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Does gait retraining have the potential to reduce medial compartmental loading in individuals with knee osteoarthritis whilst not adversely affecting the other lower limb joints? A systematic review

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Title: Does gait retraining have the potential to reduce medial compartmental loading in individuals with knee osteoarthritis whilst not adversely affecting the other lower limb joints? A systematic review

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Title: Does gait retraining have the potential to reduce medial compartmental loading in individuals with knee osteoarthritis whilst not adversely affecting the other lower limb joints? A systematic review

Abstract:

Objectives: To review the literature regarding gait retraining to reduce knee adduction moments and its effects on hip and ankle biomechanics.

Data sources: Twelve academic databases were searched from inception to January 2019. Key words “walk*” OR “gait”, “knee” OR “adduction moment”, “osteoarthriti*” OR “arthriti*” OR “osteo arthriti*” OR “OA”, and “hip” OR “ankle” were combined with conjunction “and” in all fields.

Study selection: Abstracts and full-text articles were assessed by two individuals against a pre-defined criterion.

Data synthesis: Out of the 11 studies, sample sizes varied from 8-40 participants. Eight different gait retraining styles were evaluated: hip internal rotation, lateral trunk lean, toe-in, toe-out, increased step width, medial thrust, contralateral pelvic drop, and medial foot weight transfer. Using the Black and Downs tool, the methodological quality of the included studies was fair to moderate ranging between 12/25 to 18/28. Trunk lean and medial thrust produced the biggest reductions in first peak knee adduction moment. Studies lacked collective sagittal and frontal plane hip and ankle joint biomechanics. Generally, studies had a low sample size of healthy participants and assessed gait retraining during one laboratory visit, whilst not documenting the difficulty of the gait retraining style.

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Conclusions: Gait retraining techniques may reduce knee joint loading, however the biomechanical effects to the pelvis, hip and ankle is unknown, as well as a lack of understanding for the ease of application of the gait retraining styles.

Systematic review registration number: CRD42018085738

Keywords: Gait; Gait retraining; Knee osteoarthritis; Knee adduction moment; Systematic review; Biomechanics

Abbreviations: osteoarthritis (OA); external knee adduction moment (EKAM); International Prospective Register of Systematic Reviews (PROSPERO); preferred reporting items for systematic reviews and meta-analysis (PRISMA); patient, intervention, comparison, and outcome (PICO); patient-reported outcome measures (PROMS); external hip adduction moment (EHAM).

Rationale

Overloading of the medial knee compartment has been strongly associated with osteoarthritis (OA) progression [1] and radiographic disease severity [2]. The parameter of most relevance to medial knee OA is the external knee adduction moment (EKAM) [3]. This moment, which acts to force the tibia into varus, has been validated as a reliable indicator of medial knee load [4]. The EKAM reflects medial-to-lateral knee joint load distribution during gait [5]. In the presence of increased EKAM, the medial compartment of the tibial-femoral joint will typically experience increased load [3].

Numerous potential gait modifications have been proposed to reduce EKAM [3]. These alterations include: wide stance gait [6], toe-out gait [7], [8], toe-in gait [3], medial thrust gait [9], [10], trunk lean gait [11], and medial foot weight transfer of the foot [12]. Consequently, gait modifying strategies have been proposed as a conservative strategy to reduce knee joint loading [3].

Simic et al.'s systematic review [3] analysed gait modification strategies for altering medial knee joint load. Simic and colleagues [3] concluded that different gait modifications exert different effects on dynamic knee load at varying points throughout the gait cycle. Of the 14 gait modifications identified, medial thrust and trunk lean most consistently reduced first peak EKAM. However, some of the reported results were conflicting and/or based on very few/single studies. In addition, sufficient data was not available to address whether there are any changes at other lower extremity joints with the implementation of gait modifications to reduce EKAM [3]. It has been suggested that an increased loading rate in the lower extremity joints may lead to a faster progression of existing OA and to the onset of OA at joints adjacent to the knee [3]. Therefore, any interventions for knee OA should be assessed for their effects on the mechanics of all joints of the lower extremity. This warrants the current review to establish the body of evidence on how changes to EKAM effects adjacent joints to the knee as a result of modifying an individual's gait. Richards et al. [13] outlined the potential of direct feedback on modifying gait. In this study the authors considered the effects of reducing EKAM on the hip and ankle joints. Richards et al. [13] concluded that external hip moments were not significantly increased with a modified gait, but small increases in external ankle adduction moment and external knee flexion moment (KFM) were observed. The interaction between hip, knee and ankle biomechanics is not well understood when modifying gait in medial knee OA patients and needs to be reviewed to make clinical decisions on the role of gait retraining in reducing knee joint pain and discomfort [13]; justifying the necessity of a systematic review of the current literature.

Previous research has indicated that patients with knee OA experience abnormal loads of their major weight bearing joints bilaterally, and abnormalities persist despite treatment of the affected limb [13]. Further treatment may be required if we are to protect the other major joints following joint arthroplasty. No systematic review has established what effects changing knee joint loading via gait style modification has on the other ipsilateral and contralateral joints in the lower limbs as well as trunk biomechanics. To lower knee joint loading, altered gait styles will undoubtedly change the kinematics and/or kinetics at the neighbouring joints; e.g. for toe-in gait the foot is at a more inverted position throughout the gait cycle. The clinical benefit of reducing the EKAM variables is questionable if there are detrimental consequences to other joints of the lower body. If the goal of gait retraining is to alleviate pain and to slow down the deterioration of medial joint loading at the knee itself whilst not adversely affecting hip and ankle joint function, then an appreciation of what biomechanical changes are occurring at the hip and ankle joints is fundamental.

Objectives

The objectives of this systematic review were to: (1) to identify the consequences of gait modifications on the biomechanics of the ankle and hip as well as trunk and pelvis biomechanics, and (2) to establish whether gait styles and gait retraining can reduce medial knee loading as assessed by first and second peak EKAMs. Additionally, a third objective was to outline patient/participant reported outcomes on how easy the gait retraining style was to implement. This would aid the clinical translation of aforenamed gait retraining techniques.

Methods

Protocol and registration

In accordance with the PRISMA guidelines [14] the protocol for this systematic review was registered with the International Prospective Register of Systematic Reviews (PROSPERO) on the 23rd January 2018 (registration ID: CRD42018085738) (available at https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=85738).

Eligibility criteria

No study design, date or language limits were applied. After search one, only peer-reviewed quantitative academic articles published in English were considered.

Any study design that evaluated the effect of any gait retraining technique on EKAM, whilst also evaluating at least one biomechanical variable at the ankle and/or hip were eligible for inclusion. There was no restriction on whether the participants of a study had to be clinically diagnosed as having medial knee OA. The reason for including studies involving gait retraining on healthy participants was due to the anticipated lack of studies using participants with symptomatic knee OA, as evidenced in previous systematic reviews on similar topics [3], [15]. In the interpretation of results, healthy and OA cohorts are presented separately to establish any biomechanical differences between them when adopting a gait style.

Intervention

Gait retraining was defined as any researcher-initiated alteration of natural gait without the use of any devices or walking aids. Studies were included if they used 3-dimensional motion analysis and force-plate derived data during both natural and modified gait conditions as well as providing EKAM data. The altered gait style (intervention variable) was compared to the individual's natural level gait (control variable).

Studies evaluating post knee operations such as total knee replacements as well as studies that included participants with specific diseases and conditions which can affect the participant's gait were excluded.

Information sources

Database searches were undertaken by one reviewer (JBB) with the assistance of two experienced librarians up to the January 2019 on the following databases: Cumulative index to Nursing and Allied Health (CINAHL, 1982-2019), EBSCO MEDLINE (MEDL) (1966-2019), Ovid Allied and Complementary Medicine Database (AMED) (1995-2019), Ovid EMCare (1995-2019), Ovid Joanna Briggs Institute (JBI) (1991-2019), Web of Science (1900-2019), BIOSIS Citation Index (Web of Science) (1926-2019), Scopus (1960-2019), Cochrane Library (Cochrane Library, DARE and Central), ProQuest British Nursing Index (BNI) (1994-2019), Turning Research Into Practice Pro (TRIP PRO) (1997-2019), British Library e-theses online service (EThOS) (all years until 2019) and ProQuest Dissertations & Theses (1986-2019). Additionally, PROSPERO was searched for ongoing or recently completed systematic reviews.

Preferred reporting items for systematic reviews and meta-analysis guidelines [14] were used as guidelines of how to undertake this systematic review.

Search

To ensure maximum saturation of articles, the search strategy was purposely designed to be broad in its approach. The search strategy was designed by following the PICO model (patient, intervention, comparison, and outcome) [16].

The electronic databases were searched through using the combination of key search terms organised into sets and combined with the operators 'AND' and 'OR (Appendix 1).

Study selection

Titles were assessed by one author (JBB). The Principle investigators for each ClinicalTrials.gov identifier number (NCT number) were contacted to ascertain what peer-reviewed papers had been published from these clinical trials. Two authors assessed the abstracts of the remaining articles (PRB and JBB) independently. To ensure consistency and for expert advice, articles that were included in the systematic review were collectively reviewed by JBB, PRB and CAH. During a meeting, the key data that was to be extracted from each study was determined.

Data collection process

JBB extracted the data for the following items: study design, sample size, participant characteristics, gait modification/technique used, EKAM parameters evaluated, study duration, ankle and/or hip biomechanical analysis that was undertaken, and the main study findings.

Risk of bias in individual studies

Risk of bias was assessed using the Downs and Black quality index [17]. This is a validated index for non-randomised trials [15] consisting of 27 items used to assess reporting quality (items 1-10), external validity (items 11-13), internal validity (14-26) and study power (item 27). The tool has been used in various modified forms for gait focusing on interventions aimed at individuals with knee OA [3], [18]–[21]. Piloting of the tool and agreeing on interpretation of the questions was undertaken by 2 reviewers (JBB and PRB). Risk of bias scores for individual studies were rated In line with previous systematic reviews on similar topics [3], [15]. Neither review ([3], [15]) explicitly defined their boundaries in their papers and so the authors of the current review have inferred that 10-14 and 15-20 correspond with fair and moderate scores respectively.

Summary measures

The principal summary measure from each article was the within-group mean differences in hip and/or ankle data between natural level gait and the gait retraining intervention presented as a percentage difference from natural level gait. Summarised mean difference effect sizes were also calculated for these metrics.

EKAM has been used widely in the gait retraining literature as a surrogate measurement of medial knee joint loading [3]. For the purpose of this review, 'natural level gait' is defined as an individual assessment of an individual walking without any instruction as to alter their ordinary walking pattern when being assessed in a motion capture laboratory. Finally, any data presented regarding participant perceptions on task difficulty was extracted to consider the practicality of translation to a clinical setting.

Changes from the original protocol

After analysing the data from the 11 studies that met the inclusion criteria, there was enough evidence for trunk and pelvic biomechanical data to be included in the analysis. Therefore, this review has also documented trunk and pelvic biomechanical data. Additionally, the decision was made after the databases were searched to include any information on how easy the gait retraining was to implement.

Synthesis of results

A synthesis of results is provided with information presented in the text and tables to summarise and explain the main characteristics and findings of the included studies. The narrative synthesis explores the relationship of the findings between the included studies by way of gait style comparisons and methodological quality. The standardised mean difference (SMD) using the hedges' g effect size was calculated for the change in EKAM and hip/ankle kinetic metrics. The SMDs were standardised according to small (0.2–0.5), medium (.51–0.8), and large (>0.8).

Statistical analysis

Downs and Black scoring agreement between two reviewers (JBB and PRB) was assessed using a Cohen's kappa coefficient (k) statistic, with reference to Landis and Koch's criteria where κ values >0.81 represent 'almost perfect' agreement [22]. To estimate the SMD, the mean and standard deviation values were used. If mean and standard error mean (SEM) data were provided in the studies, standard deviation was calculated as SEM multiplied by the square root of the sample size. Standardised mean differences were calculated using the Hedges' g effect size. All results are presented as Forest Plots. The 95% confidence interval (CI) was calculated and presented for each effect size.

Results

Study selection

The search strategy resulted in a possible 184 studies to be included into the review, as shown in the PRISMA flow diagram (Figure 1). The reviewers showed substantial agreement in assessing the quality of each included study, k = 0.89. The 11 included articles focused on assessing the effects of gait modifications on reducing EKAM as well as documenting biomechanical variables for the pelvis, hip and ankle joints. All data presented in this systematic review is from the medial knee OA ipsilateral limb for the patients. For healthy participants, the data presented is for the side reported in the respective article.

Study characteristics

Table 1 outlines the group demographics. All studies, except [9], utilised a within-subject design and most studies evaluated the immediate within-session effect and potential benefits of gait retraining. Sample sizes varied from 8-40 participants. Six of the 11 studies assessed healthy participants, five included knee OA participants. In Simic et al.'s systematic review [3], there was only study of interest to be included in the current systematic review [23]. Table 2 presents the Kellgren and Lawrence (K/L) grade and patient-reported outcome measures (PROMS) on knee OA disease severity for the articles that included knee OA patients in their research.

Risk of bias within studies

The methodological quality of the included studies was fair to moderate. The quality indices of included articles ranged from 12/25 to 18/28 with a mean of 15.0 (Table 3). Studies assessing OA participants ranged between 14-17, whilst the healthy cohort studies had a wider range of methodological quality ranging 12-18. All studies that involved OA participants had high reporting scores, low external validity scores, 4/6 for internal validity (bias), low scoring 0-2 out of 6 for internal validity (confounding) and scored for power reporting. Studies that used a healthy cohort varied in their reporting (6-10 out of 10), 0 out of 3 for external validity, mixed scores for internal validity (confounding) (1-3 out of 6) and varied in reporting the sample power of the respective study. Average inter-rater reliability between the two independent reviewers (JBB and PRB) across all questions was very strong (k = 0.89) (Appendix 2). Table 3 outlines JBB's scoring for the risk of bias for each study.

Results of individual studies

Overall gait retraining style strategies

Standardised mean differences were calculated using the Hedges' g effect size. All results are presented as Forest Plots in figures 2-6 for EKAM1&2, hip kinetics, hip kinematics, ankle kinetics and ankle kinematics respectively. Eight different gait retraining styles were evaluated (Table 1): hip internal rotation [9], [24], trunk lean [23]–[25], toe-in gait [26]–[28], contralateral pelvic drop [29], medial thrust gait [24], medial weight transfer at the foot [12], toe-out gait 237 [26], [28], and self-selected combination of toe-in, wide stance and medial thrust [18]. Individual studies assessing these various gait style interventions also varied in terms of study quality. Two studies assessing toe-in gait had scores of 12 and 14 out of 25 for study quality [27], [28] respectively. One hip internal rotation study [30] scored 14/25 whilst another scored 18/28 [9]. The SMD effect size varied across studies for a given measured variable, as well as varying 95% CI for the effect size.

Biomechanical variables reported

Primary analysis: Ankle/hip biomechanics

Hip kinetic biomechanics

Peak external abduction moment was addressed in two studies, one study showed a null to small effect due to a trunk lean intervention for all three trunk lean angles assessed [25], with the small effect resulting from the largest of the three trunk leans assessed (~ 12°) (SMD 0.23 CI -0.69 to 1.16). This is compared to a large increase due to a trunk lean (~ 10°) intervention in another study [23] (SMD 0.89 CI 0.23 to 1.56). These findings indicate that there may be a dose-response effect on trunk lean angle and an increase in peak external hip abduction moment. Both studies assessed healthy participants and lacked external validity which severely hinders any inferences to gait alterations on peak external hip abduction moments in a medial knee OA population.

Peak external hip adduction moment (EHAM) was assessed by one study [18] which indicated a null effect (SMD <0.2) when utilising various feedback mechanisms to reduce EKAM 1. Richards et al. paper [18] evaluated the effect of real-time feedback on an OA population. First/early peak EHAM was assessed in three trunk lean studies showing conflicting effects [23]–[25]. The conflicting findings may be due to one study using an OA cohort group [24] (indicating a small effect increase (SMD 0.36 CI -0.15 to 0.87) and the other two assessing a healthy cohort [23], [25] (indicating a small and a large effect size decrease in late stance EHAM).

Late stance peak EHAM changes due to a trunk lean intervention indicates that the greater the trunk lean implemented, the lower the reduction in late stance peak EHAM with increasingly higher effect size associated with the change accordingly to the increase in trunk lean angle. However caution must be had due to one study assessing a patient population [24] whilst the other assessed a healthy group of participants [25]. This change in late stance peak EHAM for a trunk lean intervention appears to be different to the use of a medial thrust gait style, which indicates a small effect size increase (SMD 0.25 CI -0.26 to 0.75).

In terms of sagittal plane hip kinetics, only one study [18] assessed peak external hip flexion moment, indicating a null effect for all four different feedback mechanisms (SMD <0.2). Maximum hip axial loading rates was assessed by one study [9], which indicated a null effect (SMD -0.08 CI -0.72 to 0.55).

Overall, reporting of hip kinetic data is lacking across the studies. Caution must be had when interpreting these results due to the lack of external validity and due to the different population groups assessed in each study. Additionally, the 95% CI was large for all variables assessed, with most metrics 95% CI measured crossing the line of null effect.

Ankle kinetic biomechanics

Early and late stance peak external inversion moment were assessed in one study [24]. In the early stance, a null effect for trunk lean was calculated (SMD 0 CI -0.51, 0.51) but potentially increasing when adopting a medial thrust gait (SMD 0.49 CI -0.02, 1.01). In late stance, [24] indicated null effect for trunk lean (SMD 0.15 CI -0.66, 0.36) and small effect medial thrust (SMD 0.33 CI -0.84, 0.18) reductions in peak external inversion moment. This study was rated as moderate (15/25) and assessed an OA population.

Peak frontal and sagittal plane external moments were assessed by one study [18]. In the frontal plane, the effect sizes should be interpreted with caution due to the very high standard deviation. Sagittal plane moment indicated a null effect for the various intervention types utilised in [18]. This study was rated as moderate (15/25) and assessed an OA population.

Peak external ankle eversion/inversion and plantarflexion/dorsiflexion moments were assessed in one study [26]; all of which had a 95% CI crossing the line of null effect. This indicates that caution should be taken when interpreting the SMD effect size in isolation. This was also true for peak external ankle plantarflexion/dorsiflexion moment impulses [26]. Again, limiting the interpretation of the SMD value. However, for toe-out gait peak external ankle eversion moment impulse appears to reduce whilst having a null effect for toe-in gait. Whilst for the peak external ankle inversion moment impulse, there appears to be a large effect size indicating an increased load when adopting a toe-in gait compared to natural gait (SMD of 1.43 [0.6, 2.26]). This study was rated as moderate (15/25) and assessed an OA population.

Centre of pressure at EKAM1 and EKAM2 was only assessed for toe-in gait [27]; both of which indicating no effect size (SMD < 0.2) when adopting a toe-in gait style. First and second half of stance centre of pressure were assessed in one study [12] which reported a large effect size increase in the first half of stance CoP due to the intervention and small size increase in the second half of stance CoP (SMD of 0.85 and 0.28 respectively). However, the 95% CI for these two variables cross the line of null effect, and so caution must be taken in the interpretation of these findings. Maximum ankle axial loading rates was assessed by one study [9], which indicated a null effect (SMD -0.15 CI -0.79, 0.49).

All ankle kinetic data presented above utilised an OA population within their studies, with varying methodological scores (14-17 out of 25); having scored low on external validity. Caution should be had when assessing the effect sizes alone as the 95% CI tend to cross the line of null effect. Therefore, interpretation should always consider the 955 CI values when making conclusions for a gait style.

Trunk & pelvis biomechanics

Six studies reported various pelvic/trunk biomechanics data [23]–[25], [27], [29], [30] (Table 5). Shull et al. [27] did not find any significant changes in lateral trunk sway at first or second peak EKAM between natural gait and a toe-in gait modification. Gerbrands et al. [24] reported a significant increase in peak trunk angle between natural gait to both trunk lean and medial thrust gait modifications. The trunk biomechanics presented [25] and [23] describes the mean (± SD) trunk lean angles for the gait styles performed. Van den Noort et al. [30] outlines a number of trunk and hip changes with and without hip internal rotation feedback on hip internal rotation. Dunphy et al. [29] studied the influence of contralateral pelvic drop and noted the differences in pelvic drop angle between natural gait and contralateral pelvic drop gait style.

External knee adduction moment

Trunk lean (~ 10°) [23] had the biggest reduction in EKAM1 compared to natural walking (SMD -1.99 CI -2.72, -1.18). In addition, other studies assessing trunk lean indicated large reductions in EKAM1 [24] (SMD -1.18 CI -2.24, -0.11), [25] (SMD -0.45 CI -1.12, 0.24). Trunk lean also appears to be dose dependent, the larger the degree of trunk lean, the larger the reduction in EKAM1. Hip internal rotation [9] (SMD -1.24 CI -2.31, -0.17), medial thrust [24] (SMD -0.66 CI -1.17, -0.13), toe-in gait (SMD -0.57 CI -1.29, 0.17) [26], and a self-selection of a combination of toe-in, wider stance and medialisation of the knee position whilst receiving visual direct feedback on EKAM (SMD -0.54 CI -0.98, -0.09) also had medium to large effect size on reducing EKAM1.

The effects of gait styles on EKAM2 were less pronounced, with only two studies showing a medium effect size reduction. Firstly, using polar visual feedback on hip internal rotation (SMD -0.60 CI -1.28, 0.09) [26] and toe-out gait (~ 20°) [26] (SMD -0.50 CI -1.23, 0.22). All studies that assessed a gait style compared to natural gait for EKAM2 had a CI that crossed the line of null effect.

Ease of adapting gait style

After the review protocol was made available, the authors of the review decided that it would enrich the study by extracting additional information to establish the ease of adopting a given gait style. Five studies included subjective commentary on how easy the gait retraining was to implement [9], [25]–[27], [30]; with [9], [26], [30] asking the participants for their feedback. Barrios et al. [9] found that effort and how natural the retraining was to implement improved from sessions 1 to 8. In van den Noort et al. (2015) [30], the intuitiveness of the type of feedback was verbally tested after each trial by a subjective score on the question: “how well were you able to modify your gait pattern?”. There were no significant differences between subjective scoring of the intuitiveness for all visual feedback trials. Therefore, the type of visual feedback is not of primary concern when aiming to modify gait [30]. In Charlton et al. [26] discomfort levels were low across the toe-in, natural and toe-out walks for the ankle/foot, knee and for the hip. All participants in Hunt et al. (2011) [25] reported at least some difficulty in performing the increased trunk lean walking trials. Shull et al. (2013) [27] commented on the ease of learning toe-in gait only within the paper's discussion section. Subjectively, participants in the aforementioned study appeared to walk naturally with toe-in gait.

Study quality assessment

The methodologic quality of included studies could be considered fair to moderate. Overall, 2 studies were rated fair, and 9 studies were moderately rated (Table 3). Studies lacked external validity and internal validity (confounding). In addition to the methodological issues highlighted by the Downs and Black tool, other methodologic issues included the failure to thoroughly control extraneous variables such as speed and step length, inadequate standardisation of gait modification magnitudes, and small sample sizes. Also, to assess the efficacy of gait modifications it is necessary to capture the immediate and long-term effects on patient-reported pain, function and discomfort.

DISCUSSION

Summary of evidence

This systematic review evaluated whether gait retraining can reduce EKAM whilst not affecting adjacent joints. This is the first systematic review that has evidenced a lack of reporting of hip and/or ankle joint biomechanics when altered knee joint loading is targeted during gait retraining protocols. On the evidence currently available in the gait retraining literature we cannot not confirm whether there is an adverse effect on adjacent joints to the knee when adopting a gait style due to the lack of, as well as conflicting, evidence presented.

This systematic review suggests that different gait retraining strategies may have different knee joint loading alterations. Strategies that reduced first peak EKAM the most were an increased trunk lean, hip internal rotation, and medial thrust gait (Table 4). Conclusions are based on a very limited number of studies included within this review; emphasising the need for further exploratory studies to be undertaken. In addition to the small number of included studies, the quality of the trunk lean gait style and medial thrust gait style studies was 15/25, indicating moderate methodological quality. These findings agree with the systematic review by Simic et al. (2011) [3] with medial thrust and trunk lean showing the highest reductions in early stance EKAM (Table 4). All studies lacked external validity and so the conclusions of these individual studies cannot be generalised to other populations. This systematic review has highlighted the need for further studies to assess the effect of gait retraining styles on an OA population group.

The feasibility of applying these strategies in daily life might depend greatly on changes in the loading of joints, ligaments and muscles throughout the kinematic chain, a potential increase of energy expenditure and the aesthetics of the resulting gait [24]. Other studies outside of this review have indicated that trunk lean can increase energy expenditure, which may lead to fatigue and discomfort for the individual [31], [32]. So, whilst trunk lean may aim have the biggest change in effect size to reduce knee joint loading, there may be changes in terms of energy expenditure that may be counterproductive.

In this systematic review, many studies reported very little evidence of the biomechanical effect of gait retraining on the hip and/or ankle joints. Accordingly, the adverse effects of the proposed gait retraining strategies cannot be thoroughly evaluated and should be addressed in future studies. This is an area of research that needs to be reviewed for future research before gait retraining can be recommended as a clinical intervention.

Despite the limited research available that has highlighted the consequences of reducing first peak EKAM from gait retraining interventions and its effects on the hip and ankle joints, the reduction in knee joint loading may be clinically important. However, any recommendations made must be made with caution due to the lack of available hip and ankle data as well as the lack of external validity within the studies. Hunt et al. (2011) [25] outlined a pathway towards clinical translation of their findings, such as examining the biomechanical effects at other joints and overcoming potential barriers to using this intervention in individuals with knee OA. Van den Noort et al. (2015) [30] suggested future research should focus on modification of gait patterns to the extent that a clinically significant reduction in the EKAM (and not a maximum) is achieved, and a sustainable gait pattern is developed that can be maintained by knee OA patients in daily life. Erhart-Hledik et al. (2017) [12] states that the sustainability of the gait retraining and tolerability for longer-term clinical implementation requires future consideration. While the results are promising, and the gait modification was readily achieved, a longitudinal study would be required to determine the feasibility of the gait modification to improve joint loading in the long term as well as evaluate potential improvements in clinical outcomes such as pain and function.

Limitations

Only 11 studies were identified in this review, of which varied in the consistency of biomechanics reported for the hip and ankle joints and so conclusive interpretation is limited. It is imperative to understand the consequences an altered gait has on the hip and ankle joints when considering a gait alteration for a clinical purpose and so future studies should aim to incorporate this into their study design. This lack in consistent reporting across the 11 studies also prevented the current systematic review in undertaking a meta-analysis on the current literature.

Of the 11 included studies, the majority had a low number of participants and involved one visit. Additionally, most studies used healthy participants and so the translation of the findings to medial OA patients is limited. Future studies should aim to evaluate gait retraining potential on individuals with medial knee OA and to analyse the effects of such retraining longitudinally over multiple visits. Finally, the participant's perspective on how difficult the gait retraining style is to perform should be assessed in future studies along with studies indicating the clinical translation of the retraining.

Conclusions

In conclusion, to our knowledge, this is the first systematic review that has focused on assessing gait retraining and its effects on first and second peak EKAMs as well as evaluating the biomechanical consequences to the hip and/or ankle biomechanics. This systematic review highlights the lack of studies that have included hip and/or ankle biomechanical consequences when altering an individual's gait with the objective of lowering knee joint loading. In addition, studies lacked external validity and were scored fair to moderate in their study quality. The findings from this systematic review should direct future research to undertake gait retraining research using knee OA patients, over multiple visits as well as analysing the potential changes of the gait retraining strategy to the other lower limb joints. Without a thorough understanding of the biomechanical consequences of a gait retraining style at the hip and/or ankle joints, the clinical value of such gait styles cannot be determined.

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Figure Legends

Figure 1. Flow diagram of search strategy.

Figure 2. Forest plot of EKAM1 and EKAM2 comparing the given study intervention to normal gait. Articles bold, in red, with an * indicate studies that assessed knee OA participants. EKAM1; first peak

external knee adduction moment. EKAM2; second peak external knee adduction moment. SMD; standardised mean difference. CI; confidence interval.

Figure 3. Forest plot of hip kinetic metrics comparing the given study intervention to normal gait. Articles bold, in red, with an * indicate studies that assessed knee OA participants. EHAM; external hip adduction moment. HFM; hip flexion moment. SMD; standardised mean difference. CI; confidence interval.

Figure 4. Forest plot of hip kinematic metrics comparing the given study intervention to normal gait. Articles bold, in red, with an * indicate studies that assessed knee OA participants. ROM; range of motion. HIR; hip internal rotation. MT; medial thrust. TL; trunk lean. Van den Noort et al. (2015) a; bar visual feedback on HIR. Van den Noort et al. (2015) b; polar visual feedback on HIR. Van den Noort et al. (2015) c; colour visual feedback on HIR. Van den Noort et al. (2015) d; graph visual feedback on HIR. SMD; standardised mean difference. CI; confidence interval.

Figure 5. Forest plot of ankle kinetic metrics comparing the given study intervention to normal gait. Articles bold, in red, with an * indicate studies that assessed knee OA participants. MT; medial thrust. TL; trunk lean. T-O; toe out; T-I; toe in. CoP; centre of pressure. EKAM1; first peak external knee adduction moment. EKAM2; second peak external knee adduction moment. SMD; standardised mean difference. CI; confidence interval.

Figure 6. Forest plot of ankle kinematic metrics comparing the given study intervention to normal gait. EKAM1; first peak external knee adduction moment. EKAM2; second peak external knee adduction moment. FPA; foot progression angle. IC; initial contact. T-O; toe out; T-I; toe in. SMD; standardised mean difference. CI; confidence interval.

Table 4.
Biomechanical consequences of gait retraining at the trunk, hip and ankle, foot and CoP

	Trunk and pelvis	Hip	Ankle, foot and CoP
Shull et al. (2013)	• N-S LT sway between T-I gait (0.2 (2.0)) and normal gait (0.5 (2.3)) at first peak EKAM, *p* = 0.44; • N-S LT sway between T-I gait (0.4 (1.3)) and normal gait (0.6 (1.2)) at second peak EKAM, *p* = 0.48; • N-S peak lateral trunk sway angle between normal gait (1.5° (1.6)) and T-I gait (1.3° (0.5)), *p* = 0.49.	• N-S findings for peak HIR angle between normal gait (3.2° (3.8)) and T-I gait (4.1° (4.1)), *p* = 0.18;	• Significant difference between normal gait FPA at first (3.3° (4.5)) and second (3.9° (4.6)) peak EKAM compared to FPA for T-I gait at first (-2.6° (6.3)) and second (-1.4° (6.4)) peak EKAM; • Early stance, the CoP shifted laterally from normal gait (27 (77) mm) compared to 33 (79) mm), *p* = 0.04; • Late stance CoP did not significantly change between normal gait (30 (83) mm) and TI gait (30 (83)), *p* = 0.96.
Richards et al. (2018)	• N-R	• N-S changes in the peak EHAM, *p* = 0.083; • N-S changes in peak HFM between normal gait and gait modifications, *p* = 0.182.	• Peak EAAM was significantly increased compared to baseline during the second peak EKAM visual feedback trial and the final retention trial, *p* < 0.001; • N-S in peak EAFM for any condition, *p* > 0.058; • FPA significantly more internally rotated during second EKAM visual feedback and retention trials, *p* < 0.001; • Patients significantly increased their step widths during all trials.
Gerbrands et al. (2017)	• During the MT the peak trunk angle significantly increased to 5.5° (3.7) and during the TL the peak trunk angle significantly increased to 16.1° (5.5) compared to normal walking trunk angle of 3.4° (1.8), *p* < 0.05. •	• Early stance peak hip flexion angle significantly increased from normal walking (15.3° (37.7)) to 18.2 (37.2) during TL, *p* < 0.05. N-S in early stance peak hip flexion angle between normal walking (15.3 (37.7)) and MT (10.2 (21.1)), *p* > 0.05; • N-S findings in EHAM between baseline walking trials and neither the TL, or MT gait retraining trials at both the first and second peak EKAM, *p* > 0.05.	• Significant reductions were found for late stance peak ankle inversion moment of 3% during MT gait compared to normal walking (p < 0.05). Peaks did not increase significantly for plantar and dorsal ankle moments between the two different walking styles.
Erhart-Hledik et al. (2017)	• N-R	• N-R	• N-S changes in peak ankle eversion angle in stance between control (13.9° (5.4)) and active feedback (14.7° (5.3)), *p* = 0.193 for normal walking speed. • Average foot CoP in the first half of stance phase in the medial/lateral direction was significantly different between control (43.1 mm (5.6)) and active feedback (49.0 mm (7.6)), *p* = 0.011 for normal walking speed. Average foot CoP in the second half of stance phase was significantly different between control (28.3 mm (9.5)) and active feedback (31.8 mm (13.7)), *p* = 0.079; • Average foot CoP in the first half of stance phase was significantly different between control (43.9 mm (6.0)) and active feedback (47.5 mm (6.7)), *p* = 0.006, for fast walking speed. NS CoP findings in the second half of stance phase for fast walking speed.

Table 5. (Cont'd)

Charlton et al. (2018)	• N-R	• N-R	• T-I 10° significantly increased rearfoot inversion angles by 68%, 139%, and 289% for ZR, T-O 10° and T-O 20°, respectively. T-O 20° resulted in significantly decreased rearfoot inversion angles by -57% compared to natural gait. • Significant peak frontal plane rearfoot angles during stance. T-I 10° significantly decreased rearfoot eversion by -48%, -57%, and -61% compared to all the other conditions. Significant differences in frontal plane ankle rearfoot excursion was observed. T-I 10° significantly increased frontal plane rearfoot excursion by 20%, 32%, and 50% compared to all the other conditions. Also, ZR resulted in significantly increased frontal plane rearfoot angle excursion by 25% compared to T-O 20°. • Significant differences for sagittal plane ankle angles at IC was observed. Angles at IC during T-I 10° were significantly more dorsiflexed by 129% compared to T-O 10°. Additionally, T-O 20° was significantly more dorsiflexed by 138% and 136% compared to ZR and T-O 10°. No main effects could be detected for peak sagittal plane ankle angles during stance or for sagittal plane ankle angle excursion. • The foot rotation conditions resulted in different EKAM magnitudes, evidenced by the significant main effect for early and late stance peak EKAM. • N-S findings for ankle eversion moment impulse after post-hoc correction. No main effect for ankle inversion moment impulse could be detected. • A main effect for step width was found across conditions (*P*=.001). Pairwise comparisons revealed that T-I 10° increased step width compared to all the other conditions.
Barrios et al. (2010)	• N-R	• Significant increase between baseline natural gait peak HIR: 5.3° (7.4); post-training modified peak HIR: 13.5° (8.5); 1-month post modified peak HIR: 12.8° (9.2); • N-S change in peak hip adduction angle (p = 0.073); baseline natural gait hip adduction angle: 9.2° (2.4).	• N-R
Hunt et al. (2011)	• Normal gait TL 2.61° (1.64); • Small TL 5° (0.87); • Medium TL 8.34° (1.61); • Large TL 12.88° (1.91).	• Significant early stance peak EHAM differences were observed between all TL conditions (5.22 (0.99), 4.61 (0.65), 4.09 (0.61) for small, medium and large TL respectively) compared to normal walking (5.72 (0.90), with greater early stance peak EHAM reductions associated with increasing amounts of TL, $p < 0.001$; • N-S differences in late stance peak EHAM for any TL gait modification compared to normal gait (4.16 (1.13), $p >$ 0.05; • N-S differences observed in peak hip abduction moment for any TL gait modifications compared to normal gait (1.38 (1.10)).	• N-R

Mundermaan et al. (2008)	• Increased medio-lateral trunk sway (10° (5)).	• N-S differences were observed for the maximum axial loading rates at the hip joint for normal gait (1286 (488) %Bw/s) and trunk sway (1250 (371) %Bw/s), $p = 0.763$; • Significant increase in maximum hip abduction moment of 55.3% between normal gait (2.0 (1.1)) and increased trunk sway (3.1 (1.3)), $p < 0.001$; • First peak EHAM was significantly reduced by 57.1% for the increased medio-lateral trunk sway trial (1.8 (1.5)) compared to normal gait (4.2 (1.4)), $p < 0.001$.	• N-S differences we observed for the maximum axial loading rates at the ankle joint for normal gait (1280 (490) %Bw/s) and trunk sway (1214 (356) %Bw/s), $p = 0.568$.
van den Noort et al. (2014)	• Pelvis lift decreased by more than 5° in six participants (N-S at group level), pelvis protraction increased (4-6°, only significant for graph $p = 0.03$), and ipsilateral trunk sway decreased (2-3°, $p < 0.01$ except for colour); • With HIR feedback, maximal hip extension decreased (5-6°, $p < 0.05$ for bar and polar), and pelvis protraction increased by more than 5° in six participants (but N-S at group level).	• Hip angle feedback, HIR in the early stance phase increased significantly compared with baseline levels (bar 8°, $p < 0.01$; polar 10°, $p < 0.01$; colour 8°, $p < 0.01$, graph 7°, $p < 0.01$). The bar, polar and colour showed the largest change in late stance [9° ($p = 0.01$), 11° ($p < 0.01$) and 8° ($p = 0.03$), respectively]; • The kinematic changes that occurred while visual feedback on EKAM was provided included a decreased hip adduction (5°, polar p = 0.01, graph $p = 0.02$) and a maximal hip extension decrease (4-5°, $p < 0.03$ except for colour).	• Kinematic changes that occurred while visual feedback on EKAM was provided included an increased T-I angle of more than 5° in eight participants (on average: 2-7° at group level but N-S), an increased step width (6-7 cm, $p < 0.03$ for all feedback conditions); • While HIR feedback was provided, apart from significant changes in the HIR, participants also showed a significant increase in WS (7-10 cm). Furthermore, six participants showed an increased T-I angle of more than 5°, and five participants showed an increased T-O angle (on average 3-7° increase in T-I angle in group level, but N-S).
Dunphy et al. (2016)	• Significant differences were observed in maximum pelvic drop angle between normal gait (3° (1)) and contralateral pelvic gait (7° (1)), $p < 0.001$; • The correlation between change in pelvic drop and change in EKAM peak was r = 0.88 ($p < 0.001$).	• Significant differences were observed in maximum hip adduction angle between normal gait (0° (2)) and contralateral pelvic gait (4° (2)), $p < 0.001$; • The correlation between change in peak hip adduction angle and change in EKAM peak was r = 0.83 ($p < 0.001$); • N-S differences in hip flexion/extension between normal gait and contralateral pelvic drop gait trials.	• N-R
Khan et al. (2017)	• N-R	• Through the entire range from T-I to T-O, the hip joint's contribution to the total limb work decreased significantly at slow speed from 35.00% to 22.00%; • The hip joint increased its contribution at normal gait speed (26%–37%) through T-I to T-O. • At T-O, significant increase of hip joint's contribution	• The mean (SD) of self-selected FPAs for ST, TO and TI were 12.91 cm (4.78), 31.56 cm (7.51) and 13.43 cm (3.39) respectively; • N-S findings in ankle joint contribution by the speed transitions, except at T-I in slow to fast gait speeds. The ankle joint's contribution remained consistent except at slow speeds (decreased from 43.00% to 37.00%) from T-I to T-O gait.

EKAM: external knee adduction moment; T-I: toe-in gait; HIR: hip internal rotation; EHAM: external hip adduction moment; EAAM: external ankle adduction moment; EAFM: ankle flexion moment; CoP: centre of pressure; MT: medial thrust; T-O: toe-out gait; T-L: trunk lean; ZR: N-R: not reported; N-S: non-significant.

Table 5.
Percentage (%) change in EKAM parameter measured between normal gait and gait retraining intervention

	1st peak EKAM values (presented as %BW*H unless otherwise stated)	2nd peak EKAM values (%BW*H)	% Change in 1st peak EKAM	% Change in 2st peak EKAM
Shull et al. (2013)	Baseline: 3.28 (1.37); T-I: 2.90 (1.38) **	Baseline: 1.98 (1.14); T-I: 1.94 (1.09)	T-I: -13%	N-S
Richards et al. (2018)	Combination of WS, T-I and MT gait modifications with real-time feedback. Baseline:3.29 (1.00); visual feedback with self-selected combination of WS, T-I and MT gait: 2.82 (0.71) **; retention: 3.00 (0.77) **	N-R	Visual feedback: -14% Retention: -9%	N-R
Gerbrands et al. (2017)	Baseline: 0.24 (0.12); TL:0.15 (0.10) **; MT: 0.17 (0.09) **	Baseline: 0.19 (0.12); TL:0.15 (0.10) **; MT: 0.17 (0.10)	TL: -38% MT: -29%	TL: -21% MT: N-S
Erhart-Hledik et al. (2017)	Baseline: 2.41 (1.10); medial weight transfer at the foot: 2.26 (1.04) ** Baseline, fast walking: 2.90 (1.28); medial weight transfer at the foot, fast walking: 2.63 (1.35) **	Baseline: 1.71 (1.01); medial weight transfer at the foot, normal gait: 1.47 (0.96) ** Medial weight transfer at the foot, fast gait: 1.50 (1.13)	Medial weight transfer at the foot: -6% Medial weight transfer at the foot, fast gait: -9%	Medial weight transfer at the foot, normal gait: -14% Medial weight transfer at the foot, fast gait: N-S
Charlton et al. (2018)	Baseline: 0.48 (0.14) (N m/kg); T-I: 0.4 (0.14) (N m/kg); zero rotation: 0.44 (0.13) (N m/kg); T-O (10°) 0.48 (0.14) (N m/kg); T-O (20°) 0.51 (0.14) (N m/kg)	Baseline: 0.39 (0.14) (N m/kg); T-I: 0.47 (0.13) (N m/kg); zero rotation: 0.42 (0.12) (N m/kg); T-O (10°) 0.37 (0.13) (N m/kg); T-O (20°) 0.32 (0.14) (N m/kg)	T-I: -20% zero rotation: -9% T-O (10°): 0% T-O (20°): +6%	T-I: +17% zero rotation: +7% T-O (10°): -5% T-O (20°): +22%
Barrios et al. (2010)	Baseline visit: 0.426 (0.065) (N m/kg); post-training: 0.34 (0.66) * (N m/kg); 1-month post: 0.34 (0.073) * (N m/kg)	N-R	Post-training: -20% 1-month post: -20%	N-R
Hunt et al. (2011)	Baseline: 4.07 (1.64); small lean: 3.82 (1.77); medium lean: 3.37 (1.72) *; large lean: 3.26 (1.64) *	Baseline: 1.89 (0.77); small lean: 1.64 (0.96); medium lean: 1.64 (1.02); large lean: 1.60 (0.90)	Small lean: N-S Medium lean: -21% Large lean: -25%	N-S
Mundermann et al. (2008)	Baseline: 2.0 (0.7); increased trunk sway: 0.7 (0.6) **	N-R	Increased trunk sway: -65%	N-R
van den Noort et al. (2015)	Baseline: 2.14 (0.20); HIR colour feedback: 1.92 (0.25); HIR polar feedback: 1.73 (0.24)	Baseline: 1.91 (0.29); HIR colour: 1.60 (0.34); HIR polar: 1.14 (0.32) **	HIR colour: N-S HIR polar: N-S	HIR colour: N-S HIR polar: -40.32 %
Dunphy et al. (2016)	Baseline: 0.41 (0.03); contralateral pelvic drop: 0.56 (0.04) *	N-R	Contralateral pelvic drop: +37%	N-R
Khan et al. (2017)	Slow, ST: 1.81 (N-R); slow, T-I: 1.82 (N-R); slow, T-O: 2.28 (N-R) *; Normal, ST: 1.96 (N-R); normal, T-I: 1.80 (N-R) *; normal, T-O: 2.81 (N-R) * fast, ST: 2.70 (N-R); fast, T-I: 2.23 (N-R) *; fast, T-O: 3.08 (N-R) *	Slow, ST: 1.28 (N-R); slow, T-I: 1.64 (N-R) *; slow, T-O: 1.13 (N-R) *; Normal, ST: 1.42 (N-R); normal, T-I: 1.70 (N-R) *; normal, T-O: 1.06 (N-R) *; Fast, ST: 1.56 (N-R); fast, T-I: 1.60 (N-R); fast, T-O: 1.22 (N-R) *	Slow, T-I: N-S; Normal, T-I: -9%; Fast, T-I: -21% Slow, T-O: +26%; Normal, T-O: +43%; Fast, T-O: +14%	Slow, T-I: +22%; Normal, T-I: + 20%; Fast, T-I: N-S Slow, T-O: -12%; Normal, T-O: -25%; Fast, T-O: -22%

EKAM: external knee adduction moment; baseline: normal gait; Hunt et al. (2001): small lean (4 °), medium lean (8 °), large lean (12 °); S-T: straight-toe gait; T-I: toe-in gait; HIR: hip internal rotation; WS: wide stance gait; MT: medial thrust; T-O: toe-out gait; T-L: trunk lean; N-R: not reported; N-S: non-significant, $p > 0.05$; %BW*H: % body weight multiplied by height*: $p < 0.05$; ** $p < 0.01$.

Table 1. Group demographics

Authors and year	**Population**	**Gait retraining modification**	**Gait speeds (m/s) (mean ± SD)**	**Over ground/treadmill walking**	**n (M: F)**	**Age (years) (mean ± (SD))**	**Height (m) (mean ± (SD))**	**Mass (kg) (mean ± (SD))**	**BMI (mean ± (SD))**
Shull et al. (2013)	Symptomatic knee OA (K/L grade ≥1)	• T-I	1.23 ± 0.21	Instrumented treadmill	12 (7: 5)	59.8 (12.0)	1.71 (0.8)	77.7 (18.0)	26.5 (4.2)
Richards et al. (2018)	Symptomatic knee OA	• Self-selection combination of T-I, WS and MT	N-R	Instrumented treadmill	40 (15: 25)	61.7 (6.0)	1.73 (0.10)	77.2 (11.0)	25.6 (2.5)
Erhart-Hledik et al. (2017)	Symptomatic knee OA and physician-diagnosed radiographic medial compartment knee OA (K/L grade ≥ 1)	• Medial weight transfer at the foot	Control [natural speed (1.28 ± 0.14); fast speed (1.53 ± 0.18)]; active feedback [natural speed (1.31 ± 0.12); fast group (1.50 ± 0.15)	Overground	10 (9:1)	65.3 (9.8)	NR	NR	27.8 (3.0)
Gerbrands et al. (2017)	Symptomatic knee OA; physician-diagnosed with radiographic and fulfilment of the criteria by the American College of Rheumatology	• LT; • MT	Comfortable walking (1.21 ± 0.10); MT walking (1.02 ± 0.19); TL walking (1.08 ± 0.15)	Overground	30 (10: 20)	61.0 (6.2)	1.71 (0.1)	75.7 (13.1)	NR
Charlton et al. (2018)	Radiographic medial compartment knee OA (K/L grade ≥2)	• T-I • T-O	1.22 (0.15)	Overground and a treadmill	15 (6:9)	67.9 (9.4)	1.67 (0.11)	75.6 (15.0)	NR
Barrios et al. (2010)	Healthy	• HIR strategy	1.46 (± 2.5%)	Overground	8 (7:1)	21.4 (1.6)	1.75 (0.07)	71.7 (8.8)	NR
Hunt et al. (2011)	Healthy	• LT	Natural TL (1.42 ± 0.18); small TL (1.36 ± 0.19); medium TL (1.36 ± 0.19); large TL (1.40 ± (0.19)	Overground	9 (3:6)	18.6 (0.7)	1.71 (0.11)	65.2 (13.8)	NR
Mündermann et al. (2008)	Healthy	• Increased medio-lateral trunk sway	Natural gait (1.48 ± 0.17); medio-lateral trunk sway (1.44 ± 0.15)	Overground	19 (12: 7)	22.8 (3.1)	1.75 (0.97)	70.5 (16.3)	NR
Van den Noort et al. (2015)	Healthy	• HIR feedback	1.0 ± 0.09	Instrumented treadmill	17 (8: 7)	28.2 (7.6)	1.78 (0.07)	71.6 (12.5)	NR
Dunphy et al. (2016)	Healthy	• Contralateral pelvic drop	1.31 ± 0.12	Instrumented treadmill	15 (7: 8)	25 (2.65)	1.73 (0.08)	76.7 (16.5)	25.7 (5.06)
Khan et al. (2017)	Healthy	• T-O; • T-I	Slow (0.85); natural (1.18); fast (1.43)	Overground	20 (8: 12)	29.0 (4.10)	1.65 (0.11)	59.3 (10.4)	NR

HIR = hip internal rotation; LT = lateral trunk lean; T-I = toe-in gait; KAM = knee adduction moment; WS = wide stance gait; MT = medial thrust gait; T-O = toe-out gait; BMI = body mass index; K/L grade = Kellgren and Lawrence system; m: metre; NR = not reported; M: male; F: female; SD: standard deviation.

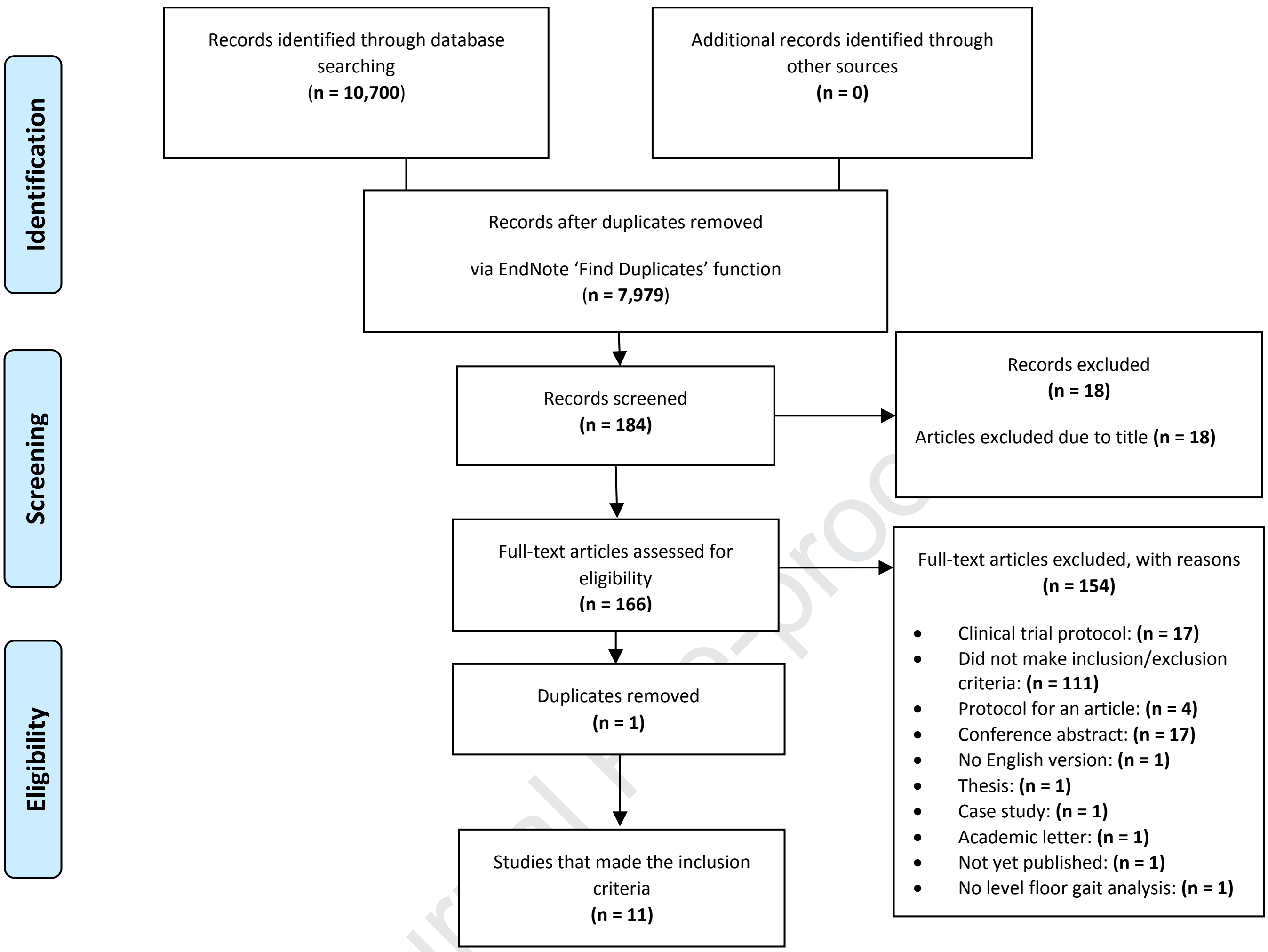
Table 2.
Disease severity

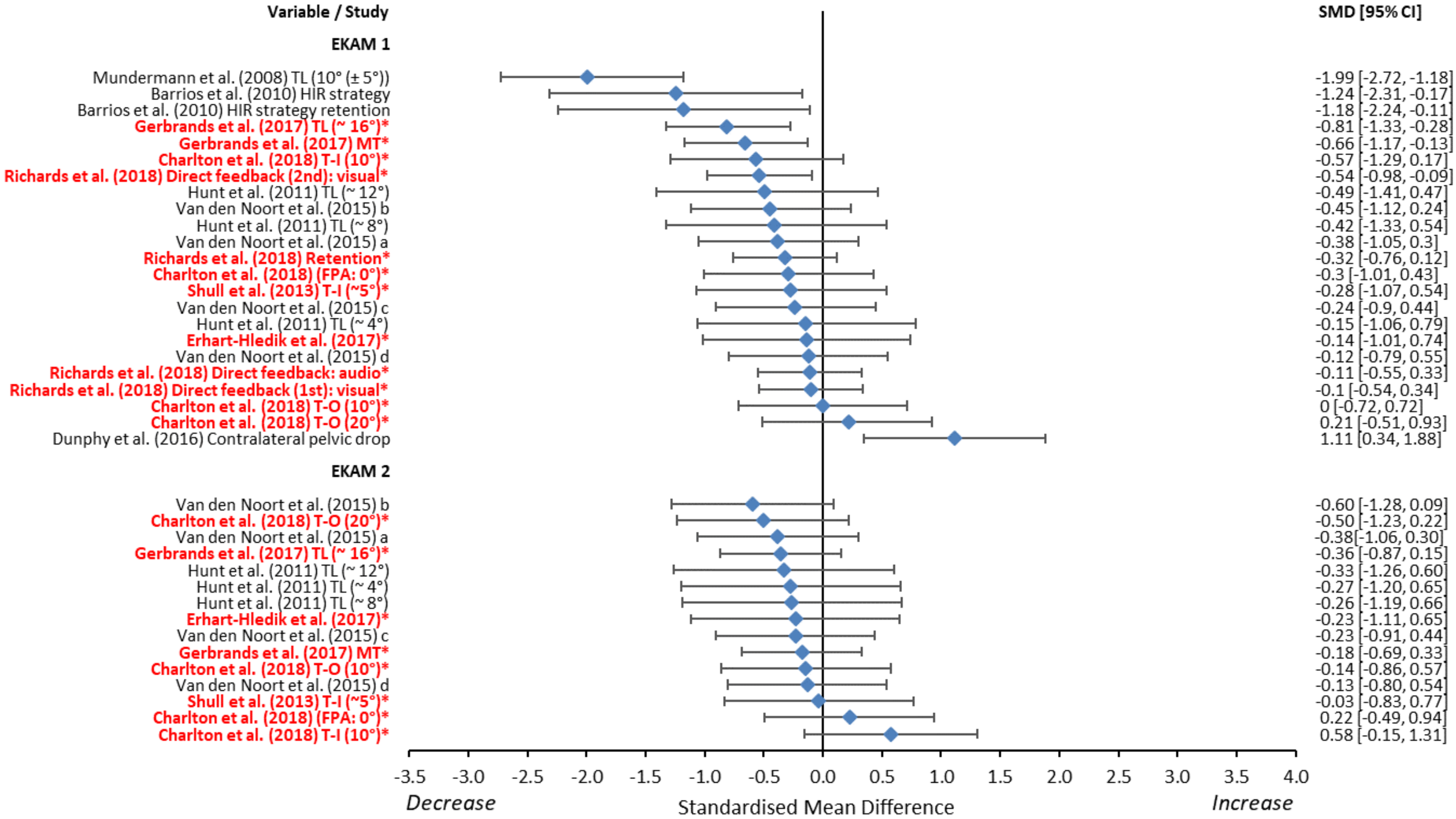
Authors and year	Population	K/L grade	PROMS
Shull et al. (2013)	Symptomatic knee OA	II: 4, III: 7, IV: 1	WOMAC pain (mean ± SD): 74.2 (19.0) [max. 100], WOMAC Function (mean ± SD): 81.7 (21.6) [max. 100]
Richards et al. (2018)	Symptomatic knee OA	I: 19, II: 8, III: 9, IV: 4	WOMAC pain (mean ± SD): 5.35 (3.13) [max. 20], WOMAC Function (mean ± SD): 19.10 (12.08) [max. 68], WOMAC stiffness: 3.25 (1.96) [max. 8], Baseline pain: 3.05 (2.16) [max. 10]
Gerbrands et al. (2017)	Symptomatic knee OA	NR	KOOS Pain (%): 57.5 (13.4), KOOS Function (%): 62.3 (14.1)
Erhart-Hledik et al. (2017)	Symptomatic knee OA	All above I.	Daily pain score: 3.2 (3.6)
Charlton et al. (2018)	Radiographic knee OA	II: 7; III: 8	WOMAC pain (mean ± SD): 4 (2.2) [max. 20] WOMAC stiffness (mean ± SD): 3.0 (1.3) [max. 8] WOMAC Function (mean ± SD): 15.4 (8.0) [max. 68]
Hunt et al. (2011)	Healthy	NR	NR
Barrios et al. (2010)	Healthy	NR	KOOS-SR score (mean ± SD): 0.7 (0.9) [max. 20]
Mundermann et al. (2008)	Healthy	NR	NR
Van den Noort et al. (2015)	Healthy	NR	NR
Dunphy et al. (2016)	Healthy	NR	NR
Khan et al. (2017)	Healthy	NR	NR

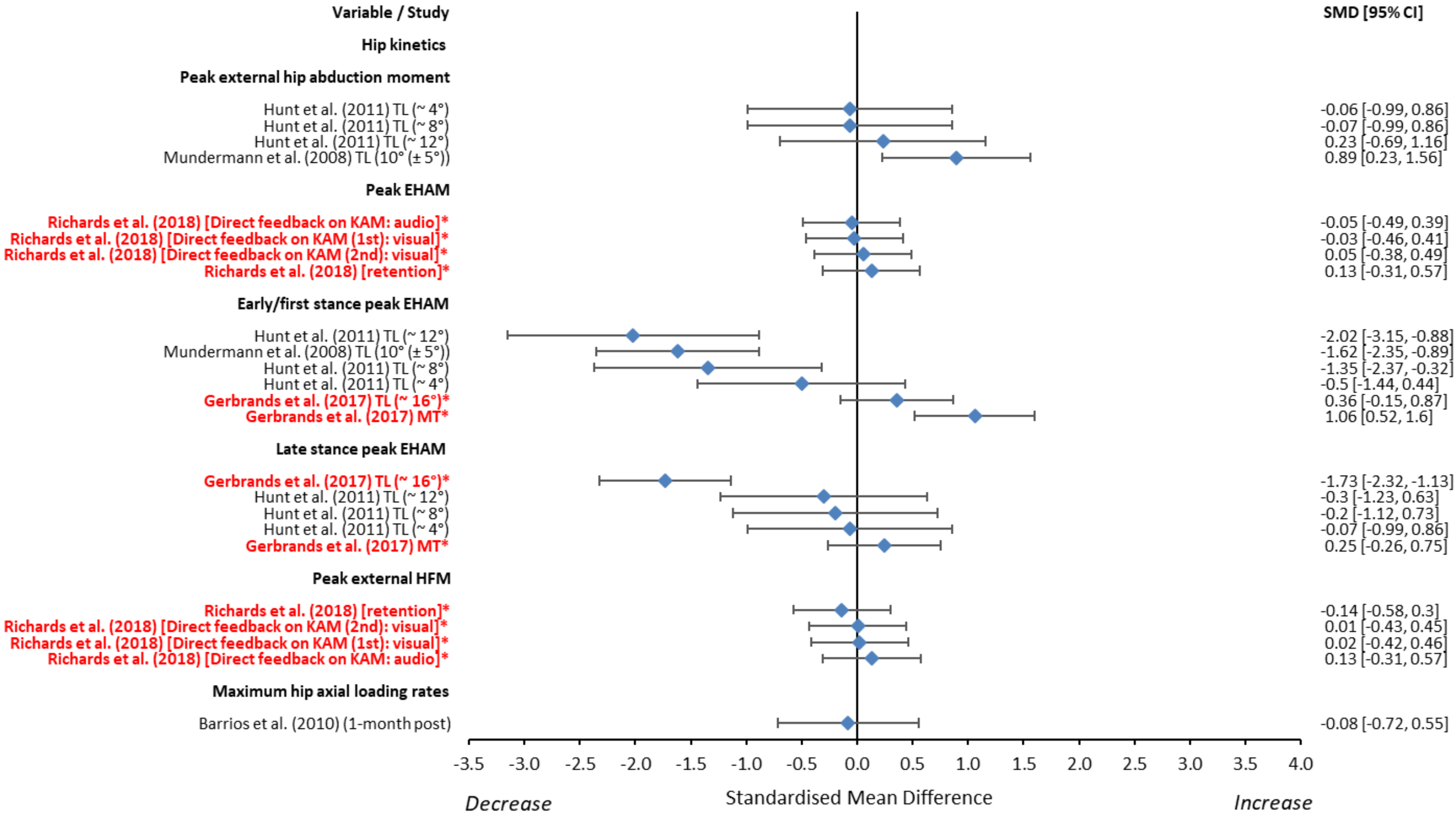
PROMS = Patient-reported outcome measures; K/L grade = Kellgren and Lawrence system; WOMAC = The Western Ontario and McMaster Universities Osteoarthritis Index; KOOS = Knee injury and Osteoarthritis Outcome Score; NR = not reported; OA = osteoarthritis; SD: standard deviation. Barrios et al. (2010) used the KOOS-SR score (Function in Sport and Recreation) which ranged from 0-20, a score of 0 indicating no difficulty. Shull et al. (2013) measured WOMAC levels on the day of assessment, with the scale ranging from 0-100 with 100 indicating no pain and perfect function (Bellamy et al., 1988). Richards et al. (2018) measured WOMAC levels on the day of assessment, evaluating the pain and function of the participant in the past week, with the lower the scoring of pain out of 20 equating to the lower the pain, and the lower the score out of a maximum of 68 being the better the function of the participant. Gerbrands et al. (2017) assessed pain and function using the Knee injury and Osteoarthritis Outcome Score (KOOS), scores are presented as a percentage, where 0% represents extreme problems and 100% represents no problems. Daily pain score ranged from 0-10, with 0 indicating no pain and 10 indicating worst pain.

Table 3.
Risk of bias within studies

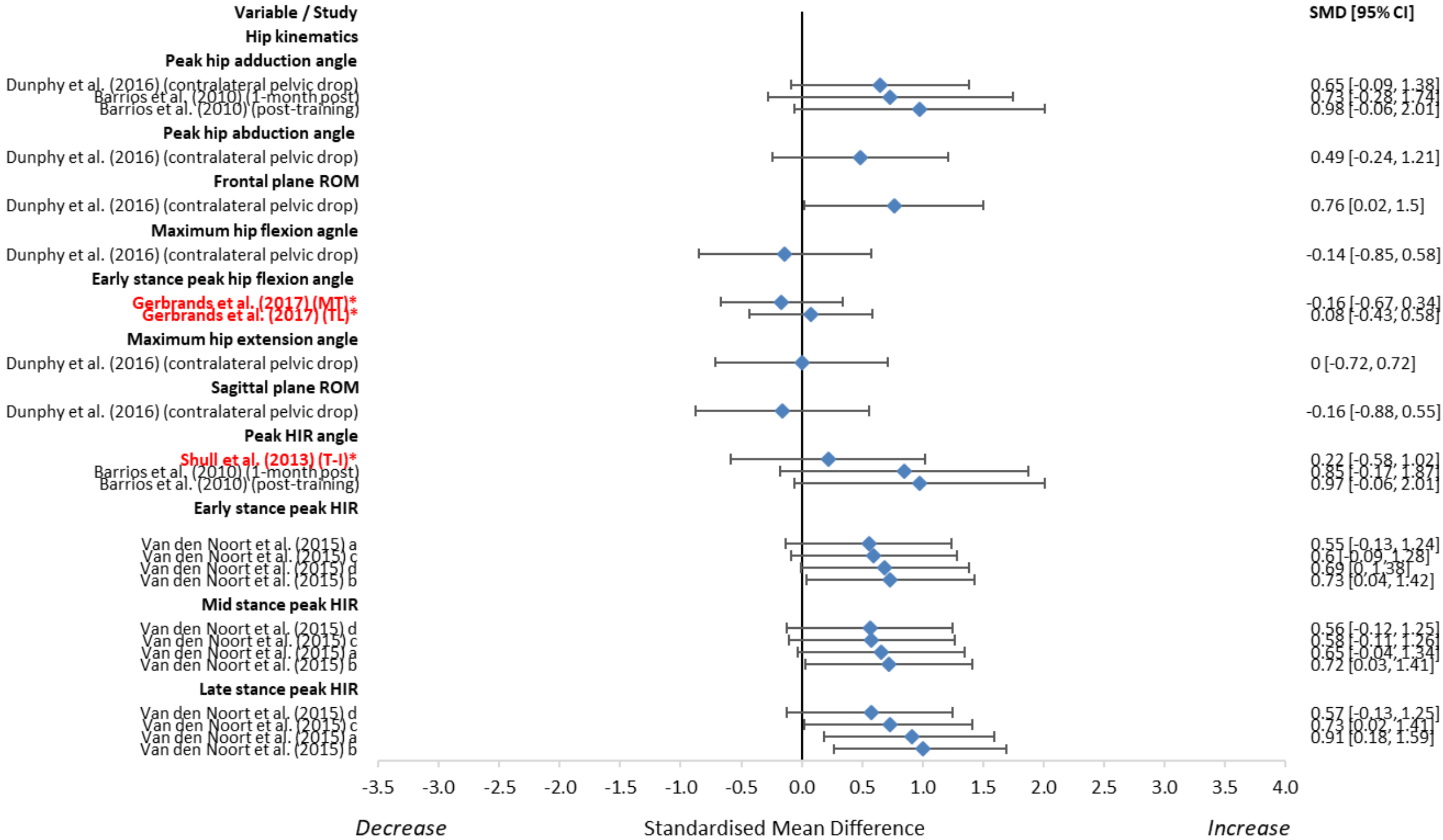
Authors and year	Population	Reporting (n = 1-10)	External validity (n = 11-13)	Internal validity: bias (n = 14-20)	Internal validity: confounding (n = 21-26)	Power (n = 27)	Methodological score (/25 or /28)
Shull et al. (2013)	Symptomatic knee OA	9	0	4	0	1	14/25
Richards et al. (2018)	Symptomatic knee OA	8	0	4	2	1	15/25
Gerbrands et al. (2017)	Symptomatic knee OA	9	0	4	1	1	15/25
Erhart-Hledik et al. (2017)	Symptomatic knee OA	9	1	4	2	1	17/25
Charlton et al. (2018)	Radiographic knee OA	9	0	4	1	1	15/25
Barrios et al. (2010)	Healthy	10	0	4	3	1	18/28
Hunt et al. (2011)	Healthy	9	0	4	2	0	15/25
Mundermann et al. (2008)	Healthy	8	0	4	2	1	15/25
Van den Noort et al. (2015)	Healthy	7	0	4	3	0	14/25
Dunphy et al. (2016)	Healthy	9	0	4	2	0	15/25
Khan et al. (2017)	Healthy	6	0	4	1	1	12/25

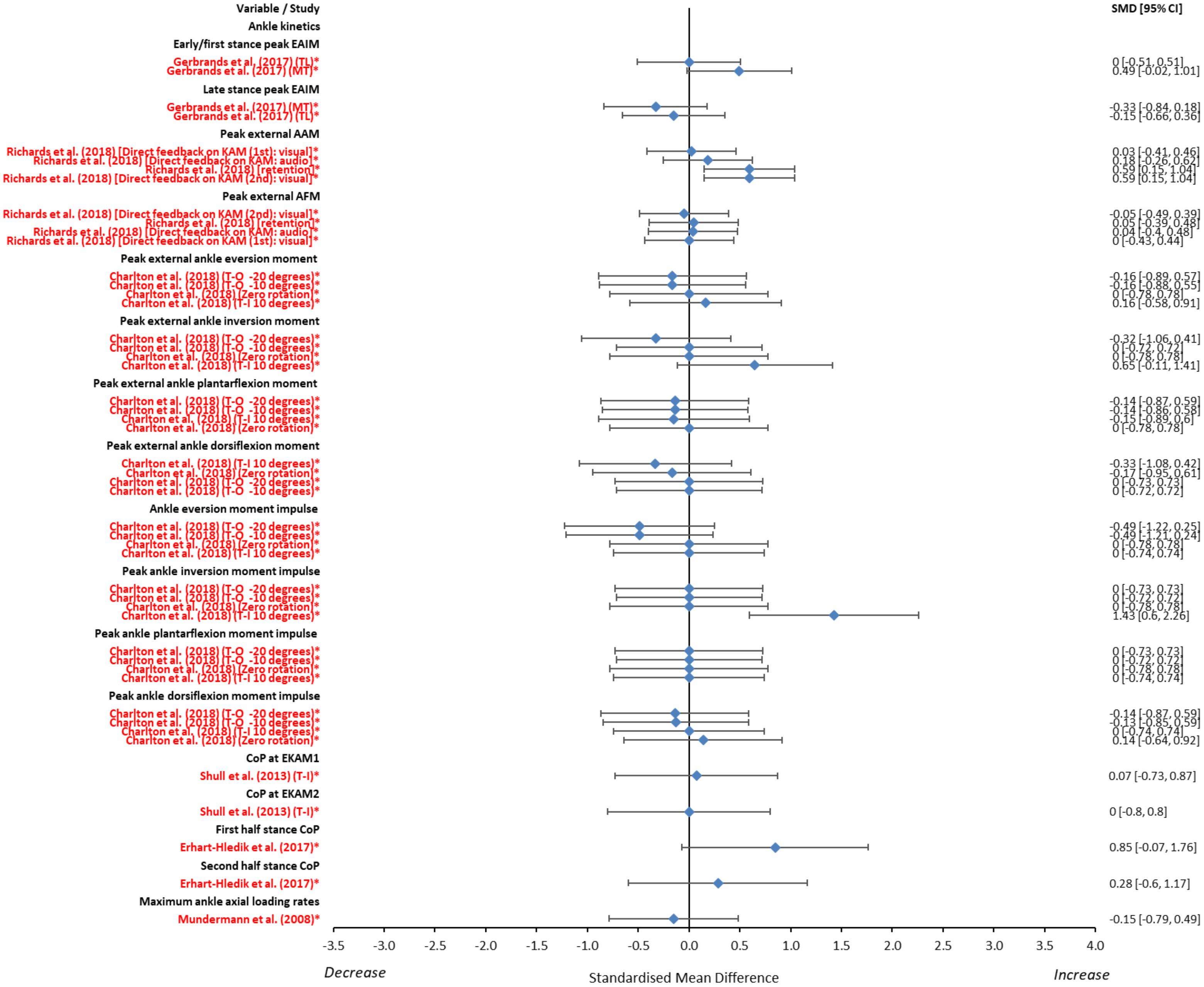

Identification
Screening
Eligibility
Records identified through database searching (n = 10,700)
Additional records identified through other sources (n = 0)
Records after duplicates removed
via EndNote 'Find Duplicates' function (n = 7,979)
Records screened (n = 184)
Records excluded (n = 18)
Articles excluded due to title (n = 18)
Full-text articles assessed for eligibility (n = 166)
Full-text articles excluded, with reasons (n = 154)
Clinical trial protocol: (n = 17)
Did not make inclusion/exclusion criteria: (n = 111)
Protocol for an article: (n = 4)
Conference abstract: (n = 17)
No English version: (n = 1)
Thesis: (n = 1)
Case study: (n = 1)
Academic letter: (n = 1)
Not yet published: (n = 1)
No level floor gait analysis: (n = 1)
Duplicates removed (n = 1)
Studies that made the inclusion criteria (n = 11)

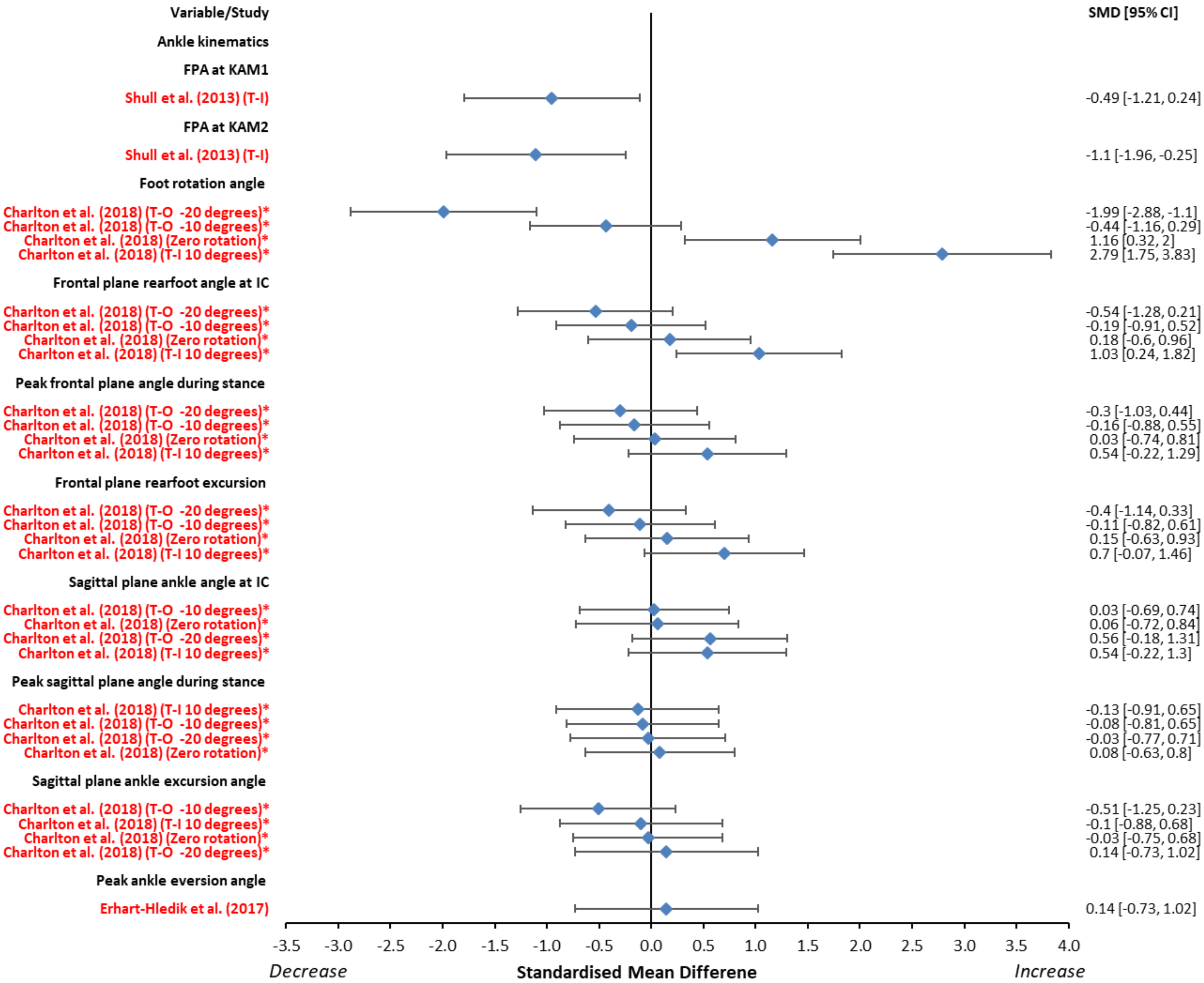

Variable / Study
SMD [95% CI]
EKAM 1
Mundermann et al. (2008) TL (10° (± 5°)) -1.99 [-2.72, -1.18]
Barrios et al. (2010) HIR strategy -1.24 [-2.31, -0.17]
Barrios et al. (2010) HIR strategy retention -1.18 [-2.24, -0.11]
Gerbrands et al. (2017) TL (~ 16°)* -0.81 [-1.33, -0.28]
Gerbrands et al. (2017) MT* -0.66 [-1.17, -0.13]
Charlton et al. (2018) T-I (10°)* -0.57 [-1.29, 0.17]
Richards et al. (2018) Direct feedback (2nd): visual* -0.54 [-0.98, -0.09]
Hunt et al. (2011) TL (~ 12°) -0.49 [-1.41, 0.47]
Van den Noort et al. (2015) b -0.45 [-1.12, 0.24]
Hunt et al. (2011) TL (~ 8°) -0.42 [-1.33, 0.54]
Van den Noort et al. (2015) a -0.38 [-1.05, 0.3]
Richards et al. (2018) Retention* -0.32 [-0.76, 0.12]
Charlton et al. (2018) (FPA: 0°)* -0.3 [-1.01, 0.43]
Shull et al. (2013) T-I (~5°)* -0.28 [-1.07, 0.54]
Van den Noort et al. (2015) c -0.24 [-0.9, 0.44]
Hunt et al. (2011) TL (~ 4°) -0.15 [-1.06, 0.79]
Erhart-Hledik et al. (2017)* -0.14 [-1.01, 0.74]
Van den Noort et al. (2015) d -0.12 [-0.79, 0.55]
Richards et al. (2018) Direct feedback: audio* -0.11 [-0.55, 0.33]
Richards et al. (2018) Direct feedback (1st): visual* -0.1 [-0.54, 0.34]
Charlton et al. (2018) T-O (10°)* 0 [-0.72, 0.72]
Charlton et al. (2018) T-O (20°)* 0.21 [-0.51, 0.93]
Dunphy et al. (2016) Contralateral pelvic drop 1.11 [0.34, 1.88]
EKAM 2
Van den Noort et al. (2015) b -0.60 [-1.28, 0.09]
Charlton et al. (2018) T-O (20°)* -0.50 [-1.23, 0.22]
Van den Noort et al. (2015) a -0.38[-1.06, 0.30]
Gerbrands et al. (2017) TL (~ 16°)* -0.36 [-0.87, 0.15]
Hunt et al. (2011) TL (~ 12°) -0.33 [-1.26, 0.60]
Hunt et al. (2011) TL (~ 4°) -0.27 [-1.20, 0.65]
Hunt et al. (2011) TL (~ 8°) -0.26 [-1.19, 0.66]
Erhart-Hledik et al. (2017)* -0.23 [-1.11, 0.65]
Van den Noort et al. (2015) c -0.23 [-0.91, 0.44]
Gerbrands et al. (2017) MT* -0.18 [-0.69, 0.33]
Charlton et al. (2018) T-O (10°)* -0.14 [-0.86, 0.57]
Van den Noort et al. (2015) d -0.13 [-0.80, 0.54]
Shull et al. (2013) T-I (~5°)* -0.03 [-0.83, 0.77]
Charlton et al. (2018) (FPA: 0°)* 0.22 [-0.49, 0.94]
Charlton et al. (2018) T-I (10°)* 0.58 [-0.15, 1.31]
-3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Decrease
Standardised Mean Difference
Increase



Variable / Study
SMD [95% CI]
Hip kinetics
Peak external hip abduction moment
Hunt et al. (2011) TL (~ 4°) -0.06 [-0.99, 0.86]
Hunt et al. (2011) TL (~ 8°) -0.07 [-0.99, 0.86]
Hunt et al. (2011) TL (~ 12°) 0.23 [-0.69, 1.16]
Mundermann et al. (2008) TL (10° (± 5°)) 0.89 [0.23, 1.56]
Peak EHAM
Richards et al. (2018) [Direct feedback on KAM: audio]* -0.05 [-0.49, 0.39]
Richards et al. (2018) [Direct feedback on KAM (1st): visual]* -0.03 [-0.46, 0.41]
Richards et al. (2018) [Direct feedback on KAM (2nd): visual]* 0.05 [-0.38, 0.49]
Richards et al. (2018) [retention]* 0.13 [-0.31, 0.57]
Early/first stance peak EHAM
Hunt et al. (2011) TL (~ 12°) -2.02 [-3.15, -0.88]
Mundermann et al. (2008) TL (10° (± 5°)) -1.62 [-2.35, -0.89]
Hunt et al. (2011) TL (~ 8°) -1.35 [-2.37, -0.32]
Hunt et al. (2011) TL (~ 4°) -0.5 [-1.44, 0.44]
Gerbrands et al. (2017) TL (~ 16°)* 0.36 [-0.15, 0.87]
Gerbrands et al. (2017) MT* 1.06 [0.52, 1.6]
Late stance peak EHAM
Gerbrands et al. (2017) TL (~ 16°)* -1.73 [-2.32, -1.13]
Hunt et al. (2011) TL (~ 12°) -0.3 [-1.23, 0.63]
Hunt et al. (2011) TL (~ 8°) -0.2 [-1.12, 0.73]
Hunt et al. (2011) TL (~ 4°) -0.07 [-0.99, 0.86]
Gerbrands et al. (2017) MT* 0.25 [-0.26, 0.75]
Peak external HFM
Richards et al. (2018) [retention]* -0.14 [-0.58, 0.3]
Richards et al. (2018) [Direct feedback on KAM (2nd): visual]* 0.01 [-0.43, 0.45]
Richards et al. (2018) [Direct feedback on KAM (1st): visual]* 0.02 [-0.42, 0.46]
Richards et al. (2018) [Direct feedback on KAM: audio]* 0.13 [-0.31, 0.57]
Maximum hip axial loading rates
Barrios et al. (2010) (1-month post) -0.08 [-0.72, 0.55]
-3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Decrease
Standardised Mean Difference
Increase


Variable / Study
Hip kinematics
Peak hip adduction angle
Dunphy et al. (2016) (contralateral pelvic drop)
Barrios et al. (2010) (1-month post)
Barrios et al. (2010) (post-training)
Peak hip abduction angle
Dunphy et al. (2016) (contralateral pelvic drop)
Frontal plane ROM
Dunphy et al. (2016) (contralateral pelvic drop)
Maximum hip flexion agnle
Dunphy et al. (2016) (contralateral pelvic drop)
Early stance peak hip flexion angle
Gerbrands et al. (2017) (MT)*
Gerbrands et al. (2017) (TL)*
Maximum hip extension angle
Dunphy et al. (2016) (contralateral pelvic drop)
Sagittal plane ROM
Dunphy et al. (2016) (contralateral pelvic drop)
Peak HIR angle
Shull et al. (2013) (T-I)*
Barrios et al. (2010) (1-month post)
Barrios et al. (2010) (post-training)
Early stance peak HIR
Van den Noort et al. (2015) a
Van den Noort et al. (2015) c
Van den Noort et al. (2015) d
Van den Noort et al. (2015) b
Mid stance peak HIR
Van den Noort et al. (2015) d
Van den Noort et al. (2015) c
Van den Noort et al. (2015) a
Van den Noort et al. (2015) b
Late stance peak HIR
Van den Noort et al. (2015) d
Van den Noort et al. (2015) c
Van den Noort et al. (2015) a
Van den Noort et al. (2015) b
SMD [95% CI]
0.65 [-0.09, 1.38]
0.73 [-0.28, 1.74]
0.98 [-0.06, 2.01]
0.49 [-0.24, 1.21]
0.76 [0.02, 1.5]
-0.14 [-0.85, 0.58]
-0.16 [-0.67, 0.34]
0.08 [-0.43, 0.58]
0 [-0.72, 0.72]
-0.16 [-0.88, 0.55]
0.22 [-0.58, 1.02]
0.85 [-0.17, 1.87]
0.97 [-0.06, 2.01]
0.55 [-0.13, 1.24]
0.6 [-0.09, 1.28]
0.69 [0, 1.38]
0.73 [0.04, 1.42]
0.56 [-0.12, 1.25]
0.58 [-0.11, 1.26]
0.65 [-0.04, 1.34]
0.72 [0.03, 1.41]
0.57 [-0.13, 1.25]
0.73 [0.02, 1.41]
0.91 [0.18, 1.59]
-3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Decrease
Standardised Mean Difference
Increase


Variable / Study
SMD [95% CI]
Ankle kinetics
Early/first stance peak EAIM
Gerbrands et al. (2017) (TL)* 0 [-0.51, 0.51]
Gerbrands et al. (2017) (MT)* 0.49 [-0.02, 1.01]
Late stance peak EAIM
Gerbrands et al. (2017) (MT)* -0.33 [-0.84, 0.18]
Gerbrands et al. (2017) (TL)* -0.15 [-0.66, 0.36]
Peak external AAM
Richards et al. (2018) [Direct feedback on KAM (1st): visual]* 0.03 [-0.41, 0.46]
Richards et al. (2018) [Direct feedback on KAM: audio]* 0.18 [-0.26, 0.62]
Richards et al. (2018) [retention]* 0.59 [0.15, 1.04]
Richards et al. (2018) [Direct feedback on KAM (2nd): visual]* 0.59 [0.15, 1.04]
Peak external AFM
Richards et al. (2018) [Direct feedback on KAM (2nd): visual]* -0.05 [-0.49, 0.39]
Richards et al. (2018) [retention]* 0.05 [-0.39, 0.48]
Richards et al. (2018) [Direct feedback on KAM: audio]* 0.04 [-0.4, 0.48]
Richards et al. (2018) [Direct feedback on KAM (1st): visual]* 0 [-0.43, 0.44]
Peak external ankle eversion moment
Charlton et al. (2018) (T-O -20 degrees)* -0.16 [-0.89, 0.57]
Charlton et al. (2018) (T-O -10 degrees)* -0.16 [-0.88, 0.55]
Charlton et al. (2018) (Zero rotation)* 0 [-0.78, 0.78]
Charlton et al. (2018) (T-I 10 degrees)* 0.16 [-0.58, 0.91]
Peak external ankle inversion moment
Charlton et al. (2018) (T-O -20 degrees)* -0.32 [-1.06, 0.41]
Charlton et al. (2018) (T-O -10 degrees)* 0 [-0.72, 0.72]
Charlton et al. (2018) (Zero rotation)* 0 [-0.78, 0.78]
Charlton et al. (2018) (T-I 10 degrees)* 0.65 [-0.11, 1.41]
Peak external ankle plantarflexion moment
Charlton et al. (2018) (T-O -20 degrees)* -0.14 [-0.87, 0.59]
Charlton et al. (2018) (T-O -10 degrees)* -0.14 [-0.86, 0.58]
Charlton et al. (2018) (T-I 10 degrees)* -0.15 [-0.89, 0.6]
Charlton et al. (2018) (Zero rotation)* 0 [-0.78, 0.78]
Peak external ankle dorsiflexion moment
Charlton et al. (2018) (T-I 10 degrees)* -0.33 [-1.08, 0.42]
Charlton et al. (2018) (Zero rotation)* -0.17 [-0.95, 0.61]
Charlton et al. (2018) (T-O -20 degrees)* 0 [-0.73, 0.73]
Charlton et al. (2018) (T-O -10 degrees)* 0 [-0.72, 0.72]
Ankle eversion moment impulse
Charlton et al. (2018) (T-O -20 degrees)* -0.49 [-1.22, 0.25]
Charlton et al. (2018) (T-O -10 degrees)* -0.49 [-1.21, 0.24]
Charlton et al. (2018) (Zero rotation)* 0 [-0.78, 0.78]
Charlton et al. (2018) (T-I 10 degrees)* 0 [-0.74, 0.74]
Peak ankle inversion moment impulse
Charlton et al. (2018) (T-O -20 degrees)* 0 [-0.73, 0.73]
Charlton et al. (2018) (T-O -10 degrees)* 0 [-0.72, 0.72]
Charlton et al. (2018) (Zero rotation)* 0 [-0.78, 0.78]
Charlton et al. (2018) (T-I 10 degrees)* 1.43 [0.6, 2.26]
Peak ankle plantarflexion moment impulse
Charlton et al. (2018) (T-O -20 degrees)* 0 [-0.73, 0.73]
Charlton et al. (2018) (T-O -10 degrees)* 0 [-0.72, 0.72]
Charlton et al. (2018) (Zero rotation)* 0 [-0.78, 0.78]
Charlton et al. (2018) (T-I 10 degrees)* 0 [-0.74, 0.74]
Peak ankle dorsiflexion moment impulse
Charlton et al. (2018) (T-O -20 degrees)* -0.14 [-0.87, 0.59]
Charlton et al. (2018) (T-O -10 degrees)* -0.13 [-0.85, 0.59]
Charlton et al. (2018) (T-I 10 degrees)* 0 [-0.74, 0.74]
Charlton et al. (2018) (Zero rotation)* 0.14 [-0.64, 0.92]
CoP at EKAM1
Shull et al. (2013) (T-I)* 0.07 [-0.73, 0.87]
CoP at EKAM2
Shull et al. (2013) (T-I)* 0 [-0.8, 0.8]
First half stance CoP
Erhart-Hledik et al. (2017)* 0.85 [-0.07, 1.76]
Second half stance CoP
Erhart-Hledik et al. (2017)* 0.28 [-0.6, 1.17]
Maximum ankle axial loading rates
Mundermann et al. (2008)* -0.15 [-0.79, 0.49]
-3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Decrease
Standardised Mean Difference
Increase



Variable/Study
Ankle kinematics
FPA at KAM1
Shull et al. (2013) (T-I)
FPA at KAM2
Shull et al. (2013) (T-I)
Foot rotation angle
Charlton et al. (2018) (T-O -20 degrees)*
Charlton et al. (2018) (T-O -10 degrees)*
Charlton et al. (2018) (Zero rotation)*
Charlton et al. (2018) (T-I 10 degrees)*
Frontal plane rearfoot angle at IC
Charlton et al. (2018) (T-O -20 degrees)*
Charlton et al. (2018) (T-O -10 degrees)*
Charlton et al. (2018) (Zero rotation)*
Charlton et al. (2018) (T-I 10 degrees)*
Peak frontal plane angle during stance
Charlton et al. (2018) (T-O -20 degrees)*
Charlton et al. (2018) (T-O -10 degrees)*
Charlton et al. (2018) (Zero rotation)*
Charlton et al. (2018) (T-I 10 degrees)*
Frontal plane rearfoot excursion
Charlton et al. (2018) (T-O -20 degrees)*
Charlton et al. (2018) (T-O -10 degrees)*
Charlton et al. (2018) (Zero rotation)*
Charlton et al. (2018) (T-I 10 degrees)*
Sagittal plane ankle angle at IC
Charlton et al. (2018) (T-O -10 degrees)*
Charlton et al. (2018) (Zero rotation)*
Charlton et al. (2018) (T-O -20 degrees)*
Charlton et al. (2018) (T-I 10 degrees)*
Peak sagittal plane angle during stance
Charlton et al. (2018) (T-I 10 degrees)*
Charlton et al. (2018) (T-O -10 degrees)*
Charlton et al. (2018) (T-O -20 degrees)*
Charlton et al. (2018) (Zero rotation)*
Sagittal plane ankle excursion angle
Charlton et al. (2018) (T-O -10 degrees)*
Charlton et al. (2018) (T-I 10 degrees)*
Charlton et al. (2018) (Zero rotation)*
Charlton et al. (2018) (T-O -20 degrees)*
Peak ankle eversion angle
Erhart-Hledik et al. (2017)
SMD [95% CI]
-0.49 [-1.21, 0.24]
-1.1 [-1.96, -0.25]
-1.99 [-2.88, -1.1]
-0.44 [-1.16, 0.29]
1.16 [0.32, 2]
2.79 [1.75, 3.83]
-0.54 [-1.28, 0.21]
-0.19 [-0.91, 0.52]
0.18 [-0.6, 0.96]
1.03 [0.24, 1.82]
-0.3 [-1.03, 0.44]
-0.16 [-0.88, 0.55]
0.03 [-0.74, 0.81]
0.54 [-0.22, 1.29]
-0.4 [-1.14, 0.33]
-0.11 [-0.82, 0.61]
0.15 [-0.63, 0.93]
0.7 [-0.07, 1.46]
0.03 [-0.69, 0.74]
0.06 [-0.72, 0.84]
0.56 [-0.18, 1.31]
0.54 [-0.22, 1.3]
-0.13 [-0.91, 0.65]
-0.08 [-0.81, 0.65]
-0.03 [-0.77, 0.71]
0.08 [-0.63, 0.8]
-0.51 [-1.25, 0.23]
-0.1 [-0.88, 0.68]
-0.03 [-0.75, 0.68]
0.14 [-0.73, 1.02]
0.14 [-0.73, 1.02]
-3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Decrease
Standardised Mean Differene
Increase

Online Supplement Material

Bowd JB, Biggs PR, Holt CA, Whatling GA. Does gait retraining have the potential to reduce medial compartmental loading in individuals with knee osteoarthritis whilst not adversely affecting the other lower limb joints? A systematic review

Appendix 1: Example database search keywords

Appendix 2: Appendix 2: Methodological agreement between JBB and PRB Kappa statistic

Appendix 1. Example database search keywords

Syntax was adjusted appropriately for use in multiple databases. Keywords were identical for all searches.

The following keywords were grouped and searched in all fields with conjunction “OR” in each group to ensure that all relevant articles were obtained. Group one consisted of keywords “walk*” OR “gait”. Keywords “knee” OR “adduction moment” built up the second group. Group three consisted “osteoarthriti*” OR “arthriti*” OR “osteo arthriti*”, OR “OA”. Group four included “hip” OR “ankle”.

In the second stage, the searched results of each group were combined with conjunction “AND” in all fields. CINAHL subject headings were “walking” for the first group, “knee” and “adduction” for the second group, “osteoarthritis” and “knee” for the third group, and, “ankle” and “hip” for the fourth group. All searches were initially carried out in any language in their titles, abstracts and full-length articles and later assessed for English language only versions.

	Search ID#	Search Terms
	S21	S4 AND S9 AND S15 AND S20
	S20	S16 OR S17 OR S18 OR S19
	S19	ankle
	S18	hip
	S17	(MH "Ankle")
	S16	(MH "Hip")
	S15	S10 OR S11 OR S12 OR S13 OR S14
	S14	oa
	S13	(MH "Osteoarthritis, Knee")
	S12	arthriti*
	S11	"osteo arthriti*"
	S10	osteoarthriti*
	S9	S5 OR S6 OR S7 OR S8
	S8	"adduction moment"
	S7	(MH "Adduction")
	S6	(MH "Knee")
	S5	knee
	S4	S1 OR S2 OR S3
	S3	gait
	S2	(MH "Walking+")
	S1	walk*

Appendix 2: Methodological agreement between JBB and PRB Kappa statistic

Reporting by JBB.

	REPORTING										External Validity			Internal Validity - bias							Internal validity - confounding (selection bias)						Power		
Study	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**		**Total:**
Barrios, J; Crossley, K; Davis, I (2010) Gait retraining to reduce the knee adduction moment through real-time visual feedback of dynamic knee alignment	1	1	1	1	2	1	1	1	0	1	0	0	0	0	0	1	1	1	0	1	1	**1**	**0**	0	1	0	1		18
Hunt, M; Simic, M; Hinman, R; Bennell, K; Wrigley, T (2011) Feasibility of a gait retraining strategy for reducing knee joint loading: Increased trunk lean guided by real-time biofeedback	1	1	1	1	1	1	1	1	**NA**	1	0	0	0	0	0	1	**NA**	1	1	1	1	**0**	**0**	0	1	**NA**	0		15
Mundermanna ET AL. (2008) Implications of increased medio-lateral trunk sway for ambulatory mechanics	1	1	1	1	1	1	1	0	**NA**	1	0	0	0	0	0	1	**NA**	1	1	1	1	**0**	**0**	0	1	**NA**	1		15
Shull, P; Shultz, R; Slider, A; Dragoo, J; Besier, T; Cutkosky, M; Delp, S (2013) Toe-in gait reduces the first peak knee adduction moment in patients with medial compartment knee osteoarthritis	1	1	1	1	2	1	1	0	**NA**	1	0	0	0	0	0	1	**NA**	1	1	1	0	**0**	**0**	0	0	**NA**	1		14
Van Den Noort, J; Steenbrink, F; Roeles, S; Harlaar, J (2015) Real-time visual feedback for gait retraining: toward application in knee osteoarthritis	1	1	1	1	1	1	0	0	**NA**	1	0	0	0	0	0	1	**NA**	1	1	1	1	**1**	**0**	0	1	**NA**	0		14
Dunphy, C; Casey, S; Lomond, A; Rutherford, D (2016) Contralateral pelvic drop during gait increases knee adduction moments of asymptomatic individuals	1	1	1	1	2	1	1	0	**NA**	1	0	0	0	0	0	1	**NA**	1	1	1	1	**0**	**0**	0	1	**NA**	0		15
Ota, S; Ogawa, Y; Ota, H; Fujiwara, T; Sugiyama, T; Ochi, A (2017) Beneficial effects of a gait used while wearing a kimono to decrease the knee adduction moment in healthy adults	1	1	1	1	1	1	0	0	**NA**	1	0	0	0	0	0	1	**NA**	1	1	1	1	**0**	**0**	0	1	**NA**	0		13
Richards, R; Van Den Noort, J; Van Der Esch, M; Booij, M; Harlaar, J (2017) Effect of real-time biofeedback on peak knee adduction moment in patients with medial knee osteoarthritis: Is direct feedback effective?	1	1	1	1	2	1	0	0	**NA**	1	0	0	0	0	0	1	**NA**	1	1	1	0	**1**	**0**	0	1	**NA**	1		15
Erhart-Hledik, J; Asay, J; Clancy, C; Chu, C, Andriacch (2017) Effects of Active Feedback Gait Retraining to Produce a Medial Weight Transfer at the Foot in Subjects with Symptomatic Medial Knee Osteoarthritis	1	1	1	1	2	1	1	0	**NA**	1	1	0	0	0	0	1	**NA**	1	1	1	0	**1**	**0**	0	1	**NA**	1		17
Khan, S; Khan, S; Usman, J (2017) Effects of toe-out and toe-in gait with varying walking speeds on knee joint mechanics and lower limb energetics	1	1	1	1	1	1	0	0	**NA**	0	0	0	0	0	0	1	**NA**	1	1	1	0	**0**	**0**	0	1	**NA**	1		12
Gerbrands, T; Pisters, M; Theeven, P; Verschueren, S; Vanwanseele, B (2017) Lateral trunk lean and medializing the knee as gait strategies for knee osteoarthritis	1	1	1	1	2	1	1	0	**NA**	1	0	0	0	0	0	0	**NA**	1	1	1	1	**1**	**0**	0	1	**NA**	0		15

Reporting by PRB.

	REPORTING										External Validity			Internal Validity - bias							Internal validity - confounding (selection bias)						Power		
Study	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**		**Total:**
Barrios, J; Crossley, K; Davis, I (2010) Gait retraining to reduce the knee adduction moment through real-time visual feedback of dynamic knee alignment	1	1	1	1	2	1	1	1	0	1	0/unable to determine.	unable to de	0	0	0	1	1	1	0	1	1	**1**	**0**	0	1	Unable to determine	1		18
Hunt, M; Simic, M; Hinman, R; Bennell, K; Wrigley, T (2011) Feasibility of a gait retraining	1	1	1	1	1	1	1	1	**NA**	1	0/unable to determine.	unable to de	0	0	0	1	**NA**	1	1	1	1	**1**	**0**	0	1	**NA**	0		16
Mundermanna ET AL. (2008) Implications of increased medio-lateral trunk sway for ambulatory	1	1	1	1	1	1	1	0	**NA**	1	0/unable to determine.	unable to de	0	0	0	1	**NA**	1	1	1	1	1	0	0	1		1		16
Shull, P; Shultz, R; Slider, A; Dragoo, J; Besier, T; Cutkosky, M; Delp, S (2013) Toe-in gait reduces the first peak knee adduction moment in patients with medial compartment	1	1	1	1	2	1	1	0	**NA**	0	0/unable to determine.	unable to de	0	0	0	1	**NA**	1	1	1	1	**1**	**0**	0	1	**NA**	1		16
van den Noort, J; Steenbrink, F; Roeles, S; Harlaar, J (2015) Real-time visual feedback for gait retraining:	1	1	0	1	1	1	0	0	**NA**	0	0/unable to determine.	unable to de	0	0	0	1	**NA**	1	1	1	1	**1**	**0**	0	1	**NA**	0		12
Dunphy, C; Casey, S; Lomond, A; Rutherford, D (2016) Contralateral pelvic drop during gait increases	1	1	1	1	1	1	1	0	**NA**	1	0/unable to determine.	unable to de	0	0	0	1	**NA**	1	1	1	1	**1**	**0**	0	1	**NA**	0		15
Ota, S; Ogawa, Y; Ota, H; Fujiwara, T; Sugiyama, T; Ochi, A (2017) Beneficial effects of a gait used	1	1	0	1	1	1	0	0	**NA**	1	0/unable to determine.	unable to de	0	0	0	1	**NA**	1	1	1	1	**1**	**0**	0	1	**NA**	0		13
Richards, R; Van Den Noort, J; Van Der Esch, M; Booij, M; Harlaar, J (2017) Effect of real-time biofeedback on peak knee adduction moment in patients with medial	1	1	1	1	2	1	0	0	**NA**	1	0/unable to determine.	unable to de	0	0	0	1	**NA**	1	1	1	1	**1**	**0**	0	1	**NA**	1		16
Erhart-Hledik, J; Asay, J; Clancy, C; Chu, C, Andriacch (2017) Effects of Active Feedback Gait Retraining to Produce a Medial Weight Transfer at the Foot in Subjects with	1	1	1	1	2	1	1	0	**NA**	1	0/unable to determine.	unable to de	0	0	0	1	**NA**	1	1	1	1	**1**	**0**	0	1	**NA**	1		17
Khan, S; Khan, S; Usman, J (2017) Effects of toe-out and toe-in gait with varying walking speeds on knee joint mechanics and lower limb	1	1	1	1	1	1	0	0	**NA**	0	0/unable to determine.	unable to de	0	0	0	1	**NA**	1	1	1	1	**1**	**0**	0	1	**NA**	1		14
Gerbrands, T; Pisters, M; Theeven, P; Verschueren, S; Vanwanseele, B (2017) Lateral trunk lean and medializing the knee as gait	1	1	1	1	2	1	1	0	**NA**	1	0/unable to determine.	unable to de	0	0	0	1	**NA**	1	1	1	1	**1**	**0**	0	1	**NA**	0		16

SPSS Output: Kappa measure of agreement between JBB and PRB.

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	$\boxed{.891}$	.024	20.050	.000
N of Valid Cases		297			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Kappa measure of agreement between two authors (JBB and PRB) on assessing the risk of bias in the 11 included studies in the systematic review was 0.89.