Gait retraining lowers injury risk in novice distance runners: a randomized controlled trial

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Abstract

Background: With distance running gaining popularity, there is a concurrent increase in running related injuries that up to 85% of novice runners incur an injury in a given year.

Previous studies have utilized 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 the vertical loading rates before and after the gait retraining as well as the effectiveness of the program on reducing the occurrence of running-related injury across a 12-month observation period.

Study Design: Randomized controlled clinical trial

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 into either the gait retraining or control group. In the gait retraining group (n=166), participants received a two-week real time visual feedback gait retraining. 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 two groups. Participants' running mechanics were reassessed after the training and their 12-month post-training injury profile was tracked using an online surveillance platform.

Results: There was a significant reduction in the vertical loading rates at both testing speeds in the gait retraining group ($p<0.001$, Cohen's $d>0.99$) whereas the loading rates were either similar or slightly increased in the control group after training ($p=0.001$ 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 group respectively. Hazard ratio between gait retraining and control groups was 0.38

(95%C.I.=0.25-0.59), indicating a 62% lower injury risk in gait retrained runners when compared with controls.

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

Clinical Relevance: A two-week gait retraining program may lower impact loading, thus reducing the injury occurrence in novice runners.

Keywords: Running; Kinetics; Biofeedback; Injury prevention

What is known about the subject: Running injury has been associated with high level of vertical loading rates in previous case-control and longitudinal studies. Gait retraining has been shown to successfully reduce impact loading.

What this study adds to existing knowledge: The present study provides prospective data to support the use of gait retraining to prevent running injury in novice distance runners.

INTRODUCTION

Running is a popular sport globally. The rapid growth of running population can be partially reflected by the number of participants in many distance running events worldwide. In 2015, there were 17.1 million finishers participated in over 30,000 races held in the United States.[2] Such population bloom can be explained by the positive impact on the cardiovascular and mental health in runners.[43] However, due to its repetitive nature, running-related musculoskeletal injuries are common, with 37-79% of runners sustaining an injury in a given year.[6,16] This translates to three out of four regular runners will incur an injury within three years. Compared with elite runners, novice runners are more vulnerable,[13] partially because they are less physically prepared for distance running.[9] In view of this situation, studies on the efficacies of physical training programs to prevent running-related injury have been undertaken, but their effectiveness was in doubt.[8,9,24,34] The findings of previous studies clearly indicated that a physically conditioned runner under a structured training protocol may still be at risk, if the biomechanical risk factor is not addressed.

There have been studies on the relationship between biomechanics and running-related injury. Amongst different biomechanical risk factors, such as the magnitude of ground reaction force peaks,[44] a high level of vertical loading rates, which can be expressed as vertical average and instantaneous loading rate (VALR and VILR), have been reported to associate with many injury conditions in runners, such as patellofemoral pain,[12,16] tibial stress fractures,[5,32] and plantar fasciitis.[32] Greater VALR or VILR experienced by the body is caused by an increased vertical body stiffness during landing.[21,23] 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. There are many running techniques, such as Chi running and Pose running, which target to modify running gait for a softer landing.[17,37] However, the evidence of running gait modification using these methods is mainly anecdotal.

Previous studies have utilized a gait retraining program of eight sessions in two weeks using real time visual feedback to control impact loading.[25,33] 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 eight sessions, while the real time visual feedback was progressively removed in the last four sessions. Participants presented a reduction of 18-20% impact loading after the training and this reduction was maintained at the 1-month follow-up in a feedback-free state.[28] Other biofeedback gait retraining programs using the same training and feedback weaning protocol have been applied to other cohorts and they were shown to be effective for a favorable running gait pattern transition.[15] Despite of the fact that the running biomechanics between treadmill and overground were not exactly identical, translation of the training effect from treadmill-based training to overground running has been observed in previous gait retraining studies.[38] One plausible explanation was the comparable neuromuscular control[31] and kinetics[36] between the two conditions, favoring the translation of the training effect to the alternative running environments.

However, a 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 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. On the contrary, the vertical loading rates would remain similar in the control group. It is 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 administrating institutional review board and the trial was registered at a local clinical trial registry. A total of 412 novice (< 2-year running experience) runners who regularly run > 8 km/week and aged 18-50 years were recruited in this study. Participants were free from any active injury for at least six months prior to the study. In order to avoid floor effect, all the participants underwent an initial running screening and those with VALR < 70 BW/s 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, Watertown, MA, USA) at 8 km/h (slow pace) and 12 km/h (fast pace) for five minutes with their usual running shoes. The test sequence was randomized using an online program (www.random.org) and there was a 5-minute rest period between the two running trials.

Ground reaction force data was sampled at 1,000 Hz for the last minute of the run. Data were then filtered using a second order, recursive Butterworth, lowpass 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.[14] 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 the case with an undetectable or absence of vertical impact peak within one stance phase, the vertical impact peak value would be taken as the force at 13% stance phase.[6] Both VALR and VILR were normalized by body weight (BW) and averaged across all footfalls within the one-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 year.[6,16] A reduction of 25% on the occurrence in the gait retraining group compared to the control group was considered clinically significant and relevant.[8] 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%, a total of 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. In order to ensure the participants between two groups are matched, a stratified randomization was performed. Participants were stratified for current running mileage (8-12 km/week; 12-16 km/week; >16 km/week) and gender. A block size of four 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 received a 2-week gait retraining for landing stiffness modulation according to the protocol established in a previous study.[12] In brief, they participated in eight sessions of gait modification over two weeks (four 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, Watertown, MA, USA). Visual biofeedback in the form of vertical ground reaction force signal from the treadmill was displayed on the monitor in front. 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 eight sessions and visual feedback was progressively removed in the last four 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.

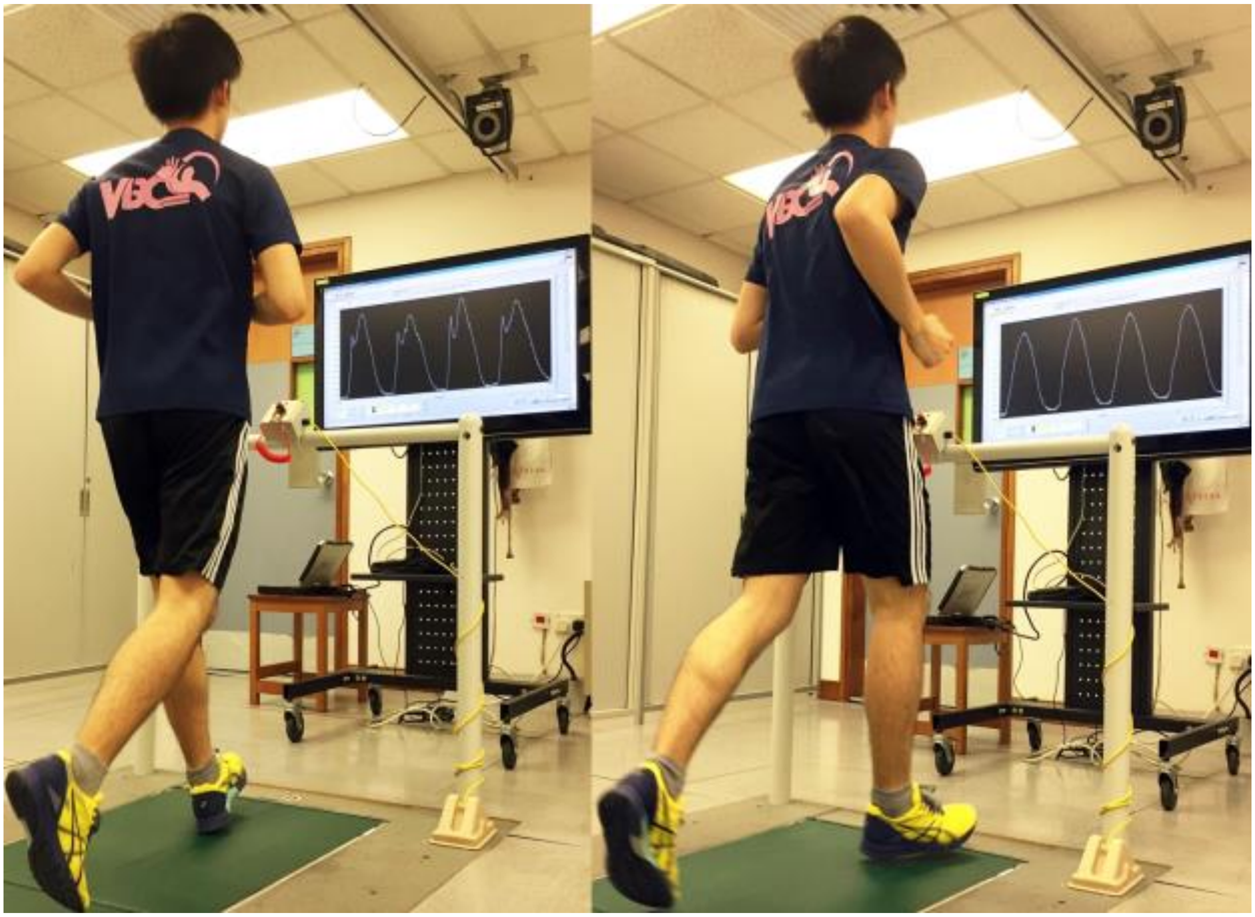

Figure 1. Runners receiving visual biofeedback during gait retraining and they were asked to reduce the vertical impact peak by softening the footfalls

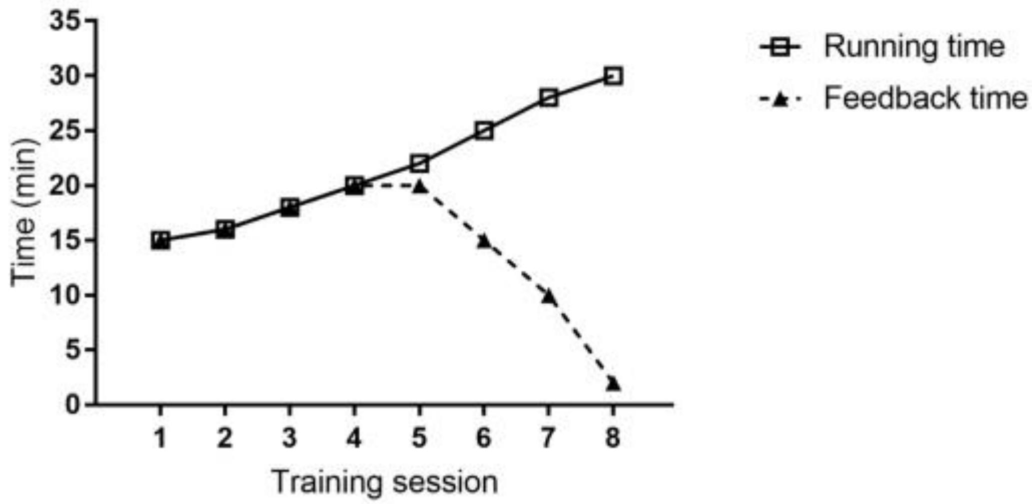

Figure 2. Training time and biofeedback time arrangement in the gait retraining group

Control group

Similar to the gait retraining group, participants in the control group were invited to the laboratory for eight times in two weeks. They were asked to run on an instrumented treadmill at a self-pace speed but no feedback of their running biomechanics was provided. The running time was identical to the protocol in the gait retraining group.

Reassessment

All participants were reassessed two 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.[3] At the first login, they were required to report their injury history and average weekly mileage over the past six months. At each of the 12 subsequent logins at each month, they were asked to report their weekly mileage, other training program involved, and injuries (if any) over the past month. They were required to specify the person who made the diagnosis for the injuries. An injury was operationally defined as any running related musculoskeletal complaint,[42] which was diagnosed by a medical professional, such as a physician, physical therapist or orthopedic surgeon, and that the condition would render them to miss at least two days of training. In order 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 group were compared using two-tailed t tests and Chi-square statistics for continuous and discrete variables, respectively. A 2x2 mixed design 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, in order to avoid overreliance on statistical tests,[30] the effect size, in terms of Cohen's d, were used to quantify the strength of comparisons. Cohen's d around 0.2, 0.5 and 0.8 are considered as 'small', 'medium' and 'large' effect sizes respectively.[41] Since this current study was not designed to investigate the effects of gait retraining on any particular injury type, the injury pattern in the two study groups were compared descriptively. Mantel-Cox test was used to compared 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 development 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., Chicago, IL, USA), with level of significance set as 0.05.

RESULTS

412 participants volunteered in this study, with 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. Finally, 320 out of remaining 390 participants completed all follow-up assessments and 70 had dropped out at different stages due to scheduling conflicts or personal reasons. No between-group differences in any demographic or baseline outcomes were found (ps>0.094, **Table 1**).

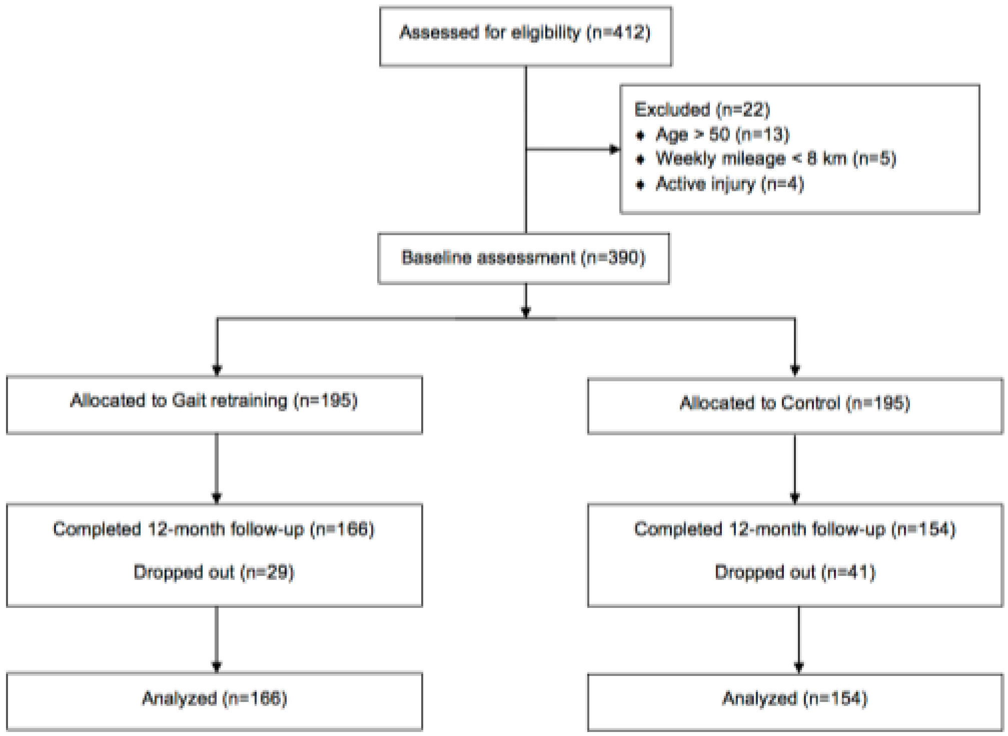

Figure 3. Consort diagram

Table 1. Baseline characteristics of participants in the gait retraining and control group

Characteristics	Gait retraining (n=166)	Control (n=154)	*P*
Gender	82 males 84 females	76 males 78 females	0.993
Age (years)	33.6 ± 9.5	34.2 ± 9.5	0.559
Weight (kg)	60.0 ± 12.6	61.6 ± 12.0	0.235
Height (m)	1.66 ± 0.09	1.65 ± 0.09	0.843
Running experience (months)	16.8 ± 5.2	16.6 ± 5.0	0.720

Weekly mileage (km)	19.5 ± 7.0	18.5 ± 6.1	0.172
VALR at 8 km/h (BW/s)	65.95 ± 9.90	67.81 ± 9.97	0.094
VALR at 12 km/h (BW/s)	81.28 ± 13.59	83.51 ± 11.41	0.115
VILR at 8 km/h (BW/s)	90.69 ± 13.90	92.32 ± 10.81	0.245
VILR at 12 km/h (BW/s)	111.87 ± 14.51	114.32 ± 16.42	0.160

Participants in both groups reported no adverse effects. 2x2 mixed design ANOVA revealed a significant interaction effects between training and time for both VALR ($p<0.001$, $\eta^2_p=0.344-0.367$) and VILR ($p<0.001$, $\eta^2_p=0.353-0.541$) at both testing speeds. Pairwise comparisons reported a significant reduction in VALR (p<0.001, Cohen's d=1.06-1.12) and VILR (p<0.001, Cohen's d=0.99-1.01) after gait modification (**Figure 4**). In the control group, there was no significant difference in the VALR at 8 km/h after the training (p=0.461) but the VALR at 12 km/h and VILR at both testing speeds were increased (p<0.029, Cohen's d=-0.09 to -0.14, **Figure 4**). For between-group comparisons, the VALR and VILR in the gait retraining group were significantly lower than that in the control group at both testing speeds after training (p<0.001, Cohen's d=1.16-1.52).

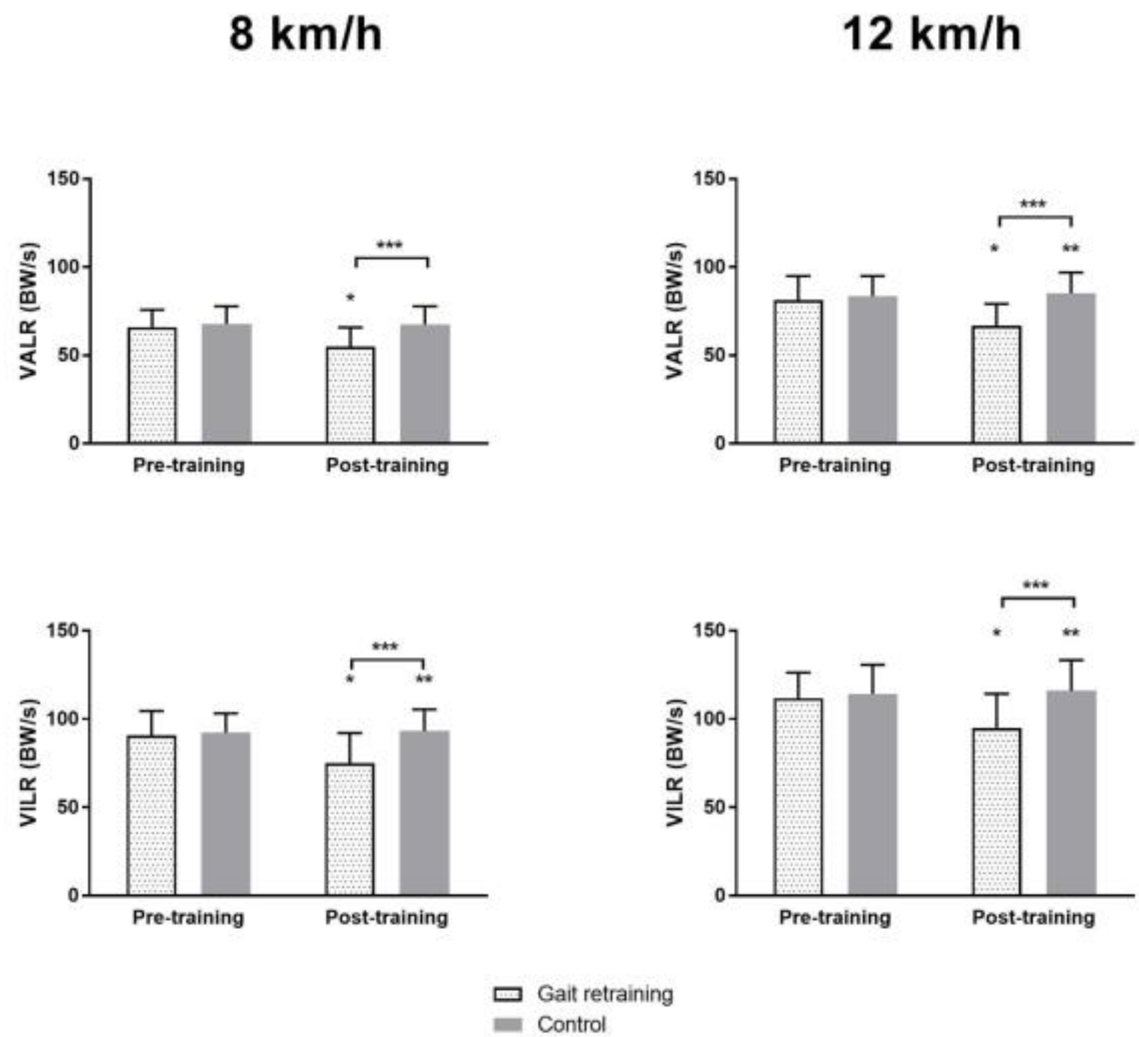

Figure 4. Vertical average and instantaneous (VALR and VILR) at 8 km/h and 12 km/h before and after training

At 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 between gait retraining and control groups was different (**Table 2**). We observed more Achilles tendinitis (18%) and calf strain (18%) in gait retraining group participants, while no such injuries were observed in the control group. On the contrary, the most common injury in the control group was 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 two groups (**Figure 5**). Hazard ratio between gait retraining and control groups was 0.38 (95%C.I.=0.25-0.59), indicating a 62% lower injury occurrence in gait retrained runners, when compared with controls.

Table 2. Absolute number of running related injuries in gait retraining and control group

Condition	Gait retraining	Control
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%)

Number in parentheses represent percentage of injury

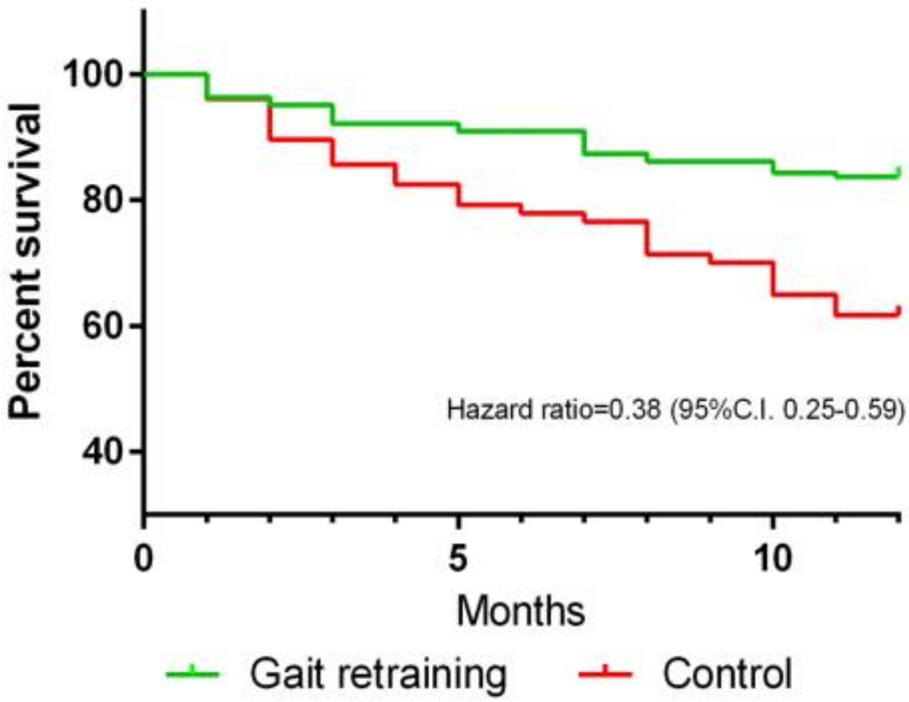

Figure 5. A Kaplan-Meier plot of running-related injury survival between participants from the gait retraining group and the control group

DISCUSSION

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

Previous gait retraining studies reported a large reduction of VALR (Cohen's d up to 3.32) and VILR (Cohen's d up to 3.74),[27] which is greater than 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 footstrike pattern,[12,40] stride frequency,[20] or lower limb alignment.[28] These modifications could be observed and measured without the use of sophisticated lab equipment, runners could attempt or practice 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, i.e. tibial shock, reported a smaller reduction of VALR and VILR (Cohen's d=1.3-1.7) after gait retraining.[14] Even so, studies relating attentional focus and motor learning suggested that feedback which promotes external focus was more effective than internal focus on both the learning outcome and retention.[45,46] In the present study, participants were provided with real time externally focused feedback, i.e. 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 favor retention during the follow-up period.

The present study, unlike previous studies where the assessment and training speeds were set by researchers, our participants completed the gait retraining at their own training pace. Together with the use of their own usual running shoes, the training was performed in a condition which best imitates their natural training conditions. This design was to minimize the effect of speed and footwear change on loading rates,[11,26] and ensure sustainability of the modified gait in participants when they return to their regular trainings.

Lower VALR or VILR after gait retraining is achieved by a reduction in the vertical body stiffness during impact.[21,23] The relationship between stiffness and running injury is well established in animal models but not in human. A rate dependent relationship between loading and bone injury has been demonstrated in rabbits,[35,39] dogs,[10] and bovine.[4] 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 with patellofemoral pain[12] and plantar fasciitis,[32] than their healthy counterparts. Such observations were in line with the injury pattern in our control group participants. On the contrary, there were more incidence of calf injury, i.e. calf strain and Achilles tendinitis, in the gait retraining group than the control group. This pattern can be explained by a greater strain on the ankle plantar flexors when the participants attempted to soften the footfalls by a footstrike pattern switch,[29] which has been shown to be effective in lowering vertical loading rates.[22]

The findings of this study supported to use of visual biofeedback in reducing the impact loading and being an effective way in injury prevention, these could have a direct impact on reducing the health care costs. A recent study reported that the economic burden of a single running-related injury is approximately US$90.[19] Given the fact that over 54 million people currently engage in running, be it for recreational or competitive reason,[1] and up to 79% of runners incur an injury in a given year,[7,18] the total cost of running related injury is estimated at US$4 billion annually. Further study could investigate the cost effectiveness and economic impact 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 only be delivered 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 environment thus sustainability of the modified gait biomechanics in the actual environments remains unexamined. Third, similar to a previous study,[3] we used an online platform to monitor injury pattern of the participants for 12 months. Although we contacted every participant who had reported an injury to maximize data validity, we did not clarify with uninjured participants and therefore the injury occurrence may be underestimated in both groups. Finally, the exclusion of experienced runners may have affected the generalizability of our findings.

CONCLUSION

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

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