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Gait modifications to change lower extremity gait biomechanics in runners: a systematic review

Christopher Napier,[1] Christopher K Cochrane,[1] Jack E Taunton,[2] Michael A Hunt[1]

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[1]Faculty of Medicine, Department of Physical Therapy, University of British Columbia, Vancouver, British Columbia, Canada
[2]Faculty of Medicine, Division of Sports Medicine, Department of Family Practice, University of British Columbia, Vancouver, British Columbia, Canada

Correspondence to
Dr Michael A Hunt, Department of Physical Therapy, University of British Columbia, 212-2177 Wesbrook Mall, Vancouver, British Columbia, Canada V6T 1Z3; michael.hunt@ubc.ca

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ABSTRACT

Background Abnormal biomechanics have been cited as a potential risk factor for running-related injury. Many modifiable biomechanical risk factors have also been proposed in the literature as interventions via gait retraining.

Aim To determine which interventions have successfully modified biomechanical variables linked to running-related injury.

Study design Systematic literature review.

Methods MEDLINE, EMBASE, CINAHL, SportDiscus and PSYCINFO were searched using key terms related to running biomechanics and gait retraining. Quality of included studies was assessed using the modified Downs and Black Quality Index and a best evidence synthesis was performed.

Results 27 studies investigating the effect of biomechanical interventions on kinetic, kinematic and spatiotemporal variables were included in this review. Foot strike manipulation had the greatest effect on kinematic measures (conflicting evidence for proximal joint angles; strong evidence for distal joint angles), real-time feedback had the greatest effect on kinetic measures (ranging from conflicting to strong evidence), and combined training protocols had the greatest effect on spatiotemporal measures (limited to moderate evidence).

Conclusions Overall, this systematic review shows that many biomechanical parameters can be altered by running modification training programmes. These interventions result in short term small to large effects on kinetic, kinematic and spatiotemporal outcomes during running. In general, runners tend to employ a distal strategy of gait modification unless given specific cues. The most effective strategy for reducing high-risk factors for running-related injury—such as impact loading—was through real-time feedback of kinetics and/or kinematics.

The incidence of running-related injury varies from 19% to 85%[1–4] and this rate has not decreased appreciably in the past 30 years.[4] A significant portion of runners who become injured do not return to running.[1]

Abnormal biomechanics have long been proposed as a potential risk factor for running-related injury.[3 5 6] For example, several measures—including rearfoot eversion,[7–11] vertical loading rate[12–16] and foot strike index[17]—have all demonstrated a significant association with running-related injury. Given the possible links between faulty lower limb biomechanics and injury risk during running, many interventions have been aimed at modifying these biomechanical risk factors through the varied use of orthotics,[18] shoes, the absences of shoes,[19] changing surfaces and other structural interventions in an effort either to treat running-related injury or lower injury risk.[20–25] Some of these biomechanical variables—such as cadence and foot strike—may be modifiable via specific interventions while others may not. To know which interventions may be effective in treating running-related injury, it is important to know which biomechanical variables have been successfully modified during running gait. To date, only one paper has reviewed the influence of stride frequency/length on running mechanics, finding that an increased stride frequency reduced the magnitude of several biomechanical variables associated with running-related injury.[26] However, none have looked at the effect of other commonly used clinical interventions on running gait. The aim of this systematic review, therefore, was to determine which interventions have successfully modified individual kinetic, kinematic and spatiotemporal variables. For practical reasons, only the most commonly reported biomechanical variables will be included.

METHODS

Identification and selection of the literature

This systematic review was conducted and reported according to the PRISMA protocol. A search strategy was devised for electronic databases (MEDLINE, EMBASE, CINAHL, SportDiscus and PSYCINFO), with restrictions for English language and publication type (reviews and conference abstracts excluded). No date restrictions were included. The final search was completed on 22 July 2014 and involved the following search strategy (identical for all databases): (1) Biomechanics/ or Kinetics/, (2) Biomechanic$.mp, (3) Kinetic$.ti,ab or Kinematic$.ti,ab, (4) 1 or 2 or 3, (5) running/ or jogging/, (6) runner$.ti,ab or running.ti,ab, (7) 5 or 6, (8) 4 and 7, (9) Animals/, (10) 8 not 9.

Titles and abstracts of all identified citations were screened by two reviewers (CN and CKC), with the full-text of articles meeting the initial inclusion criteria retrieved for further screening. Reference lists of all publications considered for inclusion were further reviewed and a manual search of one author's (CN) private collection was conducted until no additional eligible publications were identified. In cases of disagreement between the first two reviewers, a third reviewer (MAH) determined the final eligibility of the selected publications.

Selection criteria

An article was eligible for inclusion if it met all of the following criteria: (1) the statistical comparison of at least one intervention with a biomechanical variable of interest was reported; (2) data were

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derived experimentally from a cohort of skeletally mature able-bodied subjects using a within-subjects design; (3) the outcome of interest was a biomechanical (kinetic, kinematic and/or spatiotemporal) variable; (4) the protocol included straight-line, submaximal running (either on a treadmill or overground); (5) the primary independent variable was a biomechanical intervention intended to have a direct result on lower extremity biomechanical characteristics during running. Articles were excluded if: (1) the study sample consisted of disabled or chronic disease populations; (2) the protocol only included lateral, cutting, sprinting or other modes of locomotion; (3) the study was designed to investigate the effect of a 'negative' intervention (eg, fatigue, pain, swelling, delayed onset muscle soreness, etc) on running gait biomechanics; (4) the intervention did not include gait modification—studies that only varied the surface (treadmill, overground, trail, road, etc), incline/decline, footwear or velocity were excluded, as were studies where the primary objective was to modify some physiological parameter (eg, muscle strength) that may have had an indirect effect on lower extremity biomechanics during running; or (5) the study did not control for running speed.

Assessment of methodological quality

Publications that met all selection criteria were assessed for methodological quality by two independent reviewers (CN and MAH). A modified version of a quality index for randomised and non-randomised trials was used.[27] This tool contains 27 items evaluating 5 subscales: reporting, external validity, bias (intervention and outcome measurement), confounding (cohort selection bias) and power. As recommended in the literature,[28] the power subscale (question 27) was not used in this study due to item ambiguity. The quality index awards one point for each item. No points are awarded if the answer is negative or is unable to be determined. Thus, the maximum score for the modified index was 26 points. Agreement between reviewers was assessed using a κ statistic, with reference to Landis and Koch's criteria where κ values >0.81 represent 'almost perfect' agreement; >0.61, 'substantial' agreement; 0.41–0.60, 'moderate' agreement; and <0.40, 'poor to fair' agreement.[29]

Data synthesis and analysis

A single reviewer (CN) extracted group means, SDs, and sample sizes directly from the selected articles and all reviewers checked extracted data. Statistical pooling of the data was not performed because of the small number of studies that addressed the same outcome measure with the same intervention. However, a best evidence synthesis was performed (see online supplementary table S1). Our inclusion/exclusion criteria limited the studies to repeated measures designs. Studies that only looked at immediate effects (ie, within a single session) and longitudinal effects (ie, multiple training sessions) were not considered to be different. Rather, the methodological quality of the studies and the consistency of findings across studies were deemed to be important and used to determine level of evidence, as has previously been used.[30] Effect sizes (ESs) were also calculated for the primary outcome variables for all studies that provided discrete data (ES=mean difference between normal and intervention measurements/pooled SD). Authors of publications that did not provide data in an extractable form were contacted. Effect sizes were used in this review to provide a means of evaluating success of the intervention because these are not directly affected by sample size but take into account within-group variability. Effect size magnitudes were interpreted based on Cohen (small=0.2, moderate=0.5 and large=0.8).[31]

RESULTS

Selection of studies

A search of the MEDLINE, EMBASE, CINAHL, SportDiscus and PSYCINFO databases identified a total of 3558 articles (figure 1). A total of 36 articles met the initial search criteria and their full texts were retrieved. After further review by two reviewers (CN and CKC), 11 of these articles were excluded because they did not meet the inclusion criteria. Ten additional articles were included from one author's personal collection (CN). As these studies reported on 143 different biomechanical variables, further analysis was conducted only on variables that were reported by three or more papers.[32] This reduced the number of biomechanical variables to 14, from 27 articles. Online supplementary table S2 summarises the characteristics of the included studies with regard to participant population, sample sizes, participant ages, intervention protocols, quantitative biomechanical variables and the mode of testing.

Methodological quality

Two reviewers (CN and MAH) assessed the final 27 studies using the modified quality index instrument. Of the 27 articles assessed, all achieved a score of 14 or above out of a possible 26, with the majority (n=19) scoring between 16 and 19 (see online supplementary table S3), indicating generally low to moderate methodological quality. A study was considered to be of high quality if the methodological quality score was greater than or equal to the mean of all of the quality scores.[33] All studies scored zero on items 13 (external validity items), 14, 15 (internal validity: bias items) and 24 (internal validity: confounding items). While studies scored poorly on blinding items, some (n=13) did use a randomised order of conditions (item 23). In addition, items 8 (reporting item), 10–12 (external validity items), 18 (internal validity: bias item) and 23 (internal validity: confounding item) also scored poorly. Studies generally scored well on items 1–7, 9 (reporting items), 16, 17, 19, 20 (internal validity: bias items), 21, 22, 25 and 26 (internal validity: confounding items). The initial agreement between reviewers was almost perfect (κ=0.923) and reliability for individual items ranged from substantial (κ=0.609, item 18) to perfect (items 5, 9, 13–15, 17, 20–22, 24 and 26).[29] Consensus was reached on all items at the initial discussion between the two reviewers.

Study characteristics

The 27 studies that qualified for final inclusion in this review consisted of a mix of gait retraining interventions (see online supplementary table S4). Foot strike manipulation (forefoot/mid-foot strike vs rearfoot strike) was the most common intervention with nine studies using this intervention.[20 24 34–40] Step frequency (six studies)[37 41–45] and step length (six studies)[45–50] modifications were also common interventions, followed by step width (three studies).[36 49 51] Four studies provided real-time feedback about peak-positive tibial acceleration.[22 52–54] Finally, two studies provided a combined intervention consisting of a patented technique (Pose method).[21 24] In studies with additional conditions—such as shoe type or velocity—only outcomes that were compared within the same condition were analysed.

Intervention outcomes

Results are grouped by the variable of interest, rather than a specific gait modification. Further, unless specifically stated, all changes described pertain to comparisons with normal,

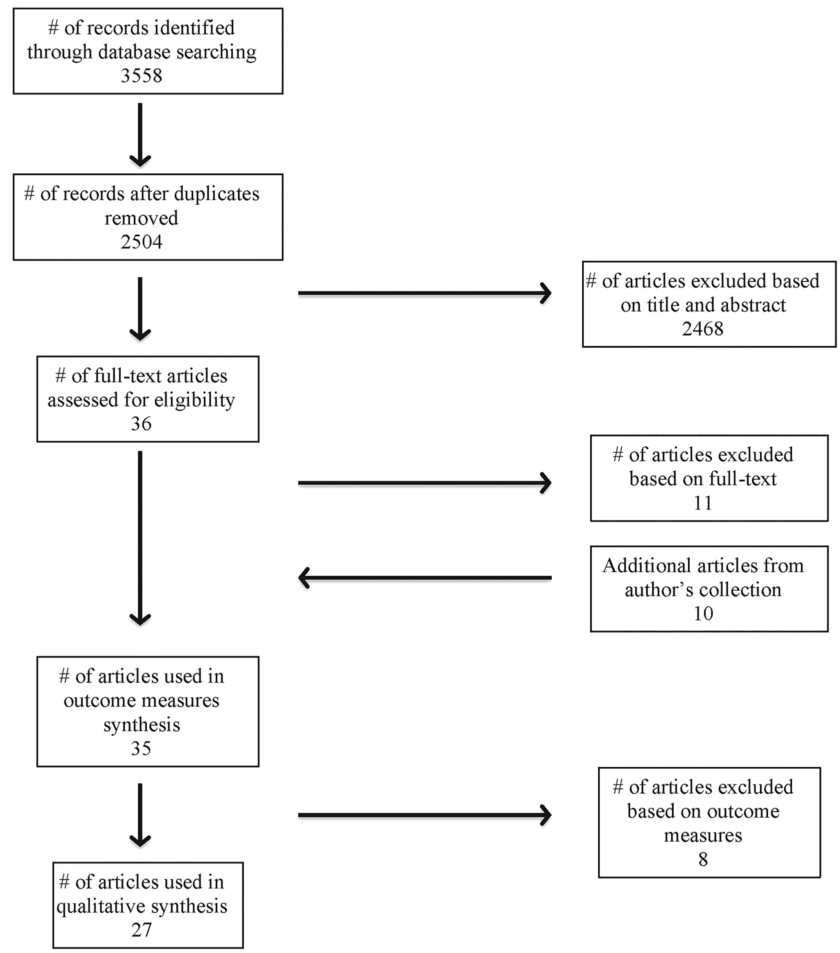

Figure 1 Flow diagram of the systematic review process. '#' denotes 'number'.

self-selected (ie, not modified) running trials. Studies that only provided a subjective comparison between conditions (eg, 'more' or 'less') are also detailed below, although these do not contain quantifiable data such as effect sizes or statistical comparisons. Six studies[20–22,24,52,55] employed multiple training sessions and examined longitudinal effects, while the remaining studies were limited to a single session and examined immediate effects.

Kinematics

Nine publications looking at kinematic variables were included in this review. Variables examined were: hip angle (sagittal plane) at initial contact, knee angle (sagittal plane) at initial contact, ankle angle (sagittal plane) at initial contact and peak rearfoot eversion/rearfoot eversion at maximum pronation.

Changes in hip kinematics

Based on our best evidence synthesis, there was no evidence found to support changing sagittal hip angle at initial contact by modifying stride length or from peak-positive acceleration feedback. There was conflicting evidence for foot strike manipulation. Hip angle at initial contact showed decreased flexion in one study when subjects were asked to run forefoot in shod and barefoot conditions (ES=0.44 and 0.48, respectively).[38] However, Williams *et al*[40] found no difference in hip flexion angle at initial contact with a forefoot strike versus rearfoot strike (ES=0.01), and Seay *et al*[47] found no difference when stride length was increased (ES=0.87) or decreased (ES=0.11). Peak-positive acceleration feedback also did not change hip angle postfeedback protocol (ES=0.17) or at 1 month follow-up (ES=0.18).[52]

Changes in knee kinematics

There was no evidence to support peak-positive acceleration feedback or stride length manipulation in changing sagittal knee angle at initial contact. The evidence for foot strike manipulation was conflicting, and limited evidence supported the Pose technique and step frequency manipulation. Contrasting results were reported for knee angle at initial contact, with Shih *et al*[38] reporting increased flexion with a forefoot strike versus rearfoot strike (ES=0.78 and 1.95 for barefoot and shod conditions, respectively), while Williams *et al*[40] found no significant difference (ES=0.02). Arendse *et al*[24] also found increased knee flexion at initial contact with the Pose technique (which employs a forefoot strike and an increased step rate; ES=0.61), but no difference with a mid-foot strike (0.02). Step rate and step length had no significant effect on knee angle at initial contact except when step rate was increased by 10% (ES=0.44).[42,47] Peak-positive acceleration feedback had no effect on knee angle postfeedback protocol (ES=0.04) or at 1 month follow-up (ES=0.21).[52]

Changes in ankle kinematics

There was no evidence to support peak-positive acceleration feedback in changing sagittal ankle angle at initial contact, and limited evidence to support the Pose technique and stride length manipulation. Foot strike manipulation, however, was supported by strong evidence. The largest ES from non-pooled data involved the sagittal angle at the ankle at initial contact. Specifically, the ankle tended to be more plantarflexed at initial contact with a mid-foot strike (ES=4.76),[24] forefoot strike (ES=3.88 and 5.60 for barefoot and shod, respectively,[38] and ES=4.26[40]) or Pose technique (ES=2.35).[24] Peak-positive acceleration feedback resulted in significantly increased plantarflexion both immediately postfeedback protocol (ES=0.76) and at 1 month follow-up (ES=0.90).[52] A 20% increase in stride length had the effect of decreasing plantarflexion (ES=0.26).[47] No significant difference was reported when stride length was decreased by 20% (ES=0.23).[47]

Changes in foot kinematics

There was no evidence to support step length manipulation in changing rearfoot eversion angle at initial contact. Step width and foot strike manipulation were both supported by limited evidence. Three studies examined peak rearfoot eversion. Two of these studies varied step width, finding that in all but one instance ('normal' vs 'wide step' (ES=0.37)[56]) that a crossover gait increased peak rearfoot eversion (compared with 'normal' (ES=0.44[56] and 0.66[49]and 'wide step' (ES=0.80[56]) and a wide gait decreased it (ES=1.21)).[49] Pohl *et al*[36] also found that peak eversion decreased with a forefoot strike versus rearfoot strike (ES=0.69). This was even more pronounced with a toe foot strike (compared with rearfoot strike (ES=1.81) and forefoot strike (ES=1.03)).[36] No significant differences were shown with a change in step length ('long' step length (ES=0.03) or 'short' step length (ES=0.27)).[49]

Kinetics

Kinetic variables were examined from 17 papers and included: vertical impact peak, average vertical loading rate, instantaneous vertical loading rate, peak-positive tibial acceleration, shock attenuation, vertical stiffness and leg/lower extremity stiffness.

Vertical impact peak

There was conflicting evidence for step length and step frequency manipulation, as well as peak-positive acceleration feedback to reduce vertical impact peak. Limited evidence supported hip adduction angle retraining as a means to reduce vertical impact peak, while foot strike manipulation and the Pose technique were backed by moderate evidence. Vertical impact peak was reduced by increasing step frequency (with a 36% increase when compared to a 26% decrease from preferred step frequency (ES=NA; not applicable)[41]) and was increased when step frequency was reduced (with a 30% reduction (ES=NA)[43]) or when step length was increased (ES=1.54).[48] However, contrasting results from some studies[13 37 43 48] suggest that an increase/decrease in step frequency or step length does not consistently affect vertical impact peak. Two studies showed a decrease in vertical impact peak with a mid-foot strike (ES=1.39),[24] forefoot strike (ES=0.30)[21] or Pose technique (ES=1.33),[24] but Cheung *et al*[20] did not find a difference between foot strikes (rearfoot strike vs forefoot strike ES=1.06). Peak-positive acceleration feedback did not affect vertical impact peak postfeedback protocol (ES=0.58) or at 1 month follow-up (ES=0.70).[52]

Average vertical loading rate

Evidence was conflicting for the effect of step frequency manipulation on average vertical loading rate. Limited evidence supported the Pose technique and hip adduction angle retraining. Moderate evidence supported foot strike manipulation and peak-positive acceleration feedback for reducing average vertical loading rate. Average vertical loading rate was consistently reduced with a forefoot strike (ES range from 1.93–3.32)[20 37 38] and mid-foot strike pattern (ES=1.97).[37] Average vertical loading rate was not affected by stride frequency unless significantly altered (30% decrease from preferred step frequency (ES=NA)).[43] A Pose training protocol also decreased average vertical loading rate (ES=0.57).[21] The hip adduction angle retraining protocol similarly produced a reduction in average vertical loading rate (ES=1.05).[55] Peak-positive acceleration feedback training reduced average vertical loading rate by 27.6% (ES=NA)[53] and 32% (ES=1.50)[22] in two studies and in another, showed a significant decrease immediately postfeedback protocol (ES=0.72), but not at 1 month follow-up (ES=0.26).[52]

Instantaneous vertical loading rate

Reductions in instantaneous vertical loading rate were supported by limited evidence when step frequency was manipulated or with the Pose technique or hip adduction angle retraining. Moderate evidence supported foot strike manipulation and peak-positive acceleration feedback as a means to reduce instantaneous vertical loading rate. Instantaneous vertical loading rate was reduced with a forefoot strike (ES range from 2.32–3.74)[20 38] and mid-foot strike (ES=1.49),[24] and increased with a 30% decrease in preferred step frequency (ES=1.02).[43] Peak-positive acceleration feedback training[22 53] reduced instantaneous vertical loading rate (ES=1.70)[22] in one study, while in another it showed a reduction immediately postfeedback protocol (ES=0.70), but not at 1 month follow-up (ES=0.34).[52] Hip adduction angle retraining also reduced instantaneous vertical loading rate (ES=1.02),[55] as did the Pose technique (ES=1.33).[24]

Peak-positive tibial acceleration

Evidence was limited for the reduction of peak-positive tibial acceleration by manipulating foot strike or step length. Strong evidence supported using real-time direct peak-positive acceleration feedback to reduce peak-positive tibial acceleration. Reductions in peak-positive tibial acceleration were seen by altering foot strike (forefoot strike; ES=1.14)[35] and decreasing step length.[46] An increase in step length produced an increase in peak-positive acceleration.[46] This is consistent with the reductions in impact loading noted above (vertical impact peak, average vertical loading rate and average vertical loading rate). Direct feedback about peak-positive acceleration produced a reduction of 32.2% (ES=NA)[53] and 48% (ES=1.50)[22] post-training in studies by Crowell *et al* and 30.7% (post-training; ES=1.89) and 22.2% (1 month follow-up; ES=1.25) in Clansey *et al*[52] Another study showed reductions within a single session using audio feedback for peak-positive acceleration (ES=0.31–1.02).[54]

Shock attenuation

Evidence was conflicting for step length manipulation in decreasing shock attenuation, and limited for foot strike and step frequency manipulation. Derrick *et al*[46] found no difference in shock attenuation when step length was altered by 10–20%. However, Mercer *et al*[45] found a 10% decrease in step length and corresponding 10% increase in step frequency produced a decrease in shock attenuation (ES=0.41), but the reverse had no significant effect (ES=0.12). Delgado *et al*[35] found that shock attenuation decreased with a forefoot strike versus rearfoot strike (ES=1.18).

Vertical and leg/lower extremity stiffness

No evidence supported using foot strike manipulation as a means to change vertical or leg stiffness. Evidence was conflicting for the effect of step frequency manipulation on leg stiffness, but it was limited for its effect on vertical stiffness. Vertical stiffness and leg stiffness followed similar patterns of increasing stiffness with increasing step frequency,[37 41 44] but no difference with a change in foot strike pattern.[37 38]

Spatiotemporal

Thirteen papers reporting on three spatiotemporal variables (step frequency, step length and ground contact time) were considered.

Step frequency

There was no evidence to support foot strike or step width manipulation to change step frequency.[34 38 39 51] Limited evidence supported the Pose technique for increasing step frequency (ES=1.05).[21]

Step length

Similarly, step length did not respond to alterations in foot strike pattern or step width (no evidence).[24 34 49] Step length was decreased by the Pose technique (ES=0.54[24] and 0.66[21] moderate evidence). One study that held speed constant while manipulating step frequency also showed a corresponding manipulation of step length (limited evidence).[42]

Ground contact time

There was no evidence to support step length manipulation to reduce ground contact time. Evidence was conflicting for foot strike and step frequency manipulation, and limited for the Pose technique. In general, ground contact time decreased with either decreased step length or increased step frequency,[41 42 46 50] but these differences did not always reach significance, especially with smaller manipulations.[37 42 45 46] Foot strike manipulation did not appear to have a significant impact on ground contact time[34 37 39] except in one study by Shih *et al*,[38] which showed a reduction in ground contact time with a forefoot strike (ES=0.19 and 0.31 in barefoot and shod conditions, respectively). The training protocol study utilising the Pose technique showed a decrease in ground contact time.[21]

DISCUSSION

We reviewed the effectiveness of biomechanical interventions on modifying aspects of running gait that may be associated with running-related injuries. Foot strike manipulation protocols had the greatest effect on kinematic measures (such as sagittal ankle joint angles); real-time feedback protocols had the greatest effect on kinetic measures (vertical impact peak, average vertical loading rate and instantaneous vertical loading rate); and combined training protocols had the greatest effect on spatiotemporal measures (step frequency, step length and ground contact time). Overall, this systematic review shows that many biomechanical parameters can be altered with running modification training programmes.

Effect of gait modification on kinetic measures

Impact loading (the sudden force applied to the skeleton at initial contact) has demonstrated the greatest association with lower extremity overuse injuries from any of the biomechanical variables.[10 13–15 57–62] Of the variables used to measure impact loading, average vertical loading rate appears to be the greatest running-related injury risk factor. A systematic review by Zadpoor *et al*[16] found that while average vertical loading rate was significantly different between populations who had suffered a tibial stress fracture and control populations, the overall magnitude of ground reaction force was not. A recent prospective study on the relationship of kinetic variables between injured and non-injured runners showed a higher average vertical loading rate in injured compared to non-injured male runners, but no difference in females.[12] Findings from this review show that the most effective strategy for reducing impact loading is through real-time feedback of kinetics and/or kinematics.[22 52–55] While the tibial peak-positive acceleration feedback interventions had the expected effect of decreasing peak-positive acceleration, they also reduced average vertical loading rate and instantaneous vertical loading rate, but not consistently the vertical impact peak.[22 52–54] Interestingly, the hip adduction angle feedback intervention also produced reductions in vertical impact peak, average vertical loading rate and instantaneous vertical loading rate.[55] The influence of real-time feedback of kinetic measures to reduce impact forces is logical, but does not explain why the hip adduction angle feedback protocol produced a similar effect on kinetics. While the authors did not explore this relationship in detail, it can be posited that the reduction in impact forces may be due to a compensatory strategy for impact load absorption when hip adduction angle is reduced. Unfortunately, individual joint stiffness was not measured in these studies, but might be used in the future to help explain this mechanism.

Average vertical loading rate and instantaneous vertical loading rate were both reduced with a forefoot strike or mid-foot strike versus a rearfoot strike pattern, while instantaneous vertical loading rate was increased with a pronounced decrease in step frequency. The reduction of the average vertical loading rate and instantaneous vertical loading rate is a result of the smoothing or loss of the vertical impact peak and may be indicative of the ability of the spring mechanism of the Achilles tendon to absorb the impact load from initial contact over a greater period of time. The reduction of the average vertical loading rate with the Pose technique likely occurred via the same mechanism of a forefoot strike.

Multiple kinematic and spatiotemporal variables have been proposed to contribute to the development of running-related injury. These include angles at the ankle, knee and hip;[5 9 10] rearfoot eversion/inversion;[7 9 10] sagittal and frontal plane movements of the pelvis;[63] angle of the tibia at initial contact;[42] foot strike index;[17] horizontal distance from centre of mass to heel at initial contact;[42] vertical excursion of centre of mass;[42] percentage of available pronation range of motion used;[64] step frequency, step length and ground contact time.[42 65] Of these, sagittal angles at the ankle, knee and hip; rearfoot eversion; step frequency, step length and ground contact time were explored in this review.

Effect of gait modification on kinematic measures

Sagittal ankle joint kinematics showed the largest ES in this review and were most influenced by foot strike modification. In fact, distal kinematics appeared to be affected to a greater degree than proximal when foot strike was manipulated. This is not surprising given that an individual is most likely to initially focus one's intentions on this joint specifically to produce the change in foot strike pattern. Interestingly, ankle kinematics also varied the most in a recent study using a peak-positive acceleration feedback protocol, suggesting that individuals used an ankle strategy first to minimise impact forces.[52] Hip and knee kinematics were minimally changed with this intervention. Effects of stride length and stride frequency manipulations on distal kinematics are most likely due to the fact that a relative increase in stride length tends toward a greater foot strike index (rearfoot strike) at initial contact.

Rearfoot eversion measures were most influenced by a narrow step width. This increased peak value most likely occurs as a direct result of the greater available eversion range of motion at the rearfoot when initial contact occurs closer to (or beyond) the midline as compared to when it occurs more lateral to the vertical projection of the centre of mass. The decreased rearfoot eversion seen with a toefoot strike and forefoot strike indicates that the toefoot strike and forefoot strike may result in a more rigid foot at initial contact than with rearfoot strike running and might account for different shock attenuation strategies employed by rearfoot strike (foot pronation) and toefoot strike/forefoot strike runners (Achilles spring).

Effect of gait modification on spatiotemporal measures

Step frequency, step length and ground contact time are innately linked. Generally, a greater step length and ground contact time has been associated with novice runners and potentially a higher incidence of injury.[65] In runner's terms this is called 'overstriding.' Horizontal distance from centre of mass to heel may be considered representative of overstriding, producing a braking effect and a higher impact load at initial contact.[42] Step frequency and step length did not appear to be sensitive to manipulations in foot strike pattern or step width, but did change following a 6-week Pose running programme. This effect was likely due to the specific emphasis given to 'increasing the running step rate to 3 steps per second' during the intervention.[21] The adaptation to a greater step frequency and shorter step length in the Pose technique versus pure manipulation of foot strike pattern could also be attributed to the greater amount of training time (three times/week for 45 min over 6 weeks) given to the Pose technique. Indeed, it is conceivable that foot strike manipulation alone could have produced similar changes had the interventions been over a longer period rather than training and measuring within a single session.

A reduction in ground contact time was generally associated with a decreased step length or increased step frequency, but appeared to depend on the magnitude of these manipulations. This suggests that runners maintain or increase their swing time to increase their step frequency, while reducing the time spent in stance phase. Though not covered under the scope of this review, Stearne *et al*[39] looked at the fraction of the stride spent in contact with the ground (duty factor) in their study on foot strike manipulation. While not reaching significance, there was a trend toward an increased proportion of time spent in the swing phase versus the stance phase in rearfoot strike versus forefoot strike running.[39] Further investigation of this concept is warranted as it applies to step frequency/length manipulation.

While the Pose technique produced a significant reduction in ground contact time, only one study[38] showed a significant change in this variable with foot strike manipulation. Generally, stance time has been shown to be greater in habitual rearfoot strike compared to forefoot strike runners, but when foot strike is imposed—at least within a single session—there is no difference.[39] The Pose technique and a forefoot strike pattern both might be expected to decrease ground contact time because of the increased step frequency/decreased stride length associated with these running patterns. Again, the fact that this change only reached significance in the study teaching the Pose technique is likely due to the length of the training programme given to adapt to the Pose technique as opposed to the single session training and testing in the foot strike manipulation studies.

In general, it can be said that runners tend to employ a distal strategy of gait modification unless specific cues (eg, 'maintain a flexed knee throughout the gait cycle') are given. Longer training programmes also likely contribute to global changes that may produce more proximal effects. It is also important to realise that kinetic measures can be influenced by both foot posture at initial contact as well as foot position relative to the centre of mass. Future studies should employ longer gait retraining programmes and test for long-term retention. Including measures of running economy may also help to distinguish between efficient and inefficient patterns of movement.

LIMITATIONS OF THE REVIEW

The risk of selection bias was minimised by using a modified version of a quality index for randomised and non-randomised trials.[27] Publication bias may bias results toward positive treatment effects, but this limitation is difficult to quantify with such a large variation in interventions. Owing to the large variation in interventions, it was impossible to undertake a meta-analysis in this review. Some outcomes were similar in what they attempted to measure, but could not be directly compared because they were measured at different intervals (eg, terminal swing vs initial contact). Some outcomes used different units, which also did not allow for direct comparison (eg, dB vs kg/Nm). All of the studies included in this review were a within-subjects design and as such, none had a control group.

While the inclusion of variables in the analysis that appeared most frequently was necessitated by the large number of variables in the initial search (n=143), it does not necessarily mean that these variables are the most important clinically or biomechanically. Instead, these may simply be variables that are easier to manipulate or measure. Further research is required to ascertain the clinical relevance of a range of biomechanical variables to the onset and progression of running-related injury.

Limitations of the actual study methods included the assessment of long-term retention and multiple session interventions. Only two studies[20 22] had follow-up measurements taken to test for retention of biomechanical changes. As a result, it is unclear what effect some of these interventions might have once they become incorporated into a habitual running pattern as opposed to being tested when the intervention is still novel. Similarly, the only studies that incorporated an intervention beyond one session were those that instructed the Pose method.[21 24] These studies showed more significant changes to running biomechanics than simple foot strike manipulations, but because of the combined nature of the intervention it is difficult to know whether it was a specific mechanical intervention or the increased time given to incorporate these changes into a habitual pattern that was the main factor that produced these changes.

SUMMARY

Gait retraining interventions appear to result in short term small to large effects on kinetic, kinematic and spatiotemporal outcomes during running. Foot strike manipulation had the greatest effect on kinematic measures (conflicting evidence for proximal joint angles, but strong evidence for distal joint angles), real-time feedback had the greatest effect on kinetic measures (ranging from conflicting to strong evidence), and combined training protocols, such as the Pose technique, had the greatest effect on spatiotemporal measures (limited to moderate evidence).

This review highlights the need for further research on interventions to modify kinetic, kinematic and spatiotemporal biomechanics in running. Future studies should include longer term follow-up measurements to assess retention of these biomechanical changes. Studies that include a longitudinal training programme would also be more useful than the majority of studies that simply investigate immediate changes from a novel intervention. Standardisation of the timing of measurements should also be ensured so that comparison between studies can be made.

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Gait modifications to change lower extremity gait biomechanics in runners: a systematic review

Christopher Napier, Christopher K Cochrane, Jack E Taunton and Michael A Hunt

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