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Research

Mobile app use to support therapeutic exercise for musculoskeletal pain conditions may help improve pain intensity and self-reported physical function: a systematic review

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KEY WORDS

Musculoskeletal pain
Exercise
Mobile applications
Physical therapy
Meta-analysis

ABSTRACT

Question: What is the effect of therapeutic exercise or tailored physical activity programs supported by a mobile app (compared with exercise or physical activity programs delivered using other modes) for people with musculoskeletal pain conditions? **Design**: Systematic review of published randomised controlled trials with meta-analysis. **Participants**: People of all ages with musculoskeletal pain conditions. **Intervention**: Therapeutic exercise or tailored physical activity programs supported by a mobile app. **Outcome measures**: Pain intensity, pain interference, self-reported physical function, physical performance, adherence, psychosocial outcomes, health-related quality of life, work participation, physical activity, goal attainment and satisfaction. **Results**: Eleven studies were eligible for inclusion, with a total of 845 participants. There was low certainty evidence that using mobile apps to deliver exercise programs helps to reduce pain intensity to a worthwhile extent (SMD –0.60, 95% CI –0.93 to –0.27). There was low certainty evidence that using mobile apps to deliver exercise programs helps to improve self-reported physical function to a worthwhile extent (SMD –0.92, 95% CI –1.57 to –0.27). Although the effect of using mobile apps to deliver exercise programs on pain interference was also estimated to be a worthwhile benefit (SMD –0.66), this estimate came with marked uncertainty (95% CI –1.52 to 0.19) so the effect remains unclear. The remainder of the outcomes were unclear due to sparse evidence. The most common behaviour change intervention functions in the mobile app interventions were: training, enablement and environmental restructuring. **Conclusion**: Mobile apps supporting therapeutic exercise or tailored physical activity programs for musculoskeletal pain conditions may help in reducing pain intensity and improving physical function. The mobile apps utilised a limited range of behaviour change intervention functions. **Registration**: CRD42021248046 **[Thompson D, Rattu S, Tower J, Egerton T, Francis J, Merolli M (2023) Mobile app use to support therapeutic exercise for musculoskeletal pain conditions may help improve pain intensity and self-reported physical function: a systematic review. *Journal of Physiotherapy* 69:23–34]**

Introduction

Musculoskeletal conditions affect approximately 1.7 billion people globally;[1] they can cause pain, decrease physical function, reduce psychological well-being, curtail social and economic participation, and are significant predictors of years lived with disability.[2] Imaging, surgery and opioids remain over-utilised in the care of musculoskeletal pain,[3] despite safe, effective, widely available alternative management options. Therapeutic exercise and tailored physical activity are high-value, low-cost interventions for improving symptoms and functional outcomes in musculoskeletal pain conditions,[2,4] provided that sufficient adherence is achieved.[5] Adherence to exercise can be improved by behaviour change interventions.[6] Using innovative digital solutions to deliver these interventions may help support exercise and physical activity behaviours.[7]

Digital health interventions, including mobile apps, use information and communication technologies to support healthcare.[8] Three systematic reviews have recently addressed the effectiveness of digital health interventions to support exercise for musculoskeletal pain conditions;[9–11] they found improved adherence in musculoskeletal conditions[9] and a beneficial effect on pain, but mixed findings for function and health-related quality of life in people with knee osteoarthritis.[10,11] The reviews reported a limited range of outcomes[9–11] and/or focused on a specific condition.[10,11] Also, mobile apps were

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Box 1. Nine behaviour change intervention functions and their definitions (adapted from Michie et al, 2011[15]).

- Education: increasing knowledge or understanding
- Persuasion: using communication to induce positive or negative feelings or stimulate action
- Incentivisation: creating expectation of reward
- Coercion: creating expectation of punishment or cost
- Training: imparting skills
- Restriction: using rules to reduce the opportunity to engage in the target behaviour (or increase the target behaviour by reducing the opportunity to engage in competing behaviours)
- Environmental: restructuring the physical or social context
- Modelling: providing an example for people to aspire to or imitate
- Enablement: increasing means/reducing barriers to increase capability or opportunity

grouped with a heterogeneous mix of digital interventions.[9–11] However, mobile apps have different features to other digital health interventions that may enhance their ability to deliver instructional content and behaviour change interventions.[12,13] For example, mobile apps are delivered via highly portable, accessible devices, making support and social networking immediately available. Sophisticated monitoring is possible (eg, via in-built sensors and synchronisation with wearable devices) and prominent messaging (eg, via notifications and alerts) can effectively deliver information. Therefore, there is a need to investigate their effectiveness more specifically.

Successful delivery of a therapeutic exercise or tailored physical activity program requires a response in the form of adherence to a set of behaviours;[5] therefore, it is worth investigating the ability of mobile apps to deliver behaviour change content designed to foster these behaviours.[14] The 'Behaviour Change Wheel' is a theory-informed framework for developing behaviour change interventions and offers a comprehensive model of behaviour change determinants.[15,16] Behaviour change intervention functions (Box 1) are broad categories of the mechanisms underlying behaviour change interventions and can assist with describing interventions in a standardised way.[15]

This review aimed to estimate the effects of using a mobile app to support therapeutic exercise or tailored physical activity programs in people with musculoskeletal pain conditions, on pain intensity, pain interference, self-reported physical function, physical performance, adherence, psychosocial outcomes, health-related quality of life, work participation, physical activity levels, goal attainment and satisfaction. Pain intensity is the predominant symptom for musculoskeletal conditions and its interference with daily activities is of key importance to clinicians and patients.[17] Since mobile apps may be theorised to affect these outcomes through psychosocial changes,[17,18] psychosocial outcomes are also considered to be important.

This review also aimed to note which behaviour change intervention functions[9] are included in the investigated mobile apps. Given that there is currently no consensus on the effectiveness of within-app behaviour change interventions,[19] this review aimed to describe interventions in the included studies using the Behaviour Change Wheel taxonomy of intervention functions.[15]

Therefore, the research question for this systematic review was:

What is the effect of therapeutic exercise or tailored physical activity programs supported by a mobile app (compared with exercise or physical activity programs delivered using other modes) for people with musculoskeletal pain conditions?

Method

This systematic review is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[20] and was registered a priori with PROSPERO. Minor modifications to the protocol are described below.

Identification and selection of studies

A comprehensive search of the bibliographic databases Medline (Ovid), EMBASE (Ovid), CINAHL complete (EBSCO), Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, Physiotherapy Evidence Database (PEDro) and Scopus was conducted from inception of indexing to 16 March 2021 and updated on 29 January 2022. The search strategy consisted of key words (including exploded terms) and Medical Subject Headings, relevant to three key concepts: musculoskeletal pain conditions, exercise and mobile apps (see Appendix 1 on the eAddenda for the detailed search strategy). Peer review of the search strategy was undertaken by an experienced librarian using the PRESS checklist.[21] Clinical trial registries (Clinicaltrials.org), ProQuest Dissertations and Theses, grey literature databases (TROVE) and reference lists of relevant systematic reviews and included clinical trials were also searched.

Screening of each title and abstract for potential eligibility against pre-published criteria was performed independently by any two of three reviewers (DT, SR and JT) using Covidence software[a]. Full-text articles were each independently screened against the eligibility criteria by any two of three reviewers (DT, SR and JT). Reviewers were not blinded to the authors, journals or results of the studies. Conflicts at each stage were resolved by discussion between the two reviewers who screened the article, with the third and, where necessary, a fourth reviewer (MM) assisting in reaching consensus. Article authors were contacted via email if the full-text manuscript was unavailable or if clarification was required on aspects of their study.

The inclusion criteria are listed in Box 2. Studies with mixed populations were excluded unless a subgroup of patients meeting the eligibility criteria were analysed and reported separately. Studies were eligible if their experimental interventions delivered healthcare professional-prescribed (either directly or via artificial intelligence), tailored, therapeutic exercise or physical activity via a patient-focused app for mobile phone or tablet. Studies were excluded if: the experimental intervention involved exercise not delivered by an app (eg, delivered via a website); exercise was not a target behaviour (eg, app for mindfulness); the exercise or physical activity intervention was

Box 2. Inclusion criteria.

Design
- Randomised controlled trial
- Published in peer-reviewed journal
- Available in English full text

Participants
- Acute, subacute or persistent musculoskeletal pain condition
- Any age

Intervention
- Tailored therapeutic exercise or physical activity, prescribed by healthcare professional
- Delivered via mobile app
  - ± in-app interventions such as wearable electronic devices and education
  - ± additional interventions other than exercise/mobile app received by both groups
- Home or community settings

Outcome measures
- Pain severity
- Pain interference
- Self-reported physical function
- Physical performance
- Psychosocial outcomes
- Adherence to exercise program
- Physical activity levels
- Health-related quality of life
- Work participation
- Goal attainment

Comparator
- Equivalent therapeutic exercise or physical activity not delivered via mobile app

generic and non-tailored (eg, recommending World Health Organization physical activity guidelines); or if the app was designed for healthcare professional use (eg, for monitoring). Studies were eligible if the app included features that were related to the exercise program (eg, education or wearable electronic devices) but not education or wearable devices alone. Studies were eligible only if any additional interventions other than exercise (eg, face-to-face physiotherapy) were the same in both groups.

Eligible comparator groups received similar exercise or physical activity interventions as the experimental group, but without mobile app support, such that the mobile app was the primary point of difference between the groups. Similarity of exercise or physical activity interventions between groups was judged in terms of type, frequency, duration and intensity of exercise. Studies were excluded if they had an inactive comparator (eg, exercise and mobile app versus a no-exercise attention comparator), more intensive face-to-face comparator conditions, or inadequately described comparator conditions. This was changed from the registered protocol, which also included similar intensity 'self-management' interventions as eligible comparators. The change was made to increase directness of the review by ensuring that exercise/physical activity components of the interventions were similar.

Only studies measuring quantitative outcomes of interest (Box 2) were included. A broad operational definition of physical performance was used, encompassing physical function (mobility, dexterity, axial ability and ability to carry out instrumental activities of daily living)[22] and physical fitness (cardiovascular endurance, muscular strength, muscular endurance, flexibility, body composition).[22] Any measure of adherence to exercise was included (eg, self-reported number of sessions, number of exercises, duration of exercise) and physical activity included self-reported and objective measures. Work participation included length of time to return to work and work limitations.

Assessment of characteristics of studies

Clinical characteristics

The study characteristics extracted to enable consideration of clinical heterogeneity were: participant characteristics (age, sex/gender, condition, location and healthcare context); experimental and comparator group exercise/physical activity program; details of the experimental app and other components in the interventions; relevant outcome measures; and measurement time points. Data describing study design, sources of funding and conflicts of interest were also extracted.

Behaviour change components

The active behaviour change components of the mobile apps were categorised independently according to the nine behaviour change intervention functions[15] (Box 1) by any two of three reviewers (DT, SR or JT) for each included study. Differences were resolved through discussion and involvement of the third reviewer where needed.

Risk of bias

The risk of bias was independently assessed at the outcome level by any two of three reviewers (DT, SR or JT) for each included study using the Cochrane Risk of Bias tool version 2 (ROB2).[23] Differences were resolved through discussion, with involvement of a third reviewer where necessary. Risk of bias was graphically represented using the 'robvis' tool.[24] Where insufficient detail was published, an attempt was made to contact study authors to obtain further information.

Data extraction and analysis

Outcome data from each included article were independently extracted by any two of three reviewers (SR, DT or JT) for the timepoints baseline, immediately after the intervention and at the longest available follow-up. Data were cross-checked for differences, tabulated by outcome domain and sub-grouped by condition where possible. Group means with standard deviations for within-group changes, between-group differences after the intervention and/or between-group differences in change scores, with 95% CI and/or standard errors, were extracted. Incomplete data were calculated from the data provided if possible. A pooled estimate of effect was calculated using RevMan software[b] if three or more articles reported the same outcome domain. Where fewer than three articles reported the same outcome domain, findings were synthesised narratively only, rather than also being pooled quantitatively. Random effects models were used to determine weighted, standardised mean differences (SMD) between groups immediately after the intervention and at the longest follow-up. Weighted mean differences (MD) were calculated if the same measurement tool was used for the domain. Adherence was evaluated by comparing actual adherence to a target level. This method was not planned a priori; however, given the ways that adherence data were reported in the studies, this method was considered most appropriate. Subgroup analyses according to age group, condition, risk of bias and the mobile app's behaviour change intervention functions were planned, where possible. Data were narratively synthesised by outcome, considering the magnitude and precision of between-group differences in the context of risk of bias and clinical heterogeneity.

The smallest worthwhile effect of using an app to deliver an exercise program is unclear. Apps are generally cheap and smartphones are relatively common worldwide. Downloading an app is quick and using an app is arguably more convenient than using an exercise program prescribed on paper. Hence, in this context, *any* between-group difference might be seen as worthwhile. However, for people who would need to invest in a smartphone and/or increase their digital literacy in order to use the app, an important difference might be larger. We nominated that a difference of 1.5 points on a 10-point pain scale or an SMD of 0.2 would be considered worthwhile.

Certainty of findings

The certainty of the body of evidence for each outcome domain was assessed by any two of three reviewers (DT, JT or SR) using the GRADE approach.[25] The risk of bias due to missing results in the synthesis was assessed by determining missing results from included studies, compared with published protocols, and the likelihood of publication bias was evaluated via qualitative signals, since graphical and statistical methods were not appropriate.[26]

Results

Flow of studies through the review

The search identified 7,978 unique titles and abstracts (Figure 1). Eleven articles (10 studies) were included in the review. Reasons for exclusion during full-text screening are presented in Appendix 2 on the eAddenda.

Characteristics of studies

Study characteristics are summarised in Table 1. All studies were published since 2016. The included studies randomised a total of 845 participants. Sample sizes of included studies ranged from 20[27] to 220[28,29] participants. Mean ages ranged from 27[27] to 63[30] years. Participants had persistent musculoskeletal conditions in eight of the studies, and acute injuries in three studies. Conditions included knee osteoarthritis,[31–33] low back pain,[34,35] ankle sprains,[28,29] frozen shoulder,[36] neck pain[27,35] and wrist, hand and finger injuries.[37]

Exercise programs varied in their therapeutic focus, with muscular strengthening exercises being the most frequently prescribed.[28–31,34] Other exercise programs included finger/hand mobilisation exercises for wrist/hand/finger injuries,[37] passive range of motion exercises for frozen shoulder,[36] 'McKenzie' neck exercises (range of motion and stretching) for neck pain,[27] whole body physical activity,[34] activities of daily living,[34] balance and proprioception,[28,29] stretching[30,35] and

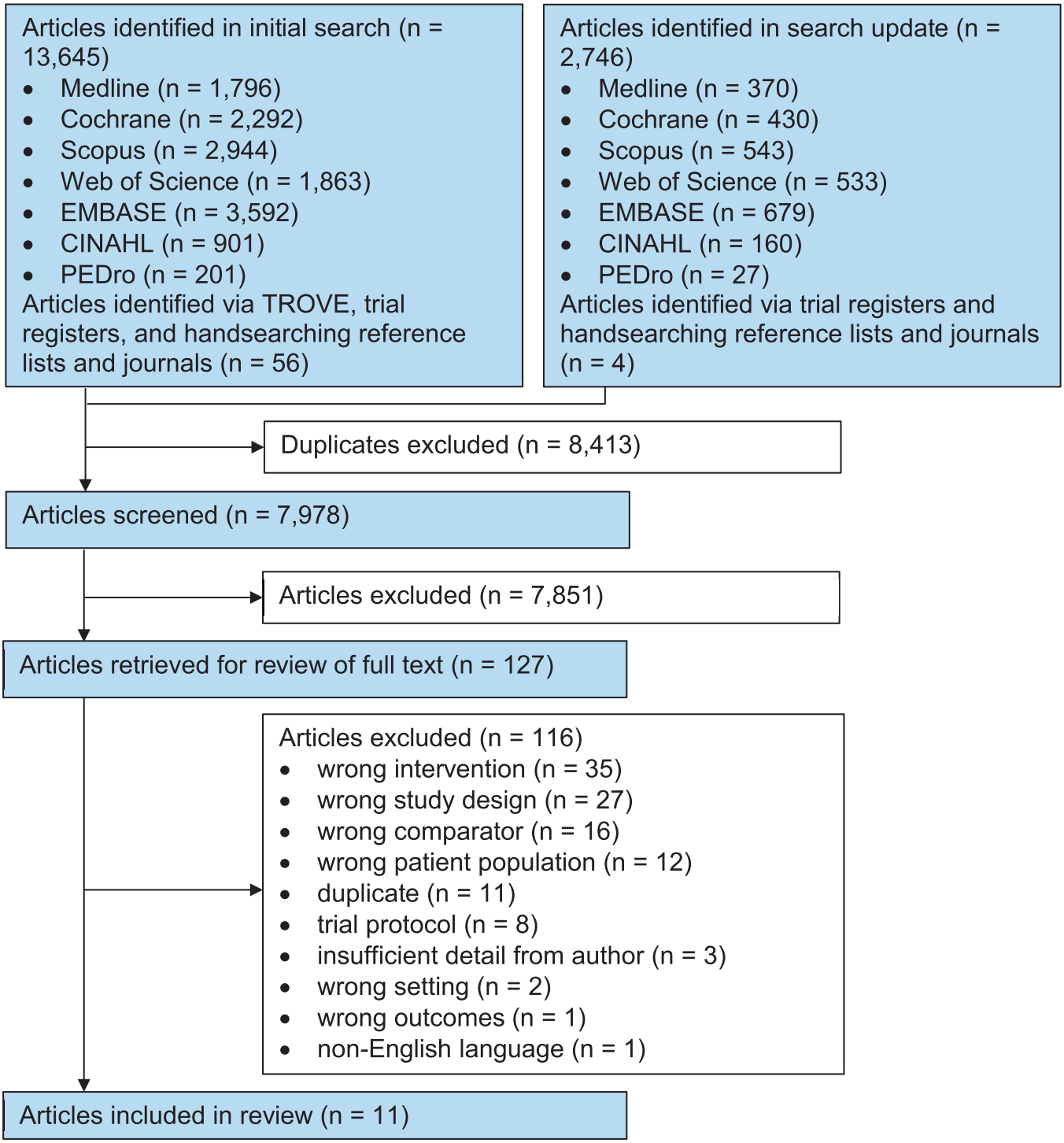

Figure 1. Flow of trials through the review.

Table 1
Study characteristics.

Study	Participants	Interventions			Outcome(s)	Time points
		Experimental	Control	Both		
Abadiyan 2021[32]	N = Exp 20, Con 20 Age *(y)* = Exp 41 (8), Con 40 (8) Sex *(%F)* = Exp 50, Con 50 Chronic non-specific neck pain, > 3 mths duration, VAS 3 to 8	Exercises: Global postural re-education Technology: Smartphone, 'Seeb' app	Exercises: Same as Exp, nil app.	Neck pain brochure, PT 50 min/d, 4 d/wk for 8 wks	VAS, NDI, PILE, SF-36	Baseline, 8 wks (post-intervention)
Alasfour 2020[31]	N = Exp 20, Con 20 Age *(y)* = Exp 54 (4), Con 55 (5) Sex *(%F)* = Exp 100, Con 100 Unilateral or bilateral knee osteoarthritis, ≥ 6 mths duration, NPRS ≤ 7	Exercises: Progressive lower limb strengthening, daily, 10 reps/exercise Technology: Tablet or smartphone, 'MyDearKnee' app	Exercises: Same as Exp, paper-based HEP in lieu of app	Education, 2 supervised exercise sessions, resistance band	Arabic NPRS, WOMAC, 5 × sit-stand test, adherence (self-report logbook)	Baseline, 3 wks (mid-intervention), 6 wks (post-intervention)
Anan 2021[35]	N = Exp 61, Con 60 Age *(y)* = Exp 42 (9), Con 42 (8) Sex *(%F)* = Exp 19, Con 28 Neck/ shoulder pain/stiffness or low back pain or both	Exercises: Chat-bot prompts for stretching and movement exercises daily Technology: Smartphone, Secaide Ver.0.9™ app	Exercises: Stretches 3 min/d during break time		Pain intensity (*1 to 5*), difference in worst pain score, absence of severe pain, subjective improvement	Baseline, 12 wks (post-intervention)
Blanquero 2020[37]	N = Exp 40, Con 34 Age *(y)* = Exp 45 (11), Con 42 (11) Sex *(%F)* = Exp 32, Con 44 Bone and soft tissue injuries of wrist/ hand/finger that limit functional ability	Exercises: Clinician-prescribed exercises, progressed by algorithm Technology: Tablet, 'ReHand' app	Exercises: Same as Exp, paper-based HEP in lieu of app	PT and OT ≥ 3 d/wk, 30 to 60-min session	VAS, QuickDASH, grip strength, pinch strength, 9-hole peg test, Time taken to return to work	Baseline, 2 wks (mid-intervention), 4 wks (post-intervention)
Chhabra 2018[34]	N = Exp 45, Con 48 Age *(y)* = Exp 41 (14), Con 41 (14) Sex *(%F)* = NS Mechanical LBP ± radicular symptoms, > 12 wks duration, NPRS ≥ 5	Exercises: Physical activity program, back exercises, activities of daily living Technology: Smartphone, 'Snapcare' app	Exercises: Same as Exp, paper-based HEP in lieu of app	Written prescription from physician (medication, physical activity, home exercises)	NPRS, MODI	Baseline, 12 wks (post-intervention)
Chitkar 2021[33]	N = Exp 32, Con 32 Age *(y)* = Exp 59 (9), Con 58 (6) Sex *(%F)* = Exp 100, Con 100 Radiologically confirmed, symptomatic knee OA	Exercises: Exercises for knee OA, unclear description Technology: Smartphone	Exercises: Same as Exp, 2 × face-to-face sessions	Education (Knee OA causes, risk factors, treatment, diet and exercises)	WOMAC, SF-36	Baseline, 8 wks (post-intervention)
Choi 2019[36]	N = Exp 42, Con 42 Age *(y)* = Exp 54 (8), Con 55 (6) Sex *(%F)* = Exp 61, Con 73 Frozen shoulder, ≥ 1 mth duration	Exercises: Passive range of motion stretches (forward flexion, external rotation, cross-body adduction, sleeper stretch). Technology: Smartphone	Exercises: Same as Exp, exercise program delivered verbally	Celecoxib NSAID	VAS, shoulder range of motion (flexion, abduction, external rotation at side, internal rotation at back)	Baseline, 4 wks (mid-intervention), 8 wks (mid-intervention), 12 wks (post-intervention)
Lee 2017[27]	N = Exp 11, Con 9 Age *(y)* = Exp 27 (5), Con 28 (5) Sex *(%F)* = Exp 55, Con 45 Self-reported chronic neck pain, > 6 mths duration, VAS ≥ 3	Exercises: McKenzie neck exercise program, ≥ 2/wk. Technology: Smartphone, bespoke app	Exercises: Neck pain brochure (including exercise program) Other: 1 neck pain education session	Weekly text message reminders	VAS, NDI, exercise adherence	Baseline, 8 wks (post-intervention)
Thiengwittayaporn 2021[30]	N = Exp 44, Con 45 Age *(y)* = Exp 62 (7), Con 63 (10) Sex *(%F)* = Exp 86, Con 93 Unilateral or bilateral primary knee OA	Exercises: Lower limb strengthening and stretching, 3 exercises, 10 times each Technology Smartphone, 'Love your knee' app	Exercises: Same as Exp, paper-based HEP in lieu of app		ROM, KOOS, KSS	Baseline, 4 wks (post-intervention)

Table 1 (*Continued*)

Study	Participants	Interventions			Outcome(s)	Time points
		Experimental	Control	Both		
Van Reijen 2016, 2017[28,29]	N = Exp 110, Con 110 Age (*y*) = Exp 38 (13), Con 38 (14) Sex (*%F*) = Exp 50, Con 50 Self-reported ankle sprain in last 2 mths	Exercises: Lower limb strengthening, balance and proprioception (neuromuscular training). Technology: Smartphone, 'Strengthen your ankle' app	Exercises: Same as Exp, paper-based HEP in lieu of app	Balance board	FADI, adherence	Baseline, weekly, 8 wks (post-intervention), monthly until 12 mths

Con = control group, Exp = experimental group, FADI = Foot and Ankle Disability Index, HEP = home exercise program, KOOS = Knee Injury and Osteoarthritis Outcome Score, KSS = Knee Society Score, MODI = Modified Oswestry Disability Index, NDI = Neck Disability Index, NPRS = numerical pain rating scale, NS = not stated, NSAID = non-steroidal anti-inflammatory drugs, OA = osteoarthritis, OT = occupational therapy, PILE = progressive isoinertial lifting evaluation, PT = physiotherapy, QuickDASH = Quick Disabilities of the Shoulder, Arm and Hand questionnaire, SF-36 = Short Form 36 quality of life questionnaire, VAS = visual analogue scale, WOMAC = Western Ontario and McMaster Universities Arthritis Index, %F = percent female.

postural education[32]; or were not clearly described.[33] The intervention durations ranged from 4[30,37] to 12 weeks[34–36] (median 8 weeks). The dosage of exercise programs varied significantly between trials with frequency ranging from 2 to 3 times daily[36] to 'at least twice per week'.[27] Additional components included education, face-to-face physiotherapy and occupational therapy, prescription of medication, and text message reminders. Most studies delivered the mobile app via mobile phones, one study delivered the mobile app via a tablet device[37] and one study allowed either device to be used.[31] Comparator groups received the same therapeutic exercise programs without the use of a mobile app in eight studies[28–33,36,37] and a similar tailored therapeutic exercise or physical activity intervention in three studies.[27,34,35]

Behaviour change intervention functions were classified for all studies[33] (Table 2) (see Appendix 3 on the eAddenda for further details). All mobile app interventions incorporated 'training'. 'Enablement' (six studies) and 'environmental restructuring' (five studies) were also commonly utilised. 'Education', 'persuasion' and 'incentivisation' were each used in single studies and no study used 'coercion', 'restriction' or 'modelling'. All comparator interventions incorporated training and two incorporated 'enablement'.

Risk of bias assessment

All included studies were assessed as having a high risk of bias overall, resulting from high risk of bias or some concern in at least three of five ROB2 domains (Figure 2). Six studies[28–31,33,35,37] had high risk of bias due to missing outcome data (Domain 3) because of high participant drop-out without appropriate analysis. Only two studies[28,29,31] followed published a priori protocols, leading to some concerns for the majority of included studies in Domain 5 (reporting of results). Comparison of the results of included studies against available protocols was attempted to determine missing results (see Appendix 4 on the eAddenda). This was not possible for most studies as no protocol was published,[27,33,34,37] the protocol was not published a priori[32] or the protocol was unavailable.[35,36] One study added additional outcomes after publication of the protocol.[30] The remaining studies followed their published protocol.[28,29,31]

Outcome measures such as pain severity and pain interference were self-reported so the participants were the assessors and unable to be blinded to allocation (Domain 4), thus potential for bias in the domain related to measurement of outcomes was inevitable. In real-world implementation of mobile app interventions, patients will be aware of their purpose and therefore this source of bias will exist in practice as a contextual factor in mobile app intervention effectiveness. Risk of bias for each of the review's outcomes are presented in more detail in Appendix 5 on the eAddenda.

Effects of mobile app interventions

Pain intensity and pain interference

A meta-analysis of the effect of mobile apps to support therapeutic exercise or physical activity programs on pain intensity immediately after the intervention pooled the SMD of nine trials (Table 3, Figure 3) and demonstrated benefit in favour of mobile apps, with substantial heterogeneity (SMD −0.60, 95% CI −0.93 to −0.27, I^2 = 70%). For a detailed forest plot, see Figure 4 on the eAddenda. No studies measured pain intensity beyond immediately after the intervention. A subgroup analysis of studies in knee osteoarthritis populations showed significant benefit, with substantial heterogeneity (SMD −0.82, 95% CI −1.45 to −0.18, I^2 = 74%). The certainty of the body of evidence for pain intensity was low using the GRADE approach,[25] after downgrading for risk of bias and inconsistency (see Appendix 6 on the eAddenda).

The three studies measuring pain interference reported mixed results immediately after the intervention. Combining these studies in a meta-analysis again produced an estimate of substantial benefit (SMD −0.66); however, that estimate came with so much uncertainty (95% CI −1.52 to 0.19) that the true effect remained very uncertain (Figure 5); there was also considerable heterogeneity (I^2 = 80%). For a detailed forest plot, see Figure 6 on the eAddenda. The GRADE

Table 2
Comparison of intervention functions behaviour change between experimental (mobile app) and comparator interventions.

Study	Group	Education[a]	Persuasion	Incentivisation	Coercion	Training	Restriction	Environmental restructuring	Modelling	Enablement
Abadiyan 2021[32]	Exp					✓		✓		✓
	Con					✓				✓
Alasfour 2020[31]	Exp		✓			✓		✓		
	Con					✓				
Anan 2021[35]	Exp					✓				✓
	Con					✓				
Blanquero 2020[37]	Exp					✓		✓		
	Con					✓				
Chhabra 2018[34]	Exp			✓		✓		✓		✓
	Con					✓				
Chitkar 2021[33]	Exp					✓				
	Con					✓				
Choi 2019[36]	Exp					✓		✓		✓
	Con					✓				✓
Lee 2017[27]	Exp	✓				✓				
	Con					✓				
Thiengwittayaporn 2021[30]	Exp					✓				✓
	Con					✓				
Van Reijen 2016, 2017[28,29]	Exp					✓				✓
	Con					✓				

Con = control group, Exp = experimental group.
[a] Refers to increasing knowledge or understanding regarding the targeted exercise behaviour.

certainty of the body of evidence for pain interference was very low after being downgraded for risk of bias, inconsistency and imprecision (see Appendix 6 on the eAddenda).

Self-reported physical function and physical performance

The pooled effect of five studies reporting self-reported physical function (Table 4, Figure 7) favoured mobile apps (SMD −0.92) and this appeared to be a clinically worthwhile effect (95% CI −1.57 to −0.27) (see Figure 7, or Figure 8 for a detailed forest plot on the eAddenda.) This estimate had considerable heterogeneity (I^2 = 88%). Subgroup analysis of studies in knee osteoarthritis populations favoured mobile apps (SMD −1.33). Although there was some uncertainty in the estimate, all values contained with the confidence interval indicated worthwhile benefits (95% CI −2.06 to −0.60). Again, there was heterogeneity among the studies (I^2 = 78%). The GRADE certainty of the body of evidence for self-reported physical function was low after being downgraded for risk of bias and inconsistency. Van Reijen et al[29] also measured ankle function longer term (10 months after the intervention) and found negligible between-group difference (MD 0.7, 95% CI −1.2 to 2.6) on the 0-to-100 FADI scale.

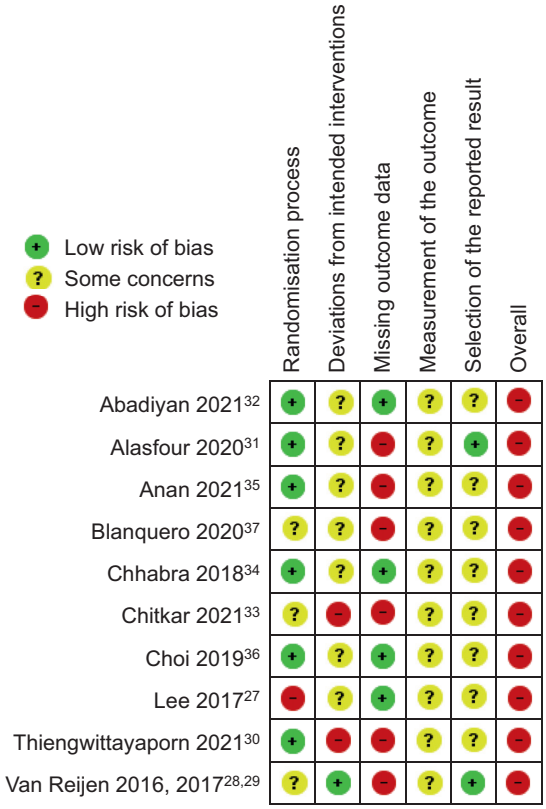

Figure 2. Risk of bias at overall study level.

Physical performance outcome measures were included in six studies[27,30–32,36,37] (Table 5). Meta-analyses were not performed due to the heterogeneity of outcomes. Of the 12 outcome measures reported, only one showed a clear between-group difference.[30] The GRADE certainty of the body of evidence for physical performance was low after being downgraded for risk of bias and imprecision (Appendix 6).

Adherence

Between-group differences in adherence to the prescribed exercise program were reported in two studies[28,31] (Table 6). Delivering exercises for knee osteoarthritis via a mobile app achieved better adherence than provision of printed materials.[31] There was similar adherence between mobile app-delivered and booklet-delivered exercises for ankle sprain.[28] One study measured adherence in the experimental group only and found that both the number of exercise sessions and the exercise time exceeded their target value.[27] The GRADE certainty of the body of evidence for adherence was very low after downgrading for study limitations, inconsistency and imprecision.

Psychosocial outcomes

One study found that the time taken to return to work was a mean of 18 days shorter (95% CI 3 to 33) in the experimental group (Table 6), which was argued by the original authors to be a worthwhile effect.[37] The GRADE certainty of evidence was very low after downgrading one level for study limitations and two levels for imprecision. One study reported fear avoidance beliefs[27] and found no clear between-group difference (Table 6). The GRADE classification of this outcome was very low after downgrading once for study limitations and twice for imprecision.

Table 3
Results for pain intensity and pain interference measures.

Study	Outcome measure	Post-intervention mean (SD)		Between-group difference mean (95% CI)
		Exp	Con	
Pain intensity				
Abadiyan 2021[32]	Pain VAS *(0 to 10)*	4.4 (1.7)	5.8 (1.1)	−1.4 (−2.3 to −0.5)
Alasfour 2020[31]	Pain NPRS *(0 to 10)*	3.6 (2.1)	5.2 (2.4)	−1.6 (−3.1 to −0.1)[a]
Anan 2021[35]	Pain scale *(1 to 5)*	3.0 (1.1)	4.0 (0.8)	−1.0 (−1.4 to −0.6)
Blanquero 2020[37]	Pain VAS *(0 to 10)*	2.7 (1.7)	3.6 (2.0)	−0.9 (−2.0 to 0.2)
Chhabra 2018[34]	NPRS *(0 to 10)*	3.3 (1.7)	3.2 (2.7)	0.1 (−0.8 to 1.0)
Chitkar 2021[33]	WOMAC – Pain *(0 to 20)*	11.8 (1.4)[b]	13.8 (1.4)[b]	−2.0 (−2.2 to −1.8)
Choi 2019[36]	Pain VAS *(0 to 10)*	1.8 (2.5)	2.2 (1.7)	−0.4 (−1.3 to 0.5)
Lee 2017[27]	Pain VAS *(0 to 10)*	2.7 (2.0)	3.7 (2.0)	−1.0 (−2.8 to 0.8)
Thiengwittayaporn 2021[30]	KOOS – Pain *(0 to 100)*	73.3 (7.2)	70.7 (5.9)	−2.6 (−5.4 to 0.2)
Pain interference				
Abadiyan 2021[32]	NDI *(0 to 50)*	19.3 (6.0)	28.5 (5.3)	−9.2 (−12.8 to −5.6)
Chhabra 2018[34]	MODI *(0 to 50)*	20.2 (17.8)	29.9 (20.1)	−9.7 (−17.4 to −2.0)
Lee 2017[27]	NDI *(0 to 50)*	17.3 (8.3)	15.9 (8.7)	1.4 (−6.1 to 8.9)

KOOS = Knee Injury and Osteoarthritis Outcome Score, MODI = Modified Oswestry Disability Index, NDI = Neck Disability Index, NPRS = Numerical Pain Rating Scale, VAS = Visual Analog Scale, WOMAC = Western Ontario and McMaster Universities Arthritis index.
[a] Calculated from published means (SD).
[b] SD calculated from published SE.

Health-related quality of life

Two studies reported health-related quality of life, using the SF-36[27,33] (Table 7). Physical functioning, bodily pain and vitality subscales were estimated to be better in the mobile app group in one study[33] but there were no clear between-group differences in any subscale in another study.[27] The certainty of this evidence using GRADE was very low after downgrading for study limitations and imprecision.

Goal attainment, physical activity and satisfaction

None of the included studies measured goal attainment, physical activity levels or satisfaction in both experimental and comparator groups.

Discussion

This systematic review identified potential benefits of using mobile apps to support therapeutic exercise and physical activity for people with musculoskeletal conditions, as well as avenues for further investigation and development in this field. Meta-analyses found low certainty evidence that mobile app-supported exercise interventions achieved greater improvements in pain intensity and self-reported physical function but no difference in pain interference compared with comparable exercise interventions without mobile app support. For the other outcomes, the limited data from low-quality studies showed mixed results for adherence and health-related quality of life, no benefit for fear avoidance beliefs, a reduction in the time taken to return to work, and no data for physical activity, goal attainment or satisfaction.

Our meta-analyses suggest that using mobile apps to support exercise may lead to a greater reduction in pain intensity, although the low certainty of evidence precluded strong recommendations from being made. The SMD of −0.6 (95% CI −0.93 to −0.27) appears to be a worthwhile improvement. When converted to the Numerical Pain Rating Scale, this equates to an improvement of 1.4 points (95% CI 0.6 to 2.2), which would be worthwhile for regular smartphone users. However, for those who would have to obtain a smartphone and/or improve their digital literacy, this result spans the smallest worthwhile effect that we nominated (1.5 points) or that others have nominated (2 points) for this outcome,[38] indicating uncertainty about whether the effect would be large enough to justify the use of an app to deliver the exercise intervention. The substantial statistical heterogeneity may reflect differences in populations between studies and the content of the mobile apps, in addition to biases due to study design. The modest reduction in pain intensity with the use of mobile apps found in this review is consistent with previous systematic reviews investigating a wider range of digital health interventions in knee osteoarthritis populations.[11,39]

The main estimate of the effect of mobile app-supported exercise on pain interference was that it has worthwhile benefit (SMD −0.66) but this estimate was so imprecise (95% CI −1.52 to 0.19) that the true

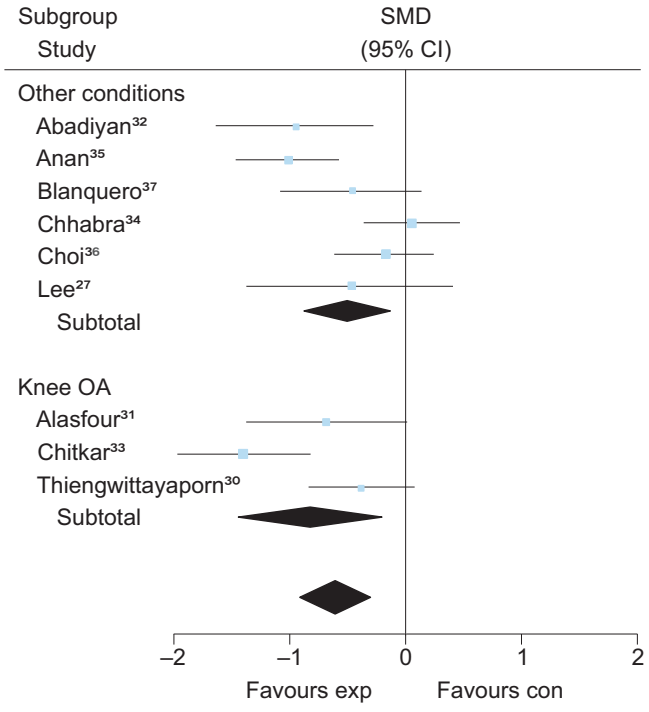

Figure 3. Forest plot of the results of random effects meta-analysis on the effect of intervention on pain intensity using post-intervention scores, demonstrated via SMD (95% CI). OA = osteoarthritis.

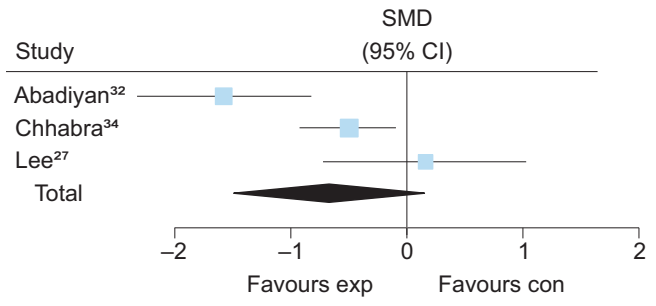

Figure 5. Forest plot of the results of random effects meta-analysis on the effect of intervention on pain interference using post-intervention scores, demonstrated via SMD (95% CI).

Table 4
Results for self-reported physical function.

Study	Outcome measure	Post-intervention mean (SD)		Between-group difference mean (95% CI)
		Exp	Con	
Alasfour 2020[31]	WOMAC – PF[a] *(0 to 28)*[c]	3.0 (1.9)	5.2 (3.2)	2.20 (0.4 to 3.96)[b]
Blanquero 2020[37]	QuickDASH *(0 to 100)*[c]	26.6 (16.8)[d]	37.7 (23.4)[d]	11.1 (–0.9 to 23.1)[d]
Chitkar 2021[33]	WOMAC – PF *(0 to 68)*[c]	41.0 (2.1)[e]	45.4 (2.0)[e]	4.9 (3.9 to 5.9)
Thiengwittayaporn 2021[30]	KOOS – ADL *(0 to 100)*[f]	80.4 (9.8)	71.2 (7.0)	9.2 (5.5 to 12.9)
Van Reijen 2016[28] (post-intervention)	FADI *(0 to 100)*[f]	95.9 (6.4)	94.6 (6.9)	1.3 (–0.6 to 3.2)
Van Reijen 2017[29] (10 mths)	FADI *(0 to 100)*[f]	97.2 (8.0)	97.9 (4.5)	0.7 (–1.2 to 2.6)

FADI = Foot and Ankle Disability Index, KOOS = Knee Injury and Osteoarthritis Outcome Score, PF = Physical Function subscale, QuickDASH = Shortened Disabilities of the Arm to Shoulder and Hand Questionnaire, WOMAC = Western Ontario and McMaster Universities Arthritis Index.
Between-group differences adjusted so positive difference indicates greater benefit in experimental group.
[a] Arabic version of the reduced WOMAC – Physical Function subscale.
[b] Calculated from published means (SD).
[c] Higher scores indicate greater disability.
[d] Re-calculated from individual participant data.
[e] SD calculated from published SE.
[f] Higher scores indicate less disability.

effect remains unclear. The evidence was also very low certainty: there were only three studies reporting this outcome, and one of the studies[27] showed a very marked baseline between-group difference, which could have influenced the result.

The meta-analysis for self-reported physical function also showed worthwhile benefit in favour of using mobile apps, albeit with low-certainty evidence; this was considered worthwhile for regular smartphone users. For others, the SMD of –0.92 equated to 7.8 points on the Knee Injury and Osteoarthritis Outcome Score, which was close to the estimated minimum important difference of 8 reported in a recent systematic review.[40] This benefit was greater in the subgroup of studies with knee osteoarthritis populations. In contrast, a recent systematic review, which looked at a broader range of technology to support exercise for people with knee osteoarthritis,[11] found no clear between-group difference in self-reported physical function. This could indicate that the use of mobile apps is more effective than other types of technology in achieving this outcome. However, further research addressing the methodological concerns of the body of evidence to date would be needed to confirm this conclusion.

Pain interference (the degree to which an individual's engagement in activities, including physical activities, is restricted) and physical function (the ability to perform physical activities) both measure aspects of physical ability. However, pain interference also includes cognitive, emotional and recreational activities, and more specifically measures the impact of pain, whereas physical function may also be impacted by factors other than pain.[41] The apparent difference in the results for pain interference and self-reported physical function

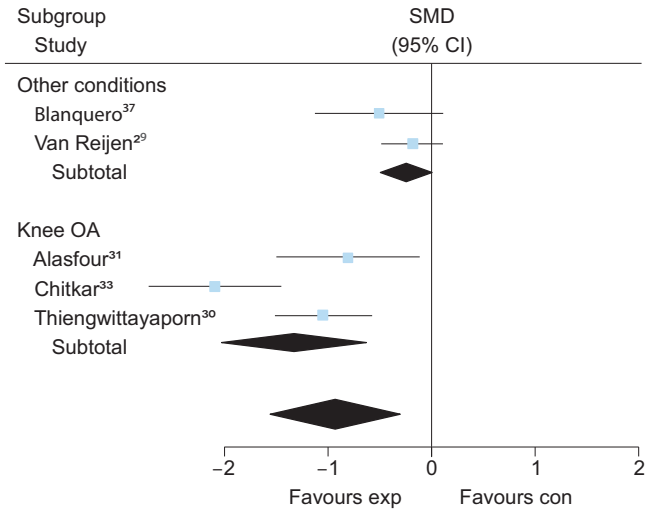

Figure 7. Forest plot of the results of random effects meta-analysis on the effect of intervention on self-reported physical function using post-intervention scores, demonstrated via SMD (95% CI). Higher mean values indicate greater disability. OA = osteoarthritis.

outcomes could reflect the different aspects of the patient experience that are being measured, differences in population, or limitations in the quality and quantity of the body of research for this outcome.

Physical performance measures were highly variable, encompassing strength, dexterity and range of motion. However, the findings were remarkably consistent, with only one of 12 physical performance outcomes demonstrating greater improvement in the mobile app group. This is consistent with previous literature,[42] suggesting that mechanisms underlying the improvements in pain and disability with exercise in chronic musculoskeletal pain may be due to factors other than improvements in physical performance, such as psychological and/or neurophysiological changes.[42]

Only two studies evaluated the effect of mobile apps on adherence to exercise.[28,31] One showed no benefit for people with ankle sprains[28] and the other found a clear benefit on adherence in women with knee osteoarthritis.[31] Two of three studies with adherence data for the experimental intervention group found that adherence exceeded the threshold for satisfactory adherence to exercise of 80% proposed by Bailey et al.[4] Despite adherence to exercise being theorised as a key mechanism influencing overall health outcomes,[4] less than one-quarter of studies reported this outcome. Furthermore, no studies measured self-reported or objectively measured physical activity levels. From a biopsychosocial perspective, physical activity participation is key to successful management of chronic disease, rather than being an end result of medical treatments that resolve disease or symptoms.[43] Measurement of adherence to exercise and physical activity levels is strongly recommended in future studies of interventions to support behaviour change in musculoskeletal pain conditions, including mobile apps. Future app design incorporating adherence-reporting features, either through self-report or incorporating data from wearable devices, could enhance research data collection and act as an additional behaviour change-focused intervention (eg, through feedback on performance).

There was very low certainty evidence of negligible between-group difference for fear avoidance beliefs and benefit in favour of mobile apps for work participation from single studies, and health-related quality of life showed mixed results. Psychosocial factors (such as anxiety, depression, illness beliefs, self-efficacy, catastrophising and coping strategies) are also important predictors of the course of musculoskeletal pain[17,44] and associated with lower adherence.[45] Further elaborating the effect of mobile apps on these factors may reveal important mechanisms of action.

Using intervention functions listed on the Behaviour Change Wheel to help understand the mechanisms of action[46] of mobile apps was an important secondary aim of this review. 'Training' in performance of the exercises (provided in all mobile app and control interventions), 'enablement' (eg, providing social support through encouragement and setting goals) and 'environmental restructuring' (eg, alarms and reminders) were used frequently in the mobile apps. In contrast, 'persuasion', 'education' and 'incentivisation' were used only in single studies and no studies incorporated 'modelling' (which

Table 5
Results for pain intensity and pain interference measures.

Study	Outcome measure	Post-intervention mean (SD)		Between-group difference mean (95% CI)
		Exp	Con	
Abadiyan 2021[32]	Progressive isoinertial lifting evaluation *(lb)*	60.2 (17.6)	66.7 (15.3)	−6.5 (−17.0 to 4.0)[a]
Alasfour 2020[31]	Five-times sit to stand test *(n)*	2.6 (1.1)	2.8 (1.3)	−0.2 (−1.0 to 0.60)[a]
Blanquero 2020[37]	Nine-hole peg test *(s)*	25 (5)	28 (8)	3.0 (−0.9 to 6.9)[a]
	Grip strength *(kg)*	22.9 (8.8)	20.1 (14.6)	2.8 (−4.3 to 9.9)[a]
	Pinch strength *(kg)*	5.6 (3.7)	5.2 (3.8)	0.4 (−1.9 to 2.7)[a]
Choi 2019[36]	Shoulder flexion ROM *(deg)*	146 (15.0)	142 (14.0)	4.0 (−2.2 to 10.2)[a]
	Shoulder abduction ROM *(deg)*	151 (18.0)	149 (16.0)	2.0 (−5.3 to 9.3)[a]
	Shoulder external rotation ROM *(deg)*	47 (15.0)	41 (15.0)	6.0 (−0.4 to 12.4)[a]
	Shoulder internal rotation ROM *(deg)*	11.7 (2.6)	12.6 (2.9)	−0.9 (−2.1 to 0.3)[a]
Lee 2017[27]	Neck flexion strength *(kg)*	13.2 (5.1)	15.8 (5.9)	−2.6 (−7.5 to 2.3)[a]
	Neck extension strength *(kg)*	25.9 (6.9)	21.1 (9.3)	4.8 (−2.5 to 12.1)[a]
Thiengwittayaporn 2021[30]	Knee flexion ROM *(deg)*	129.0 (6.5)	125.9 (5.6)	3.1 (0.5 to 5.7)[a]

ROM = range of motion.
Higher scores indicate better performance. Between-group difference adjusted so positive difference indicates greater benefit in experimental group.
[a] Calculated from published means (SD).

Table 6
Results for adherence and psychosocial outcomes.

Study	Outcome measure	Post-intervention mean (SD)		Between-group difference mean (95% CI)
		Exp	Con	
Adherence				
Alasfour 2020[31]	% of prescribed exercises completed (self-report)	85 (14)	60 (33)	25 (8 to 42)[a]
Lee 2017[27]	% of prescribed exercise sessions completed	119 (44)	Not measured	Not calculable
	% of prescribed exercise time completed	134 (89)	Not measured	Not calculable
Van Reijen 2016[28]	% of prescribed exercises completed (self-report)	64 (45)	66 (45)	−2 (−15 to 11)[a]
Psychosocial outcomes				
Blanquero 2020[37]	Time to return to work *(d)*	76 (33)	94 (32)	−18 (−33 to −3)
Lee 2017[27]	FABQ – Physical activity *(0 to 24)*	12.0 (5.7)	11.2 (5.6)	0.78 (−4.6 to 6.1)
	FABQ – Work *(0 to 42)*	20.7 (6.4)	17.1 (9.3)	3.6 (−3.7 to 11.0)

FABQ = Fear Avoidance Beliefs Questionnaire.
Between-group difference adjusted so positive difference indicates greater benefit in experimental group.
[a] Calculated from published means (SD).

Table 7
Results for health-related quality of life.

Study	Short Form-36 subscale *(0 to 100)*	Post-intervention mean (SD)		Between-group difference mean (95% CI)
		Exp	Con	
Chitkar 2021[33]	Physical functioning	42 (7)[a]	32 (7)[a]	9 (6 to 12)[b]
	Role: physical	13 (0)[a]	13 (0)[a]	0 (0 to 0)[b]
	Bodily pain	50 (8)[a]	46 (8)[a]	4 (0 to 9)[b]
	General health	29 (6)[a]	28 (6)[a]	1 (−2 to 4)[b]
	Vitality	67 (7)[a]	57 (7)[a]	10 (6 to 13)[b]
	Social functioning	41 (10)[a]	40 (10)[a]	1 (−4 to 6)[b]
	Role: emotional	30 (25)[a]	17 (25)[a]	13 (1 to 26)[b]
	Emotional well-being	59 (0)[a]	59 (0)[a]	0 (0 to 0)[b]
Lee 2017[27]	Physical functioning	90 (19)	94 (10)	−5 (−19 to 10)[c]
	Role: physical	78 (28)	73 (23)	5 (−19 to 29)[c]
	Bodily pain	68 (15)	69 (16)	−1 (−14 to 13)[c]
	General health	50 (31)	57 (12)	−7 (−30 to 16)[c]
	Vitality	57 (19)	52 (16)	5 (−12 to 22)[c]
	Social functioning	81 (21)	72 (14)	10 (−7 to 27)[c]
	Role: emotional	73 (41)	69 (43)	4 (−35 to 44)[c]
	Emotional well-being	65 (20)	64 (18)	1 (−17 to 19)[c]

Between-group differences adjusted so positive differences indicate greater benefit in the experimental group.
[a] Standard deviation calculated from published standard error.
[b] Between-group difference calculated from published means and standard deviations as calculated from standard errors.
[c] Calculated from published means (SD).

may be appropriate in this setting), 'coercion' or 'restriction' (which are perhaps not appropriate). Incorporating 'education', 'incentivisation' and 'persuasion' intervention functions, such as through the use of notifications, badges or rewards, could provide alternative avenues to improve motivation[46] and address barriers such as poor self-efficacy and low self-motivation known to negatively impact adherence in musculoskeletal pain conditions.[45] Modelling, such as the incorporation of story-telling with real-life examples, could also enhance motivation.[46]

This systematic review adhered to the recommendations for conducting and reporting systematic reviews.[20] Focusing on mobile app interventions specifically, rather than all digital health interventions, enabled a more focused exploration of the unique effects of apps. The broad population reflected clinical practice and optimised external validity and generalisability. It was judged appropriate to group all musculoskeletal pain conditions together, as the clinical course and prognostic factors are likely to be similar.[3] Narrowing the definition of exercise to include only clinician-prescribed exercise or

physical activity tailored to the individual and their condition was intended to mirror health professionals' clinical practice, rather than broader public health interventions. Narrowly defined eligibility criteria for comparators (ie, including only similar exercise/physical activity interventions and excluding usual care, inactive controls or other non-exercise programs) ensured that between-group differences could be attributed to the mobile app. The comprehensive search strategy minimised the risk of studies being missing; however, at least one non-English language study was omitted due to inability to obtain a translation. The ROB2 has been criticised due to poor clinimetric properties;[47,48] however, it is still preferred due to its measurement of risk of bias rather than methodological quality or adherence to reporting guidelines. ROB2 was assessed independently by two reviewers, followed by discussion of discrepancies, to improve accuracy of risk of bias results. The emergent nature of this field may be subject to time-lag bias, increasing the possibility that useful studies are as yet unavailable.[26] This systematic review also needs to be considered in the context of changes in technology over time and the rapidly evolving nature of research in this area; therefore, it would be good to update this review in the near future.

Categorising the behaviour change content of the mobile apps using behaviour change intervention functions[15] provided an overview of their behaviour change content and was appropriate for the level of detail likely to be found in published articles at this time. This review did not assess the quality of operationalisation of the behaviour change intervention functions, only their presence or absence. Therefore, the behaviour change categorisation undertaken should be interpreted cautiously, as a broad, preliminary exploration of behaviour change content. Future research could investigate other aspects of mobile app-based behaviour change content, such as behaviour change techniques. Future mobile app interventions need to be better described in terms of their behaviour change components, to enable future reviews to determine the mechanisms of action associated with the best outcomes (eg, intervention design could be described in terms of behaviour change models such as the Capability, Opportunity, Motivation, Behaviour (COM-B) model).[46] There is also potential to explore how unique features of mobile apps, such as synchronisation with wearable devices, may assist with delivery of interventions directed at behaviour change.

Based on these findings, it is recommended that mobile apps be considered as an option to deliver therapeutic exercise and physical activity programs for people with musculoskeletal pain conditions. Initial evidence suggests that mobile apps may help achieve worthwhile improvements in pain intensity, self-reported physical function and work participation for regular smartphone users, and potentially worthwhile improvements in these outcomes for others. There were no signals that pain interference, physical performance, fear avoidance beliefs, adherence and health-related quality of life are detrimentally affected by using mobile apps compared with other modes of delivery. Due to the low to very low quality of evidence for these outcomes, these conclusions may change as further research becomes available. Future design of mobile apps and their incorporation into therapeutic interventions should harness mobile apps' potential to deliver more behaviour change features in order to achieve the best possible outcomes for people with musculoskeletal pain conditions.

What is known on this topic: Exercise programs are a high-value, low-cost intervention for improving symptoms and function in musculoskeletal pain conditions, provided that sufficient adherence is achieved. Adherence to exercise can be improved by behaviour change interventions.

What this study adds: Mobile apps supporting therapeutic exercise or tailored physical activity programs for musculoskeletal pain conditions may help in reducing pain intensity and improving physical function. These effects are particularly evident in trials involving people with knee osteoarthritis. Mobile apps utilised a limited range of behaviour change intervention functions.

Footnotes: [a] Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia

[b] Review Manager V.5.3, The Nordic Cochrane Centre, Copenhagen, Denmark

eAddenda: Figures 4, 6 and 8, and Appendices 1 to 6 can be found online at https://doi.org/10.1016/j.jphys.2022.11.012

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