Gait Retraining for the Reduction of Injury Occurrence in Novice Distance Runners: 1-Year Follow-up of a Randomized Controlled Trial

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Gait Retraining for the Reduction of Injury Occurrence in Novice Distance Runners

1-Year Follow-up of a Randomized Controlled Trial

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Background: The increasing popularity of distance running has been accompanied by an increase in running-related injuries, such that up to 85% of novice runners incur an injury in a given year. Previous studies have used a gait retraining program to successfully lower impact loading, which has been associated with many running ailments. However, softer footfalls may not necessarily prevent running injury.

Purpose: To examine vertical loading rates before and after a gait retraining program and assess the effectiveness of the program in reducing the occurrence of running-related injury across a 12-month observation period.

Study Design: Randomized controlled trial; Level of evidence, 1.

Methods: A total of 320 novice runners from the local running club completed this study. All the participants underwent a baseline running biomechanics evaluation on an instrumented treadmill with their usual running shoes at 8 and 12 km/h. Participants were then randomly assigned to either the gait retraining group or the control group. In the gait retraining group (n = 166), participants received 2 weeks of gait retraining with real-time visual feedback. In the control group (n = 154), participants received treadmill running exercise but without visual feedback on their performance. The training time was identical between the 2 groups. Participants' running mechanics were reassessed after the training, and their 12-month posttraining injury profiles were tracked by use of an online surveillance platform.

Results: A significant reduction was found in the vertical loading rates at both testing speeds in the gait retraining group ($P <$ .001, Cohen's $d > 0.99$), whereas the loading rates were either similar or slightly increased in the control group after training (P = .001 to 0.461, Cohen's d = 0.03 to -0.14). At 12-month follow-up, the occurrence of running-related musculoskeletal injury was 16% and 38% in the gait retraining and control groups, respectively. The hazard ratio between gait retraining and control groups was 0.38 (95% CI, 0.25-0.59), indicating a 62% lower injury risk in gait-retrained runners compared with controls.

Conclusion: A 2-week gait retraining program is effective in lowering impact loading in novice runners. More important, the occurrence of injury is 62% lower after 2 weeks of running gait modification.

Registration: HKUCTR-1996 (University of Hong Kong Clinical Trials Registry).

Keywords: running; kinetics; biofeedback; injury prevention

Running is a popular sport globally. The rapid growth of the running population can be partially reflected by the number of participants in many distance running events worldwide. In 2015, 17.1 million finishers participated in more than 30,000 races held in the United States.[35] This increase in the popularity of running can be explained by its positive effect on the cardiovascular and mental health of runners.[44] However, due to the repetitive nature of running, running-related musculoskeletal injuries are common, with 37% to 79% of runners sustaining an injury in a given year.[4,14] This means that 3 of 4 regular runners will incur an injury within 3 years. Compared with elite runners, novice runners are more vulnerable,[11] partially because they are less physically prepared for distance running.[7] In view of this situation, studies of physical training programs to prevent running-related injuries have been undertaken, and the effectiveness of such programs has been questioned.[6,7,30,43] The findings of previous studies clearly indicated that a physically conditioned runner under a structured training protocol may still be at risk of injury if the biomechanical risk factor is not addressed.

Investigators have studied the relationship between biomechanics and running-related injury. Among different

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biomechanical risk factors, such as the magnitude of ground-reaction force peaks,[41] a high level of vertical loading has been reported to be associated with many injury conditions in runners, such as patellofemoral pain,[10,14] tibial stress fractures,[3,28] and plantar fasciitis.[28] Greater vertical average loading rate (VALR) or vertical instantaneous loading rate (VILR) is caused by an increased vertical body stiffness during landing.[18,20] It has been suggested that an increased vertical stiffness is associated with injury because a greater force acts on the body over a smaller joint excursion, which causes poor shock attenuation. Many running techniques, such as Chi running and Pose running, target the modification of running gait for a softer landing.[15,33] However, information about the ability of these methods to modify running gait is mainly anecdotal.

Previous studies have used a gait retraining program of 8 sessions in 2 weeks using real-time visual feedback to control impact loading.[21,29] In this training protocol, participants ran on a treadmill and the training time in each session was gradually increased from 15 to 30 minutes over the 8 sessions, while the real-time visual feedback was progressively removed in the last 4 sessions. Participants' impact loading was reduced 18% to 20% after the training, and this reduction was maintained at the 1-month follow-up in a feedback-free state.[24] Other biofeedback gait retraining programs using the same training and feedback-weaning protocol have been applied to other cohorts and were shown to cause a favorable running gait pattern transition.[13] Although the running biomechanics were not exactly identical between treadmill and overground conditions, translation of the training effect from treadmill-based training to overground running has been observed in previous gait retraining studies.[34] One plausible explanation was the comparable neuromuscular control[27] and kinetics[32] between the 2 conditions, favoring the translation of the training effect to the alternative running environments.

However, favorable running biomechanics may not equate to injury-free running. Hitherto, no published studies have examined the effect of a gait retraining program on injury prevention in novice runners. Therefore, this randomized controlled trial sought to evaluate the effectiveness of a gait retraining program on modulation of impact loading and to determine whether it can prevent running-related injury in a group of novice runners. We hypothesized that participants receiving gait retraining would present lower VALR and VILR during running. In contrast, the vertical loading rates would remain similar in the control group. It was also hypothesized that gait retraining would lower the occurrence of running-related injury when compared with the controls.

METHODS

Study Design and Participants

This laboratory-based study was a single-blinded, randomized controlled trial. The experimental procedure was reviewed and approved by the Departmental Research Committee of the Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, and the trial was registered at HKU Clinical Trials Registry (Ref: HKUCTR-1996). A total of 412 novice runners (<2 years of running experience) who regularly run more than 8 km/wk and were aged 18 to 50 years were recruited in this study. Participants were free from any active injury for at least 6 months before the study. To avoid a floor effect, all the participants underwent an initial running screening and those with VALR less than 70 body weight (BW) per second during usual speed running were excluded.

Baseline Measurements

All participants who met the study criteria and provided written consent underwent a baseline running biomechanics assessment. They were asked to run on an instrumented treadmill (AMTI force-sensing tandem treadmill) at 8 km/h (slow pace) and 12 km/h (fast pace) for 5 minutes with their usual running shoes. The test sequence was randomized by use of an online program (www.random.org), and a 5-minute rest period was provided between the 2 running trials.

Ground-reaction force data were sampled at 1000 Hz for the last minute of the run. Data were then filtered using a second-order, recursive Butterworth low-pass filter at 50 Hz. A threshold of 10 N in the vertical ground-reaction force was used to determine foot-strike and toe-off. The VALR and VILR were obtained by the method described in a previous study.[12] In brief, VALR and VILR were the average and maximum slopes of the line through the 20% point and the 80% point of the vertical impact peak, respectively. In case of an undetectable or absent vertical impact peak within 1 stance phase, the vertical impact peak value would be taken as the force at 13% stance phase.[4] Both VALR and VILR were normalized by body weight and averaged across all footfalls within the 1-minute trial.

Sample Size

The required sample size was calculated for the primary outcome variable, the annual occurrence of running-related musculoskeletal injury. According to previous studies, the occurrence varied between 37% and 79% in a given

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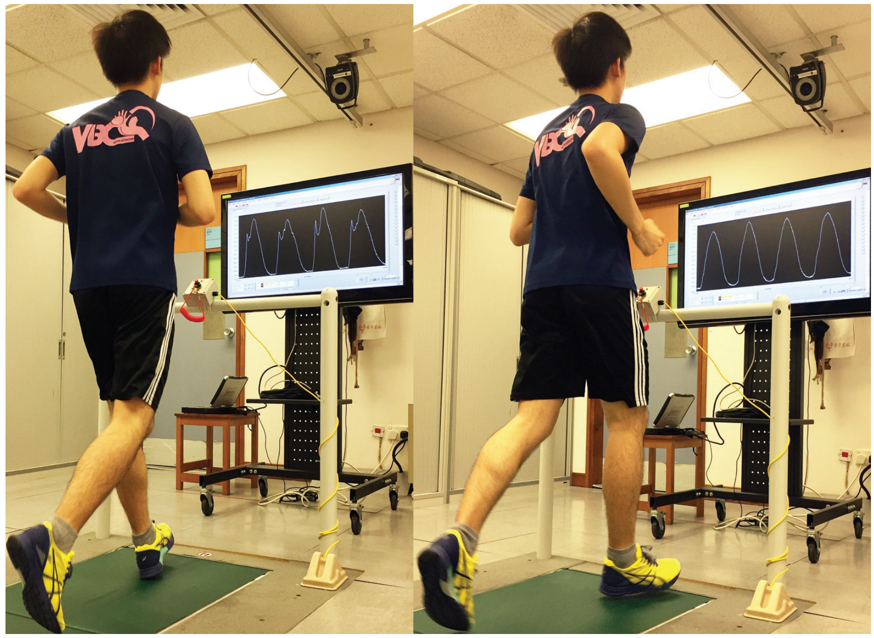

Figure 1. Runners receiving visual biofeedback during gait retraining. They were asked to reduce the vertical impact peak by softening their footfalls.

year.[4,14] A reduction of 25% of the occurrence in the gait retraining group compared with the control group was considered clinically significant and relevant.[6] A logistic rank surviving power analysis was performed with a hypothesized 25% reduction of the annual occurrence, an attrition rate of 5%, a power of 80%, and an alpha level of 5%; it was determined that 380 runners (190 in each group) were needed to detect an effect of the 2-week gait retraining program.

Randomization

After the baseline measurement, all participants were assigned to either the gait retraining group or control group. To ensure that the participants were matched between the 2 groups, a stratified randomization was performed. Participants were stratified for current running mileage (8-12 km/wk; 12-16 km/wk; >16 km/wk) and sex. A block size of 4 was used in the randomization sequence. For each stratum, participants were allocated by drawing a sealed opaque envelope.

Gait Retraining Group

Participants in the gait retraining group underwent a 2-week gait retraining for landing stiffness modulation according to the protocol established in a previous study.[10] In brief, they participated in 8 sessions of gait modification over 2 weeks (4 sessions per week). During the training, participants were asked to run at a self-selected speed on an instrumented treadmill (AMTI force-sensing tandem treadmill). Visual biofeedback in the form of a vertical ground-reaction force signal from the treadmill was displayed on the monitor in front.

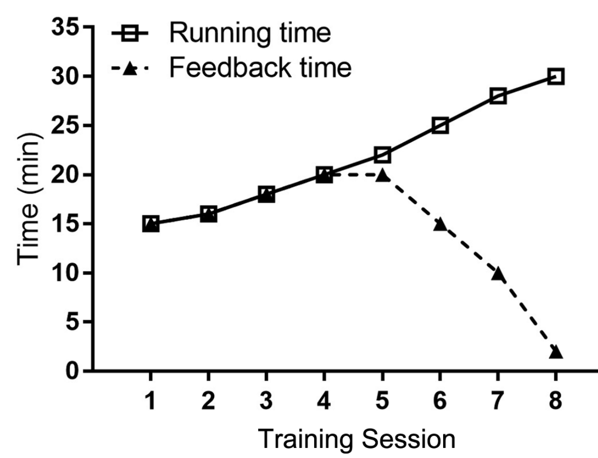

Figure 2. Training time and biofeedback time arrangement in the gait retraining group.

Participants were asked to "run softer" so that the amplitude of vertical impact peak would be reduced or even diminished (Figure 1). The training time was gradually increased from 15 minutes to 30 minutes over the 8 sessions, and visual feedback was progressively removed in the last 4 sessions (Figure 2). The participants were then advised to maintain their new gait pattern during their daily living or regular running practice after the training.

Control Group

Similar to the gait retraining group, participants in the control group were invited to the laboratory for 8 times

TABLE 1
Baseline Characteristics of Participants in the Gait Retraining and Control Groups[a]

Characteristics	Gait Retraining (n = 166)	Control (n = 154)	*P*
Sex	82 males, 84 females	76 males, 78 females	.993
Age, y	33.6 ± 9.5	34.2 ± 9.5	.559
Weight, kg	60.0 ± 12.6	61.6 ± 12.0	.235
Height, m	1.66 ± 0.09	1.65 ± 0.09	.843
Running experience, mo	16.8 ± 5.2	16.6 ± 5.0	.720
Weekly mileage, km	19.5 ± 7.0	18.5 ± 6.1	.172
VALR at 8 km/h, BW/s	65.95 ± 9.90	67.81 ± 9.97	.094
VALR at 12 km/h, BW/s	81.28 ± 13.59	83.51 ± 11.41	.115
VILR at 8 km/h, BW/s	90.69 ± 13.90	92.32 ± 10.81	.245
VILR at 12 km/h, BW/s	111.87 ± 14.51	114.32 ± 16.42	.160

[a]Data are reported as mean [plus or minus] SD, unless otherwise indicated. BW, body weight; VALR, vertical average loading rate; VILR, vertical instantaneous loading rate.

in 2 weeks. They were asked to run on an instrumented treadmill at a self-paced speed, but no feedback on their running biomechanics was provided. The running time was identical to the protocol in the gait retraining group.

Reassessment

All participants were reassessed 2 weeks after the first evaluation. The testing procedure was identical to the baseline assessment.

Tracking of Injury Occurrence

After the training program was completed, all participants were asked to log into an online running injury surveillance platform, which was designed based on a previous study.[1] At the first login, they were required to report their injury history and average weekly mileage over the past 6 months. At each of the 12 subsequent logins for each month, they were asked to report their weekly mileage, other training program involvement, and injuries (if any) over the past month. They were required to specify the person who made the diagnosis for their injuries. An injury was operationally defined as any running-related musculoskeletal complaint[40] that was diagnosed by a medical professional, such as a physician, physical therapist, or orthopaedic surgeon, and that caused the participant to miss at least 2 days of training. To ensure validity of the injury data, those who had reported an injury were contacted by a researcher to authenticate the injury incident.

Statistics

Baseline characteristics of participants in the gait retraining and control groups were compared by use of 2-tailed *t* tests and chi-square statistics for continuous and discrete variables, respectively. A 2 × 2 mixed-design analysis of variance (ANOVA) was used to compare the interaction effect of training (gait retraining vs control) and time (before and after training) on VALR and VILR. Pairwise comparisons were conducted if necessary. In addition, to avoid overreliance on statistical tests,[26] the effect size, in terms of Cohen's d, was used to quantify the strength of comparisons. Cohen's d values around 0.2, 0.5, and 0.8 are considered as small, medium, and large effect sizes, respectively.[39] Since the current study was not designed to investigate the effects of gait retraining on any particular injury type, the injury patterns in the 2 study groups were compared descriptively. Mantel-Cox test was used to compare the survival curves of the participants with an injury in the gait retraining group and the control group. A Cox proportional hazards regression was conducted to assess the difference in the occurrence of injury during the 12-month follow-up period after training. All analyses were performed following the "intention to treat" principle. All statistical tests were performed by SPSS software (version 23; SPSS Inc), with level of significance set as .05.

RESULTS

Initially 412 participants volunteered for this study; 22 of them were excluded due to the preset criteria (Figure 3). After stratified randomization, 195 runners were allocated to the gait retraining group and another 195 runners were assigned to the control group. Of these 390 participants, 320 completed all follow-up assessments; 70 dropped out at different stages due to scheduling conflicts or personal reasons. No between-group differences in any demographic or baseline outcomes were found (P values > .094; Table 1).

Participants in both groups reported no adverse effects. The 2 × 2 mixed-design ANOVA revealed significant interaction effects between training and time for both VALR ($P <$ .001, η^2_p = 0.344-0.367) and VILR ($P <$ .001, η^2_p = 0.353-0.541) at both testing speeds. Pairwise comparisons revealed a significant reduction in VALR ($P <$ .001, Cohen's d = 1.06-1.12) and VILR ($P <$ .001, Cohen's d = 0.99-1.01) after gait modification (Figure 4). In the control group, no significant difference was found in VALR at 8 km/h after training (P = .461), but VALR at 12 km/h and VILR at both testing speeds were increased ($P <$ .029; Cohen's d = −0.09 to −0.14; Figure 4). For between-groups comparisons, VALR and VILR in the gait retraining group were

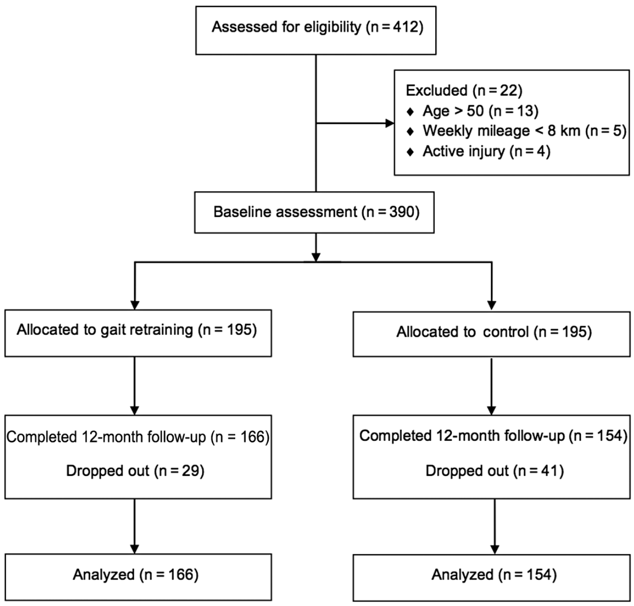

Figure 3. Consort diagram.

TABLE 2
No. (%) of Running-Related Injuries in Gait Retraining and Control Groups

Condition	Gait Retraining Group	Control Group
Patellofemoral pain	4 (14)	18 (29)
Plantar fasciitis	2 (7)	23 (38)
Iliotibial band syndrome	3 (11)	8 (13)
Hamstrings strain	3 (11)	8 (13)
Achilles tendinitis	5 (18)	0 (0)
Calf strain	5 (18)	0 (0)
Shin splints	3 (11)	1 (2)
Patellar tendinitis	2 (7)	0 (0)
Meniscal injury	1 (3)	3 (5)

significantly lower than in the control group at both testing speeds after training ($P < .001$, Cohen's d = 1.16-1.52).

At the 12-month follow-up, 16% and 38% runners reported running-related musculoskeletal injury in the gait retraining group and control group, respectively. The types of injuries reported differed between gait retraining and control groups (Table 2). We observed more Achilles tendinitis (18%) and calf strain (18%) in the gait retraining group, while no such injuries were observed in the control group. The most common injuries in the control group were plantar fasciitis (38%) and patellofemoral pain (29%), while only 7% and 14% of participants in the gait retraining group had these conditions. Mantel-Cox test indicated a significant difference in the survival curves between the 2 groups (Figure 5). The hazard ratio between the gait retraining and control groups was 0.38 (95% CI, 0.25-0.59), indicating a 62% lower injury occurrence in gait-retrained runners compared with controls.

DISCUSSION

This single-blinded, randomized controlled trial sought to evaluate the effectiveness of a laboratory-based gait retraining program on the impact of loading control and running-related musculoskeletal injury prevention in novice runners. In accordance with our original hypotheses, gait retraining was a safe and effective intervention to lower VALR and VILR during running. More crucially, the laboratory-based gait retraining program significantly reduced the occurrence of running-related musculoskeletal injuries by 62% during a 12-month follow-up period.

Previous gait retraining studies reported large reductions of VALR (Cohen's d up to 3.32) and VILR (Cohen's d up to 3.74),[23] which are greater than found in the present study (Cohen's d = 0.99-1.12). Such discrepancy can be explained by the instruction and feedback provided to participants. Most of the previous studies used an explicit and visible biomechanical parameter as a marker for the biofeedback training, such as foot-strike pattern,[10,38] stride frequency,[17] or lower limb alignment.[24] These modifications could be observed and measured without the use of sophisticated laboratory equipment, and thus runners could attempt or practice modifications outside the training sessions, possibly enhancing the effect of the retraining. This speculation is supported by the fact that another study using an implicit parameter, tibial shock, reported a smaller reduction of VALR and VILR (Cohen's d = 1.3-1.7) after gait retraining.[12] Even so, studies relating attentional focus and motor learning suggested that feedback promoting an external focus was more effective than feedback promoting an internal focus on both the learning outcome and the retention.[45,46] In the present study, participants were provided with real-time externally focused feedback (ie, vertical ground-reaction force) without instructions on the detailed movements required to achieve a reduced impact peak. This arrangement was considered to be optimal for gait retraining and to favor retention during the follow-up period.

In the present study, unlike previous studies in which the assessment and training speeds were set by researchers, participants completed the gait retraining at their own training pace. They also wore their own usual running shoes, such that the training was performed in a setting that best imitated their natural training conditions. This design was intended to minimize the effect of speed and footwear change on loading rates[9,22] and ensure sustainability of the modified gait when participants returned to their regular training.

Lower VALR or VILR after gait retraining is achieved by a reduction in the vertical body stiffness during impact.[18,20] The relationship between stiffness and running injury is well established in animal models but not in humans. A rate-dependent relationship between loading and bone injury has been demonstrated in rabbits,[31,37] dogs,[8] and bovine.[2] It has been suggested that increased strain rate is typically associated with greater risk of bony injuries in animals. In human studies, higher VALR and VILR have been reported in a group of injured athletes

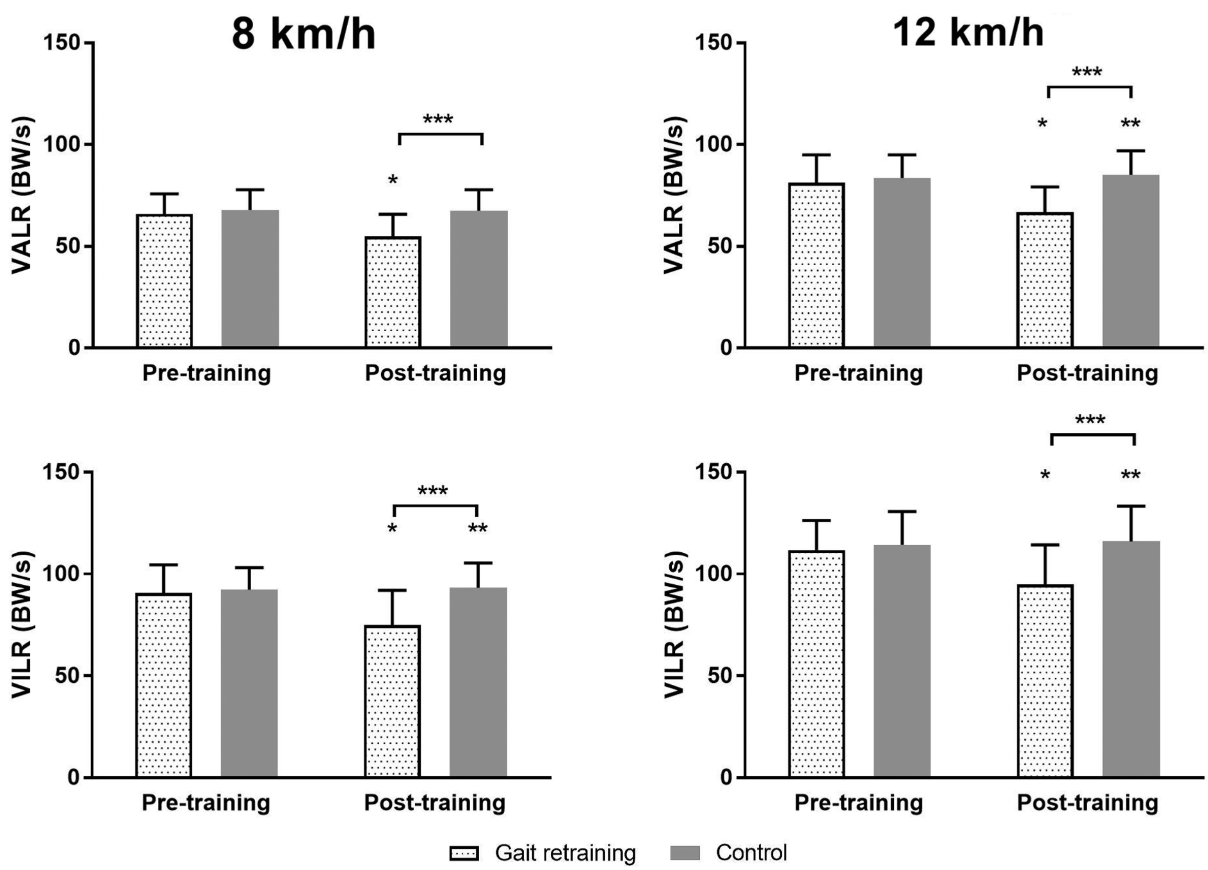

Figure 4. Vertical average loading rate (VALR) and vertical instantaneous loading rate (VILR) at 8 km/h and 12 km/h before and after training. BW, body weight.

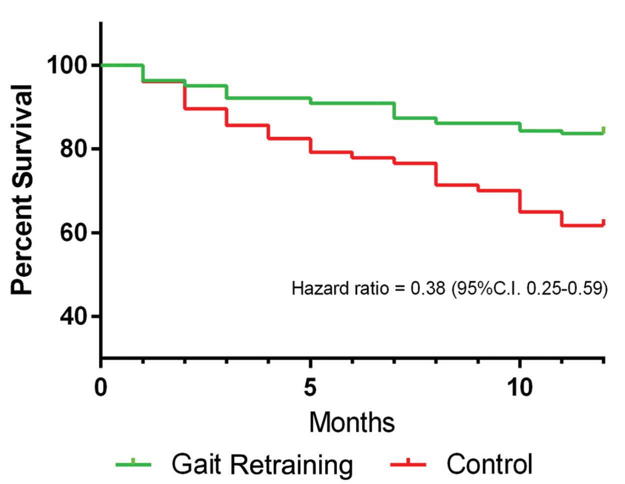

Figure 5. Kaplan-Meier plot of running-related injury survival between participants from the gait retraining group and the control group.

with patellofemoral pain[10] and plantar fasciitis[28] than in their healthy counterparts. Such observations are in line with the injury pattern in our control group participants. In contrast, the gait retraining group had a higher incidence of calf injury (ie, calf strain and Achilles tendinitis) than the control group. This pattern can be explained by a greater strain on the ankle plantar flexors when the participants attempted to soften their footfalls by switching their foot-strike pattern,[25] which has been shown to be effective in lowering vertical loading rates.[19]

The findings of this study support the use of visual biofeedback in reducing impact loading and preventing injury, which could have a direct effect on reducing health care costs. A recent study reported that the economic burden of a single running-related injury is approximately \$90.[16] Given that more than 60 million people currently engage in running, whether for recreational or competitive reasons,[36] and up to 79% of runners incur an injury in a given year,[5,42] the total cost of running-related injuries is estimated at \$4 billion annually. Further study could investigate the cost-effectiveness and economic effect of the visual biofeedback gait retraining program.

Several limitations should be considered in light of the findings presented in this study. First, the current gait retraining program can be delivered only in a biomechanics laboratory, which is not commonly accessible to most runners. Since impact loading is an invisible biomechanical marker, future research should explore the potential for wearable sensor technology to allow for VALR and VILR measurement in an outdoor environment. Second, we did not measure running mechanics outside the laboratory; thus, sustainability of the modified gait biomechanics in the actual environment remains unexamined. Third, similar to a previous study,[1] we used an online platform to monitor injury patterns of the participants for 12 months. Although we contacted every participant who had reported an injury in order to maximize data validity, we did not contact uninjured participants to verify that they had not experienced an injury, and therefore injury occurrence may have been underestimated in both groups. Finally, the exclusion of experienced runners may have affected the generalizability of our findings.

CONCLUSION

A 2-week gait retraining program using visual biofeedback is effective in lowering impact loading in novice runners. More important, the occurrence of running-related musculoskeletal injury was 62% lower after 2 weeks of gait modification over a 12-month follow-up period.

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