes 2006	Min/week exercise	Post-intervention (2 months)	248.89	150.45	115	126.67	128.66	100	Positive	Low	Combination	Combination	Non self-selected	PA + education	15	14	24
Hughes 2006	Min/week exercise	Longest F/U (12 months)	210.52	153.18	115	115.65	122.67	100	Positive	Low	Combination	Combination	Non self-selected	PA + education	15	14	24
Kloek 2018	Min/day doing MVPA	Post-intervention (3 months)	34.9	54.3	109	35	53.4	99	Positive	Low	Combination	Individual	Combination	PA + education	9	9	5
Kloek 2018	Min/day doing MVPA	Longest F/U (12 months)	43.4	71.1	109	44.6	67.2	99	Negative	Low	Combination	Individual	Combination	PA + education	9	9	5
Krein 2013	Step/day (Pedometer)	Post-intervention (12 months)	4681.8	3000.6	111	4758.1	2991.1	118	Negative	Low	Unsupervised	Individual	Non self-selected	PA + counselling/coa	10	10	NA
Lang 2021	MET-min/week (IPAQ)	Post-intervention (3 months)	3212	2798	96	2322	2688	42	Positive	Low	Unsupervised	Individual	Non self-selected	PA + education	8	8	13
Lang 2021	MET-min/week (IPAQ)	Longest F/U (12 months)	2658	3259	64	3016	3731	32	Negative	Low	Unsupervised	Individual	Non self-selected	PA + education	8	8	13
Meng 2011	Hour/week (Freiburg)	Longest F/U (12 months)	8.88	5.95	181	8.73	5.7	163	Negative	Low	Supervised	Group-based	Non self-selected	PA + education	4	4	7
Nelligan 2021	PASE	Post-intervention (24 weeks)	157.5	75.6	89	144.5	73	86	Positive	Low	Unsupervised	Individual	Non self-selected	PA + education + cou	6	6	17
Pisters 2010	Day/week ≥30 min	Longest F/U (65 weeks)	5	2.6	97	3.6	2.9	102	Positive	Low	Combination	Individual	Non self-selected	PA + education	7	7	25
Schaller 2017	MET-min/week (IPAQ)	Post-intervention (12 months)	4535	6883	201	4962	7908	211	Negative	Low	Unsupervised	Combination	Self-selected	PA + counselling/coa	6	4	5
Semrau 2021	Hours/week (Freiburg)	Longest F/U (12 months)	7.57	7.65	127	7.22	6.83	109	Positive	Low	Combination	Group-based	Non self-selected	PA + education + cou	14	13	32
Wallis 2017	Min/day walking	Post-intervention? (13 weeks)	88	36	22	60	22	23	Positive	Low	Combination	Combination	Non self-selected	PA only	6	6	NR
Zacharia 2018	MET-min/week (IPAQ)	Post-intervention (12 weeks)	6038.9	2942.1	10	5438.3	3540.6	10	Positive	Some concerns	Combination	Combination	Non self-selected	PA + counselling/coa	8	8	20