RETRAINING RUNNING GAIT TO PREVENT LOWER EXTREMITY OVERUSE INJURIES: A REVIEW OF LITERATURE

Daniel P. Sullivan¹

¹Department of Kinesiology, San José State University, San José, CA, United States

ABSTRACT

Sullivan DP. Retraining Running Gait to Prevent Lower Extremity Overuse Injuries. Journal of Undergraduate Kinesiology Research 2015;10(2):1-12. Purpose: Distance runners experience high rates of lower extremity overuse injuries due in part to a biomechanically inefficient gait pattern. Therefore, the purpose of this review was to determine if gait retraining can be used to effectively prevent the incidence of these overuse injuries. Methods: Articles on the subjects of risk factors for overuse injuries, biomechanical alterations contributing to the reduction of injuries, and the effects of gait retraining on injury treatment or prevention were compiled. These articles were analyzed in detail for pertinent methodologies and results relevant to the topic of this review. Results: Results showed multiple risk factors for runners including anthropometric and biomechanical, overtraining, and predisposition variables. Avoiding a rearfoot strike in favor of a midfoot or forefoot strike and increasing step rate were shown most effective in the reduction of injury-causing joint forces. The authors of many empirical studies who tested different gait retraining methods found significant reductions of joint forces absorbed by the lower limbs following gait retraining protocols. Some researchers did not find reductions in joint forces, but were able to attribute these inconsistencies with methodological flaws. Biofeedback, specifically visual feedback, proved to be a powerful method of successfully teaching a runner to alter his or her gait pattern. The authors of a case study even showed long-term retention of the new gait pattern in the participants of their study. Conclusion: Gait retraining appears to be a sound method for the prevention of running injuries.

Key Words: Gait retraining; Runners; Overuse injuries; Risk factors; Foot landing pattern
INTRODUCTION

This section needs to provide enough data and interpretations from past research to clearly identify the need for doing your study. However, it should not be too long. Focus the content on being able to answer several important questions.

There is a need to understand factors that lead to overuse injuries in runners. This need is directed in part by the increasing population of elite and recreational runners in the United States. The U.S. Census Bureau reported that of about 435,000 NCAA athletes, 21.5% (N=93,515) participated in either indoor or outdoor track (1). Furthermore, it was found that from a population of approximately 32,000, 58% (N=18,758) of runners were between the ages of 12 and 34 (2). In the 2008-2009 school year, track and field had the largest number of female participants and the second largest number of male participants nationwide in U.S. high schools (3). Clearly, runners make up a large portion of the athletic population in America.

Injuries involving the lower extremities are especially common for runners. Hootman et al found that 50% of all acute and overuse injuries surveyed in the NCAA over a sixteen-year period were to the lower extremities (4). Other researchers have determined overuse injury rates to be noticeably high in runner populations. Among athletes monitored in the NCAA’s Big Ten conference, male track and field athletes sustained the highest rates of overuse injuries (5). In most cases, overuse injuries are treated with minor rehabilitative interventions; long-term, preventative interventions seem to be less common.

It is essential to reduce the magnitude of injurious joint forces absorbed by the body in order to prevent overuse injuries. The retraining of an athlete’s running gait is one promising intervention that has shown reductions in multiple variables that have been linked to overuse injuries of the lower extremities (6–8).

In this literature review I analyzed available literature to determine the effectiveness of gait retraining to prevent overuse injuries. Also analyzed were other intervention methods such as different footwear and biomechanical alterations that cause changes in a person’s running gait. The goal was to identify an effective means of retraining a runner’s gait to a more biomechanically efficient one for the purpose of reducing the incidence of overuse injuries in the lower extremities, as well as to identify any gait retraining methods that were both practical in application and that led to long-term retention of the newly-learned gait pattern. This review included a discussion of (a) methodology used to obtain articles, (b) risk factors related to overuse injuries in runners, (c) prevention of running overuse injury, and (d) the findings.

METHODS

Population
The population included male and female middle distance and distance runners between the ages of 14 and 34. No limitations were placed on gender or ethnicity because there are no differences between ethnicities and few differences between males and females in terms of how injuries occur and are rehabilitated. Female athletes have been shown to experience some elevated risks and rates of certain overuse injuries (9). However, injury rates in male athletes were still high enough to warrant including both sexes in this review. This review does limit age to between 14 and 34 for two reasons: (a) this demographic was the most widely represented in the research studies, and (b) older adults and very young children have more complex needs in terms of injury rehabilitation, which exceeded the scope of this review.
Variables and Delimitations
The relevant variables included here were impact peak (IP), instantaneous loading rate (ILR), average loading rate (ALR), tibial acceleration (TA), and ground reaction force (GRF). High values for each of these variables have been linked to increased incidences of overuse injuries and are the most commonly measured variables in gait retraining studies (7, 10–13). Another important variable addressed by some studies was retention of the new gait pattern (6,7); therefore, how athletes retained their new gait pattern will be a considered variable.

This review included results only from studies on middle distance and distance runners. Power and speed-based activities such as sprinting tend to be more associated with acute injuries than they are with overuse injuries (5). Sprinting is also biomechanically different from distance running in many ways and would only complicate the interpretation of results if included. Additionally, I found no accessible research studies on gait retraining for sprinters. Only lower extremity overuse injuries were included. Although there are other overuse injuries related to running, such as those afflicting the back and abdominal region, I found no studies relating the effects of gait retraining reducing incidences of these kinds of injuries. Furthermore, no researchers included in this review examined the effects of a gait retraining program that lasted longer than two weeks. As such, only short term gait retraining intervention will be discussed in this review.

Search Criteria
Key words used for searching databases for articles included gait retraining, runners, overuse injuries, risk factors, forefoot strike, midfoot strike, rearfoot strike, step rate, and minimalist shoes. Combining these keywords (ex. gait retraining AND forefoot strike) helped increase specificity and improved the return of relevant studies. Another search tactic involved finding additional articles from the cited references of to this topic. The primary databases utilized in searching for research studies were Web of Science, SPORTDiscus, and Pubmed. These search methods returned numerous results, many of which were published in journals such as the Journal of Orthopaedic & Sports Physical Therapy, Clinical Biomechanics, and Medicine and Science in Sports and Exercise. A total of 28 core studies were selected for discussion in this review.

RESULTS

Risk Factors
To better understand how to prevent overuse injuries, it is necessary to determine what factors lead runners to become injured. For the purpose of this review, I define risk factors as any variable that enhances the probability that a runner will become injured. Some risk factors of running injury are extrinsic, while others are intrinsic. Not all of these factors can be controlled or altered through intervention. For the most part, these risk factors have been correlated with overuse injuries, but none have been shown to be a direct cause. The most common overuse injuries include patellofemoral pain syndrome (PFPS), iliotibial band friction syndrome, plantar fasciitis, meniscal injuries, medial tibial stress syndrome (MTSS), and stress fractures of the tibia (14). Taunton et al also found that the knee was the joint most vulnerable to injury, followed by the ankle and the foot. Although these injuries have many individual risk factors and etiologies, excessive joint force absorption is a common contributing factor among all of them (14). The risk factors discussed in this section can be placed in one of three main categories: anthropometric and biomechanical factors, factors related to overtraining, and unavoidable predispositions.

Anthropometric and Biomechanical Factors
Anthropometric and biomechanical risk factors include factors such as structural deformities, weakness in active or stabilizing muscles, improper technique, lack of flexibility, and/or misalignment
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of joints that can cause abnormal changes in a joint angle during running. These joint or anatomical discrepancies can cause the body to absorb additional forces. Many of these risk factors are correctable through biomechanical retraining of the running gait. Studies in which biomechanical risk factors were analyzed often approached the problem by determining the magnitude of GRF and loading rates that runners with biomechanical imperfections experienced.

A review of literature on the topic of risk factors for lower extremity stress fractures found that runners with pes cavus, genu valgum, lower muscular endurance, less flexibility, and a greater amount of body mass were at higher risk for stress fractures (15). However, the review merely analyzed the correlation between these variables and stress fractures and not the kinetic variables associated with them. Another review by Hreljac & Ferber reported that greater ankle range of motion, overpronation, and greater loading on the medial side of the foot may be linked to overuse injuries (16). A different review by Ferber et al found that ankle pronation, when prolonged beyond the midstance phase, caused the tibia to internally rotate to an excessive degree and increased the torque applied to the bone (17). However, they also found that some athletes with prior injuries displayed these overpronation tendencies, while in other studies no difference between injured and non-injured groups was found. Though there is some ambiguity and inconsistency in the findings of these studies, the negative effects that are potentially created by these risk factors are all possibly correctable through the retraining of a person’s gait pattern.

Lieberman et al, found an association between RFS patterns and overuse injuries (18). They found that RFS patterns caused a large IP, which is an initial spike in the vertical GRF experienced by the runner and therefore absorbed by the body. The IP was thought to be a major contributor to running injuries due to the high loads it placed on the runner. Lieberman et al found that individuals who ran with RFS patterns had much higher and more defined IPs than those who ran with a non-rearfoot strike. Rearfoot striking may, therefore, be directly correlated with running overuse injuries such as stress fractures of the calcaneus or tibia, MTSS, and meniscal injuries.

Overtraining

Overtraining is a common problem among runners. Frequently, competitive runners who are pushed by the desire to succeed, or those who lack the knowledge required to determine their own physical limitations end up overtraining and causing themselves injury. Overtraining to the extent that body tissues do not have enough time to heal can result in injuries. Harrast & Colonno discussed that stress fractures have been linked to overtraining, which causes longer-duration bone stress and ultimately weakens the tissues (19). The compact bone of the diaphysis remodels very slowly, and repetitive, frequent stress on the bone causes more damage before it can heal.

One theory on overtraining is that fatigue may decrease the ability of the runner to attenuate shock. Clansey et al placed a group of runners through a series of running trials designed to gradually fatigue the participants and measure their ability to attenuate shock (20). The results showed a significant increase in ALR and ILR from the first to the last trial. Other researchers found an increase in loading rates and impact force, and a decrease in the ability to attenuate shock following a local muscle fatigue protocol (21, 22). In contrast, a different study found that participants who performed multiple drops from a trapeze and landed on a single leg actually maintained the same amounts of shock attenuation as fatigue set in (23). The authors explained that this was due to the participants changing the kinematics of their landings to better attenuate the shock as they fatigued. Gerlach, et al found that runners who participated in an exhaustive treadmill run actually lowered loading rates and GRF compared to pre-exercise values (24). They explained that the runners increased their running cadence and decreased step length, which caused more knee flexion and...
resulted in the foot landing closer to the body’s center of mass, thus creating lower joint forces. It is therefore difficult to conclude what role fatigue plays in running injury due to these conflicting results.

**Gender Differences**
The discussion of predisposition deals mainly with differences between genders. Of particular importance is that females tend to show higher rates of running-related overuse injuries than males. Ferber et al hypothesized that there are differences in running kinematics between males and females, which cause females to experience higher rates of injury (25). They showed that females on average exhibited greater hip flexion, hip adduction, hip internal rotation, and knee abduction as well as greater hip frontal plane negative work, though they could not link any of these variables to an increased risk of injury. In another study, the authors found that the IP for hip adduction was much higher, that the angle of hip adduction was greater, and that ground contact time was shorter in females than in males (26). The increase in IP and hip adduction angle may have increased torques that cause an increase in the mechanical demand on the legs of female runners, but the authors speculated that the reduced ground contact time might help compensate. Hormonal factors may cause increased risk of injury for females. Estrogen has been linked with the maintenance of adequate bone mineral density (BMD); therefore low estrogen can result in low BMD. Ivkovic et al stated that females who lose excessive amounts of weight can compromise their ability to produce estrogen and may experience injury as a result of low BMD (9). Additionally, females have smaller leg-length to height ratios, wider pelvises, less muscle mass, and more joint laxity and hyper-extensibility than males do; all of which can contribute to injury (9, 25).

**Running Injury Prevention**
The topic of this review was the use of gait retraining as a preventative measure against overuse injuries. The idea behind this methodology is that if distance runners can be taught to adopt a more biomechanically efficient and less harmful gait pattern, then they can run farther and for longer periods of time without experiencing injuries that cause them to lose time or mobility, or prevent them from running entirely. This section described first the biomechanical alterations that can be made to improve running form, second how changing footwear can alter the running gait, and finally the effectiveness of gait retraining interventions.

**Kinematic Alterations**
It must be known which elements of the gait to change to produce lower joint forces before attempting to retrain a runner’s gait pattern. Giandolini et al studied the effects that different biomechanical changes had on loading rates during running trials (10). The alterations that they tested included a midfoot strike pattern, a 10% increase in step rate, and the use of either minimalist or cushioned shoes. Changing to a midfoot strike pattern and increasing step rate produced the greatest decreases in loading rate and eliminated the IP entirely, whereas shoe alterations demonstrated no significant changes in loading rate. These findings highlight the need to investigate landing pattern alteration, step frequency, and differences in footwear in depth.

**Landing pattern alteration.** There are three types of landing patterns frequently discussed in literature on the topic of landing pattern alteration: rearfoot strike (RFS), midfoot strike (MFS), and forefoot strike (FFS). Multiple sources discussed that RFS patterns are associated with greater GRF and loading rate, whereas strike patterns closer to FFS tend to reduce these variables (6, 11, 27). In one study, runners who ran barefoot experienced a much lower IP in units of body weights (BW) (0.586±0.21 BW) than runners who ran in shoes with a RFS (1.74±0.45 BW) (18). Similarly, Giandolini et al found a significant reduction in loading rates (37.4 ± 7.20 BW s⁻¹, -56.9 ± 50%) for runners who used a MFS strike versus runners who used a RFS (56.3 ± 11.5 BW s⁻¹, 10).
Lieberman et al explain this phenomenon, stating that as the foot strikes the ground with the heel in a RFS pattern, very little of the energy upon impact is translated into rotational energy and is therefore absorbed into the body (18). However, a proper FFS pattern makes initial contact on the front of the foot and causes it to land closer to under the body’s center of mass allowing the foot to be rotated around the ankle upon contact with the ground. This rotation enables greater rotational energy and reduces the amount of energy that is absorbed by the body.

**Step frequency increase.** There have been a few studies done in which the effects of increasing step rate to lower joint forces were investigated. In one study the authors demonstrated that an increase in step rate of +10% of preferred step rate reduced the distance of foot strike from center of mass, increased knee flexion, and caused a reduction of energy absorbed by about 34% (12). Similarly, Hobara et al found that an increase in step rate of 15% of preferred step rate showed reductions in IP, ILR, and ALR, whereas a decrease in step rate of 15% of preferred step rate caused an increase in all of these variables (13). In both of these studies, the authors found that greater step rates at constant speed are associated with reductions in stride length, foot strike being closer to center of mass, increased knee flexion, and a more plantarflexed ankle upon initial contact, all of which cause reductions in joint forces.

**Footwear alterations.** Three articles discussed that the type of footwear a runner chooses may have an influence on running kinematics. Lieberman et al found that very few habitually shod participants who switched to barefoot running adopted a FFS pattern, but a significant number of habitually barefoot runners who put on shoes switched to a RFS pattern (18). This suggests that while simply removing shoes does not necessarily encourage a FFS pattern, wearing shoes does encourage a RFS pattern. Willson et al discussed the idea that cushioned-heel shoes (shoes with both a midsole and an outsole) promote a RFS pattern whereas minimalist footwear (shoes that lack a midsole, but have an outsole) may promote a non-RFS pattern (28). However, in this study they found that 12 of 19 participants who converted from cushioned-heel to minimalist shoes retained a RFS pattern after a two-week training period. In one study, a 25% reduction in acceleration of the heel was found in participants who wore a flat-midsole shoe compared to those who wore regular shoes (11). To conclude, although footwear can cushion joint forces that would otherwise be greater in the absence of shoes, simply wearing a different type of shoe does not change the kinematics of running.

**Gait Retraining Interventions**

Gait retraining as a process incorporates all of the alterations thus far discussed. The purpose of gait retraining is to provide the runner with feedback to enable him or her to more easily adopt the new gait pattern. Gait retraining is typically used to treat chronic overuse injuries that have already occurred. Noehren et al found that gait retraining that focused on the reduction of peak hip adduction angle reduced pain levels by 86% in participants with PFPS (8). However, gait retraining may also be a viable method of injury prevention since it can reduce joint forces experienced by runners. In the following section, various methods of gait retraining that have been attempted, and reviewed a case study on gait retraining are discussed.

**Methods of gait retraining.** Gait retraining methodology varied in every study. One commonality of all gait retraining programs is that they provide the runner with some form of exteroceptive feedback that is intended to trigger a biomechanical correction. How that feedback was applied usually varied from study to study. Two studies utilized real-time visual feedback that measured TA using an accelerometer and displayed it on a screen in front of the treadmill (7, 29). Participants were also provided with verbal feedback on how to correct landing pattern and stride frequency so as to keep TA below a certain level. Similarly, Noehren et al used visual feedback that displayed the amount of
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hip adduction that participants were exhibiting (8). The researchers instructed the participants to keep a graph line that represented the amount of hip adduction within a target area on the screen. Another study employed the use of pressure sensitive transducers that were fixed to the runners' heels in order to train them to use a FFS pattern (6). This transducer would emit an audible tone any time the heel made contact with the ground. Two studies used an audible metronome that first matched the step rate of the participants, but was then increased in tempo to cause the runners to increase their step rate while maintaining a constant speed on a treadmill (12, 13). Finally, in an attempt to find an inexpensive method of gait retraining, Willy et al utilized a mirror in front of the treadmill as a source of visual feedback for the runners (30).

There were some common factors amongst all of these studies. The number of gait retraining sessions per program was eight sessions over a two-week period for all gait retraining studies. All of the gait retraining studies involved the use of a treadmill and were conducted in laboratory settings. Some studies included a follow-up session after one month to measure how well the gait was retained (6–8).

**Tests and outcomes.** The majority of the studies found reductions in joint forces as a consequence of gait retraining. Crowell & Davis showed a 50% reduction in TA and reductions in IP, ILR, and ALR ranging between 20% and 50% (7). Giandolini et al observed a complete elimination of the IP and a 50% reduction in ALR after retraining runners to use an increased step rate of +10% and a MFS landing pattern (10). Noehren et al reduced hip adduction angle by three degrees, decreased ALR by 18% and ILR by 20% (8). Though they did not measure joint forces applied to the body while running, Willy et al successfully used a mirror as visual feedback to reduce hip adduction angle, hip adduction moment, and collateral pelvic drop in female runners with PFPS (30). This intervention was used to treat an injury, but it could theoretically be used to prevent an injury as well. The authors of the studies who followed up with the participants one month after the retraining sessions all found that the runners had retained the majority of the new gait characteristics that they had learned in the sessions (6–8).

Not all efforts to retrain gait patterns resulted in lower joint forces. Three of the five participants in a study by Crowell et al showed reduction in all measured values (ALR, ILR, and IP), but one showed increases in these values while receiving feedback and reduction in these values when feedback was removed (29). The last showed reduction only in IP and the other values decreased only slightly when feedback was removed. This may suggest that some individuals will have difficulty interpreting feedback and adequately altering their gait pattern in response. Laughton et al found that after retraining runners to use a FFS pattern, TA increased rather than decreased as in other studies (31). In the discussion, the authors acknowledged that they had only instructed their participants to make contact with the forefoot and provided no advice on where the foot should land relative to the body's center of mass. Therefore, it is likely that the runners were still landing with their feet out in front of their center of mass as they would with a RFS pattern. Williams et al obtained similar results during their comparison of RFS, FFS, and barefoot running (32). They instructed their participants in the FFS and barefoot groups to “run on their toes”, but also failed to instruct where the foot should fall relative to the body. The runners ran so that each step landed in front of the center of mass and as a result the FFS and barefoot groups had the highest peak power absorption rates. These studies highlighted the importance of proper instruction when training someone to use a FFS pattern.

**Case study.** The purpose of the case study by Cheung & Davis was to analyze the impact of RFS to MFS retraining and its effects on PFPS (6). Three female long-distance runners who suffered from PFPS and who habitually ran with a RFS pattern participated in a total of eight sessions of landing-pattern retraining. They ran on an instrumented treadmill with a pressure-sensing mat which enabled the recording of IP, ILR, and ALR. To give feedback, a transducer was placed inside the shoe on the
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heel and triggered a buzzer when contact with the heel was made. The participants gradually increased the amount of time they spent on the treadmill from 15 minutes to 30 minutes and the feedback was gradually removed. The results showed statistically significant decreases of 10-35% in IP, ILR, and ALR and the PFPS pain rating decreased. This study supports the findings of others that MFS pattern intervention can reduce joint forces that may cause PFPS. Though this study was used to treat cases of PFPS, these methods can theoretically be used to prevent PFPS by eliminating a contributing factor to the injury.

DISCUSSION

The key findings of this review indicate that gait retraining may be a useful method of preventing overuse injuries in middle distance and distance runners. Many potential risk factors were examined; which included overpronation, low muscular endurance, less flexibility, overtraining, and misalignment of the lower limbs; though there was no consensus on whether or not these risk factors could actually be linked to increased overuse injury rates (15, 16). The most significant biomechanical risk factor determined was the rearfoot strike, which produced a large IP on initial contact (18). Giandolini et al found that strike pattern and step frequency alterations created the most statistically significant changes in joint force absorption (11). Others found that the adoption of MFS or FFS pattern and a step rate increase of 10-15% caused major reductions in TA, IP, ILR, and ALR (6, 10-13, 18, 27). Willson et al showed that wearing minimalist shoes without adequate instruction on how to change running kinematics did not convert a majority of RFS runners to MFS or FFS patterns (28). A variety of gait retraining methods were tested, which ranged from providing visual feedback to auditory or verbal feedback. Most results showed significant reductions in TA, IP, ALR, ILR, and GRF (6, 7, 10, 29, 30). Some studies did not show reductions in these variables, but in each case they were able relate these inconsistencies with errors in methodology (18, 29, 32).

Key Results and Implications

The primary goal of this review was to develop a better understanding of effective methods of gait retraining and to determine if it could be used for the purpose of injury prevention. It is clear that avoiding a RFS in favor of a MFS or FFS is the greatest single change that can be made to reduce lower extremity joint forces. The elimination of the IP which can at times be just as large as the active peak, effectively doubling the amount of force the body absorbs creates a significant reduction in the total sum of joint forces absorbed by the body. A decrease in step length is also a necessary adjustment that must accompany the adoption of a MFS of FFS pattern. Laughton et al and Williams et al determined that failure to adjust step frequency and consequently stride length resulted in increases in joint forces beyond those of RFS runners (31, 32). Though not discussed in any of the literature, it is also possible that running with a MFS or FFS pattern could also improve running performance. The foot is closer to the body’s center of mass upon contact with the ground when using a MFS or FFS causing a smaller breaking impulse compared to a RFS. Thus, the body would not slow down as much between steps and less energy would need to be expended to continue forward acceleration.

Another important point to consider is footwear. A common belief among laypersons is that minimalist footwear will improve gait patterns, making runners more biomechanically efficient. The study by Willson et al demonstrated that the majority of habitually RFS runners who typically ran in cushioned heel shoes did not automatically become FFS runners simply by converting to minimalist footwear (28). However, it should be noted that minimalist footwear can aid in the adoption of a FFS or MFS pattern because the zero drop heel helps keep the heel off the ground when making contact with the forefoot. They also noted that cushioned heel shoes promote a RFS pattern due to the raising of the heel and their heavier weight, which encourages the heel to drop out in front of the
Minimalist shoes do not have a raised heel and are lighter weight, which can make it easier for a runner to land with the foot closer to the body’s center of mass and make contact with the forefoot.

Multiple effective methods of gait retraining were identified. The most effective methods, in terms of reduction of joint forces and long-term retention by participants, used either visual or auditory feedback (6–8, 29). Though some of the studies on gait retraining were done for the purpose of treating current injuries, it is likely that these same methods could be used to prevent the injury. For example, Cheung & Davis aimed to reduce the pain of three female runners with PFPS by training them to adopt a MFS pattern (6). The alteration that reduced their pain was the improved gait pattern, which allowed them to run without experiencing high joint forces. The reduced joint forces meant that the injuries were not aggravated during running and the injury was able to heal. Likewise, a runner who was not injured and ran with a MFS pattern would have a lower TA, ALR, ILR, and experience lower GRF, resulting in less risk of injury.

However, one dilemma is that it may be difficult to convince runners to adopt a different gait pattern when no injury has yet occurred. Heiderscheit discussed the idea that people are more likely to alter a gait pattern if they see results or improvements that reinforce change (33). The three runners in the study by Cheung & Davis retained their gait pattern due in part to the fact that it lessened their pain during running (6). Without any incentive, it may be very difficult for a runner to change a motor pattern so well learned and natural as running. Though the empirical results are promising for gait retraining to be used as a method of injury prevention, the practical applications are still unclear.

Limitations of the Current Review
The major limitation of this review is that only a few articles showed reductions in joint forces as a consequence of gait retraining. Many articles explored how modifying one or two different variables affected the magnitudes of joint forces. The number of articles that utilized a proper gait retraining protocol and included various types of feedback, multiple sessions, and gradual reduction of feedback to aid retention were few. There were also limitations in the research analyzed in this review. First, population sizes were relatively low in all studies, with very few studies exceeding 10 participants. Second, it is unclear how gait retraining would affect different types of runners because the population used was relatively narrow. The studies almost exclusively used recreational or non-elite competitive athletes and did not represent elite or highly-competitive athlete populations. Likewise, no information about gait retraining for sprinters could be found; which is one reason why sprinters were excluded from this review.

Future Research and Considerations
The first improvement that could be made to future gait retraining research is to use larger sample sizes. Sample sizes of at least 20 would be still reasonable and may help to better identify the number of participants who are non-responsive to gait retraining methods, such as the two participants in the study by Crowell et al (29). Another focus of future research could be on the types of gait retraining feedback that are more effective than others. I did not encounter a study that compared the effectiveness of two or more types of gait retraining. Finally, none of the studies identified whether or not using these more efficient gait patterns yielded improved performance. Though theory suggests that a more efficient gait may improve performance, to my knowledge this hypothesis has yet to be tested.
CONCLUSIONS

To conclude, I found evidence that suggests that gait retraining as a method of lower extremity overuse injury prevention in distance runners is effective. Multiple studies showed that methods of gait retraining not only help the runners to successfully adopt and retain a new gait pattern, but that the new gait pattern reduced the magnitude of joint forces acting on the body. Alterations such as adopting a MFS or FFS pattern, decreasing step rate by 10-15%, and wearing minimalist shoes (in combination with these biomechanical alterations) can all contribute to lower TA, IP, ILR, ALR, and GRF. Reductions in these joint forces are linked with lower rates of overuse injuries. With less risk of injury comes reduced loss of activity time, less pain, less risk of permanent injury, less risk of developing chronic injuries, and improved quality of exercise for runners.

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Address for correspondence: Sullivan DP, Department of Kinesiology, San José State University, San José, California, United States, 95192. Email: dpsu70@gmail.com
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