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Reducing Impact Loading in Runners: A One-Year Follow-up

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Abstract

Increased vertical impact loading during running has been associated with a variety of running related injuries including stress fractures, patellofemoral pain and plantar fasciitis.

Purpose: The purpose of this study was to examine the acute and long-term effect of a gait retraining program aimed at teaching runners with high impact loading to run softer.

Methods: 19 runners with high tibial shock first underwent a control period of 8 sessions of treadmill running over 2 weeks, progressing from 15 to 30 minutes. This was followed by 8 sessions of gait retraining over two weeks using the identical treadmill protocol. Real-time feedback of tibial shock was provided as the participant ran. Feedback was gradually removed during the last 4 sessions. Variables of interest included peak tibial shock (TS), vertical impact peak (VIP) and vertical average (VALR) and instantaneous loading rates (VILR). These variables were assessed at intervals following the retraining and at a one-year follow-up.

Results: All variables of interest were significantly reduced post-retraining ($p<0.001$). TS was reduced by 32%, VIP by 21%, VILR by 27%, and VALR by 25%. All variables continued to be significantly reduced at a one-year follow-up.

Conclusions: Impact loading can be reduced through gait retraining and the results persist at least one year. As impact loading is associated with injury, this simple intervention may provide a powerful method of reducing musculoskeletal injury risk in runners.

Keywords

gait retraining; loading rates; running; biofeedback; running injuries

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Introduction

The Healthy People 2020 initiative and the Exercise is Medicine™ Campaign encourage people to engage in regular exercise throughout their lifetime. Running is one of the most popular fitness activities that Americans engage in with over 16.9 million Americans running in over 30 thousand races in 2016 (1). However, due to the repetitive nature of running, overuse injuries are common. It has been suggested that up to 79% of runners get injured in a given year (2) and up to 70% of these will be recurrences (3).

The etiology of running injuries is known to be multifactorial in nature, however, running mechanics certainly play a role. A number of recent studies have reported an association between vertical impact loading and running injuries. Specifically, variables such as the vertical impact peak, vertical loading rate and tibial shock have been linked with a variety of injuries such as tibial stress fractures, plantar fasciitis and patellofemoral pain syndrome (4–7). Physical therapy intervention for these musculoskeletal injuries typically involves progressive strengthening with the assumption that strengthening will lead to improved mechanics. However, it has been shown that strengthening alone has no effect on mechanics, leaving the underlying cause of the injury unaddressed (8, 9). This explains, at least in part, the high rate of injury recurrence that has been reported in runners and highlights the importance of retraining faulty gait mechanics to reduce these injuries.

Gait retraining is not a new concept and has historically been a component of physical therapy interventions. The use of real-time feedback is also not new. Limb-load monitors, measuring the forces under the feet, have been used to improve walking symmetry in children with cerebral palsy (10) and adults with fractures, amputations, total hip replacements, and chronic pain (11). Real-time force feedback from instrumented treadmills has been shown to acutely improve gait symmetry in trans-tibial amputees (12) and individuals with total hip replacements (13). More recently gait retraining using real-time, faded feedback (sequential reduction of real-time feedback) over multiple sessions has been implemented in runners. A number of studies have utilized this approach to address patellofemoral pain in runners that had not resolved with other approaches (14–16). Real-time feedback of tibial acceleration during running has also been used in studies to acutely reduce the impact loading. Using an 8 session, faded feedback design, Crowell et al. (17) demonstrated a significant reduction in both tibial shock as well as vertical loading rates. These changes persisted at a 1-month follow-up. Clansey et al. (18) provided real-time feedback on tibial shock during 6 sessions over 3 weeks. Their reductions in tibial shock and loading rates were smaller than those of Crowell (17), and did not persist well at the 1-month follow-up visit.

Permanently altering one’s running mechanics involves developing a new running pattern that replaces the old one. This area is where clinical interventions have generally fallen short. It is not enough to demonstrate the new pattern to the patient and have them reproduce it. The patient must be able to consistently produce this pattern on their own and without feedback. The optimal way to develop a new motor skill is to provide extrinsic feedback that is gradually removed so that an individual learns to rely on their own intrinsic feedback mechanisms to produce the correct mechanics (19). Establishing the adjusted running mechanics as a new motor skill requires a series of training sessions in which feedback is gradually removed. Studies that have utilized this approach have shown persistence (14–16, 20), while those that did not were much less successful (18, 21). The effects of using the faded feedback technique have been shown to last from 1 to 3 months after the completion of a gait retraining protocol (15, 16). To our knowledge no studies have looked at the long-term persistency of these changes past 3 months. Without a persistent change in mechanics, injury risk is not likely to be altered.

Therefore, the purpose of this study was to examine the short and long-term effect of a gait retraining program using real-time feedback to reduce impact loading in runners. It was hypothesized that impact loading (including vertical impact peak, vertical loading rates and tibial shock would not be reduced following a control period but would be reduced following the retraining. Additionally, reductions in impact loading would persist over a 12-month period. We also expected that tibial shock would be significantly correlated with loading rates. Finally, we did not expect peak vertical force to change as a result of the retraining.

Methods

An a priori power analysis (alpha=0.05, beta=0.20) utilizing an effect size of 0.85 (pilot data) determined that 19 participants were necessary to identify a large effect of a gait retraining program among time points on the variables of interest [tibial shock, vertical impact peak, vertical load rates, peak vertical force] (G*Power Version 3.1.4). Runners were rearfoot strikers running at least eight miles/week and were injury free upon entrance into the study. Prior to any data collections, we obtained written informed consent from each participant as approved by the University's Institutional Review Board.

Participants were screened to determine their vertical impact loading. An accelerometer (model 32A56, PCB Piezotronics, Depew, NY, USA) was attached to the anteromedial aspect of the participant's distal tibia (Figure 1). Participants ran along a 25 m runway and traversed a forceplate (Bertec Corp., Columbus, OH, USA) at its center. Speed was monitored via photocells and maintained at 3.70m/s ±5%. Vertical accelerations during stance were collected at 1200 Hz using Vicon Nexus Software (Vicon, Centennial, CO, USA). Participants completed five trials for each limb. Tibial shock (TS) represents the peak vertical acceleration during stance across the five trials for each limb. Participants with $TS \geq 8$ g for either limb were invited to participate in this study as this is considered >1sd of a healthy group of runners at this speed (5). If both limbs exhibited $TS \geq 8$ g, the limb with the higher loading was used for the retraining portion of this study.

Runners who displayed increased tibial shock during the screening were enrolled in this study and completed a baseline gait analysis to determine baseline vertical loading rates. Data were processed with customized LabVIEW (National Instruments, Austin, TX, USA) software. Force and accelerometer data were filtered at 50 and 75 Hz, respectively. Footstrike and toe-off were identified from the vertical ground reaction force using a 20 N threshold. Tibial shock was identified as the peak positive tibial acceleration (5). The vertical impact peak (VIP) was identified as a local maximum before 25% of stance and vertical average (VALR) and instantaneous (VILR) loading rates were calculated from the slope to the vertical impact peak (5). If no vertical impact peak was identified, then the force value from 13% of stance was used as the vertical impact peak value (22). The peak vertical force (PFV) was identified as the peak vertical ground reaction force.

Participants then underwent eight control sessions. During these sessions, they ran at a self-selected pace on an instrumented treadmill (AMTI, Watertown, MA, USA). The duration of each control session increased gradually from 15 minutes for the first session to 30 minutes in the eighth session. Post-control, the overground gait analysis was repeated. They then began the retraining sessions. With an accelerometer tightly affixed on the distal tibia of their retraining limb, they ran at their initially chosen self-selected pace on an instrumented treadmill (AMTI, Watertown, MA, USA). Identical to the control sessions, run times were gradually increased from 15 to 30 minutes over the eight retraining sessions. During these sessions, the accelerometer signal was displayed in real time on a monitor. Participants were instructed to keep their TS below a line, placed at 50% of their baseline TS (Figure 2), and to make their footfalls softer. We utilized a faded feedback paradigm designed to facilitate internalization and persistence of the new gait pattern (19). Participants received visual feedback for 100% of the time during the first four sessions. During the last four sessions, the feedback was gradually removed such that participants received only three minutes of feedback in the final session, with one minute at the start, middle and end of the session (Figure 3). For both the control and retraining sessions, participants had a minimum of one day off after two consecutive days of running in order to minimize muscle fatigue. All participants were required to complete all running sessions within a three-week window of time. During this three-week window, participants refrained from running outside the laboratory in order to minimize reinforcement of their old running pattern. Post-retraining, another gait analysis was conducted.

Participants returned to the lab for follow-up data collections at 1, 6 and 12 months following the retraining. Repeated measures ANOVAs were calculated for the five variables of interest (TS, VIP, VALR, VILR, PFV) across six time points (baseline, post control, post retraining, 1-month, 6-month and 12-month). Skewness of the residuals was used to test the assumption of normality with skewness scores between ±2 considered normally distributed (23). Mauchly's test was used to test the assumption of sphericity. The Greenhouse-Geisser adjustment to the degrees of freedom were used when the assumption of sphericity was violated. Planned comparisons were conducted across specific time points of interest: baseline versus post control and post-control versus post-retraining, months 1, 6 and 12. A modified Bonferroni correction was applied ($p<0.05$) to the planned comparisons (24). Partial Eta squared for each of the ANOVAs and Cohen's d for the planned comparisons were used to determine effect sizes. A large effect size was defined as $\eta_p^2 \geq 0.26$, $d \geq 0.80$; moderate $\eta_p^2 \geq 0.13$, $d \geq 0.40$; and small $\eta_p^2 < 0.02$, $d < 0.40$ (25). Additionally, the relationships between reductions in tibial shock and the ground reaction force variables from post-control to post retraining were calculated using correlation coefficients (Pearson's r).

Results

Of the 261 participants screened, 44 exhibited tibial shock ≥ 8 g and were invited to participate in the study. Of the 44 participants, 32 completed the baseline gait analysis. A total of 19 participants (9 male, 10 female; Age 26±7.6 yr; height 1.75±0.1 m; mass 76.6±14.2 kg; weekly mileage 16±9.8 miles) who completed the retraining program and the gait analysis sessions remained in the study. Reasons for the reduction of participants from 32 to 19 included TS < 8 g at the baseline gait analysis (11 participants), undisclosed previous injury (1 participant), and inability to complete multiple data collection sessions (1 participant) (Figure 4).

Evaluation of the skewness of the residuals for each variable indicated that all variables were approximately normally distributed. Apart from TS decreasing by 17%, no other impact variables displayed a significant change following the control period (baseline to post-control). However, following the intervention (post-control to post-retraining), runners significantly reduced their TS by 32%, VIP by 21%, VILR by 27%, and VALR by 25% (Table 1). TS, VIP, VILR and VALR were also found to be significantly reduced (ranging between 16 and 29%) at each of the follow up visits (post-control to months 1, 6, & 12) indicating persistence of these changes for at least 12 months following gait retraining (Table 1, Figure 5). Finally, reductions in TS from post-control to post retraining were positively correlated to changes in VILR ($r = 0.71$, $p = 0.001$), and VALR ($r = 0.61$, $p = 0.006$), but not VIP or PFV ($r < 0.40$, $p > 0.05$). As expected, no changes were seen in the PFV compared to post-control at any of the six time points.

Discussion

The purpose of this study was to examine the short and long-term effect of a gait retraining program in runners with high impact loading. We hypothesized that runners would be able to significantly reduce their impact loading following training and that these reductions would persist out to the 1-year follow-up period.

Control period

We utilized a repeated measures design where participants served as their own controls. Each participant underwent a control period where they gradually increased their run time from 15 to 30 minutes over 8 sessions, but had no feedback provided. TS decreased was the only variable to change over the control period. However, no differences in any of the ground reaction force variables were noted during this period. Therefore, the 8-session, progressive run program without feedback did not influence the primary outcome variables in the study.

Immediate effects

Following the retraining, all the impact variables significantly decreased as hypothesized. The greatest reduction was seen in TS. This finding was not surprising as the variable provided for feedback typically demonstrates the greatest change with retraining (14, 16, 18, 20). In support of our findings, others have reported significant TS reductions between 30–48% following gait retraining (20). The reductions in TS were moderately to strongly correlated (r=0.71) to reductions in loadrates, suggesting TS can be used as a surrogate for loadrates when a force plate is not available. The reductions in VALR and VILR were within the ranges noted in the literature, with reports of 18–32% and 19–34% reductions for VALR (17, 18, 26). In terms of force magnitudes, it was not surprising that VIP was significantly reduced with the retraining as it occurs during the impact phase of running and is nearly synchronous with TS. As expected, the peak vertical force, which occurs at mid-stance, did not change. However, peak vertical force has yet to distinguish between those with a history of stress fractures and those without (27).

The post-retraining reductions in loadrates were greater than those reported by Clansey et al (18). This may be related to differences in the retraining approaches. First, the type of feedback was different. Clansey et al. used a traffic light placed on a monitor in front of the treadmill. Feedback was provided every 5th step as the average TS over the 5 previous stance periods. A high TS was indicated by a red light, medium by a yellow light, and low by a green light. We provided a continual trace of the accelerometer data in real-time and provided a target for them to remain under. The dosage of the feedback was different. Clansey's retraining involved six rather than eight sessions in 3 weeks, and nearly half the training time of the current study (100 vs 190 minutes). This may have led to less reinforcement than in the current study. They also did not slowly progress the run time. We felt this was important to allow the body time to adapt to the new motor pattern. They also did not incorporate a faded feedback design. Faded feedback has been shown to be an important training component for altering movement patterns (19). Finally, they allowed their subjects to run in between the training sessions. This, in the absence of feedback in the field, may have potentially reinforced their older, habitual pattern. Subjects in our study were not allowed to run on their own until they completed their retraining, at which time they were doing most of their 30-minute run without any feedback.

Long-term results

The reductions found immediately post-retraining are less impactful if the gait alterations do not persist over time. The long-term success of the retraining program in our study was extremely encouraging. Runners demonstrated a persistence of the loading rate reductions following the retraining, with no differences noted between the 1, 6, & 12-month follow ups. These findings were in contrast to those reported Clansey and colleagues (18) who reported that reductions in vertical loading noted following the retraining did not persist at the 1-month follow up. This, again, may be due to the differences in the retraining protocols noted previously. Four other studies that have incorporated a similar approach as used in our study (14–16, 28) reported greater improvements in mechanics, greater persistence of the mechanics and greater reduction of symptoms in patients than studies that have not (18, 20). This suggests the components of the current retraining study are important for altering faulty mechanics and achieving persistence of these changes. The importance of adhering to these motor control principles was further underscored by the successful retention of the gait changes at the 1 year follow-up.

Implications for injury

The reduction in loading rates is an important finding in this study, as these have been strongly correlated to running-related injuries in the literature. Most of these studies have been retrospective in nature (4–6). However, a prospective study of 242 runners demonstrated that those with high loading rates were at a 3X Vertical loading variables greater risk of developing a running-related injury than those with low loading rates (4). Even more compelling is the recent large RCT that found that runners retrained to reduce their impact loading had 62% fewer injuries at the one year follow up than runners in the control group (26). This study, along with ours suggests that gait retraining aimed at reducing loadrates can be a powerful way to help reduce injuries in runners.

Unintended consequences

It must be noted that changing running mechanics to reduce impact loading may have unintended consequences. A reduction in running economy has been suggested to be one of those consequences. However, Clansey et al. reported no changes in running economy immediately following gait retraining for runners who significantly reduced impact loading (18). They also reported no changes in running economy at the 1-month follow-up, however, changes in running mechanics did not persist. Future studies may need to explore the long-term effects of gait retraining on running economy. Another unintended consequence of changing a runner's gait pattern is the potential increased risk for developing a different injury. Similar to other gait retraining studies, our protocol did not appear to cause any injuries (17, 18). Participants did report mild soreness, but the soreness did not persist beyond a few sessions.

Summary

In summary, this is the first study to demonstrate the long-term (1 year) retention of retrained gait patterns. The recent emergence of wearable sensors and the correlation noted between TS and loadrates provides for the translation of this retraining into the clinical environment where force plates are less accessible. These wearable sensors also allow the monitoring of running gait out in the community, which will increase the ecological validity of the retraining approach implemented in our study.

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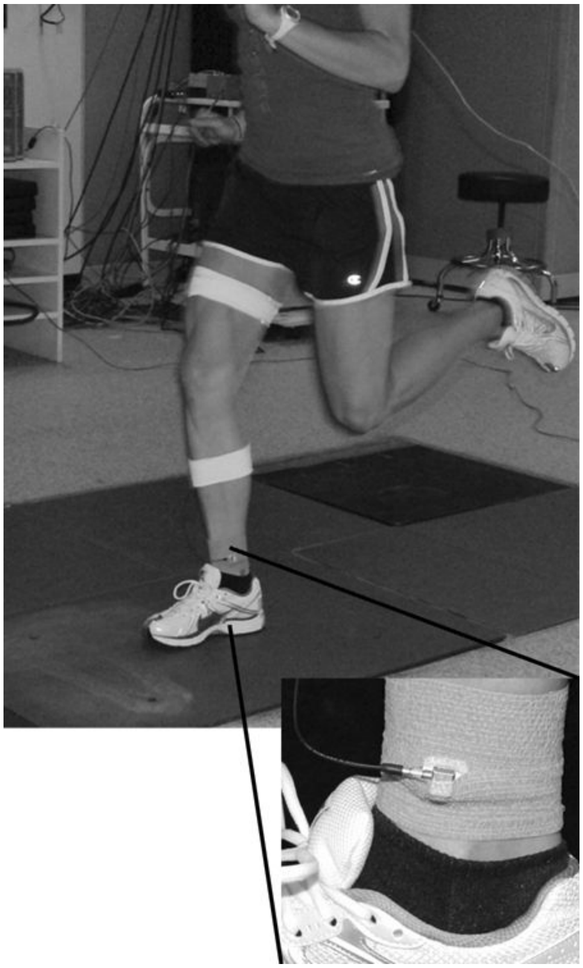

Figure 1:

Accelerometer Placement for the running trials.

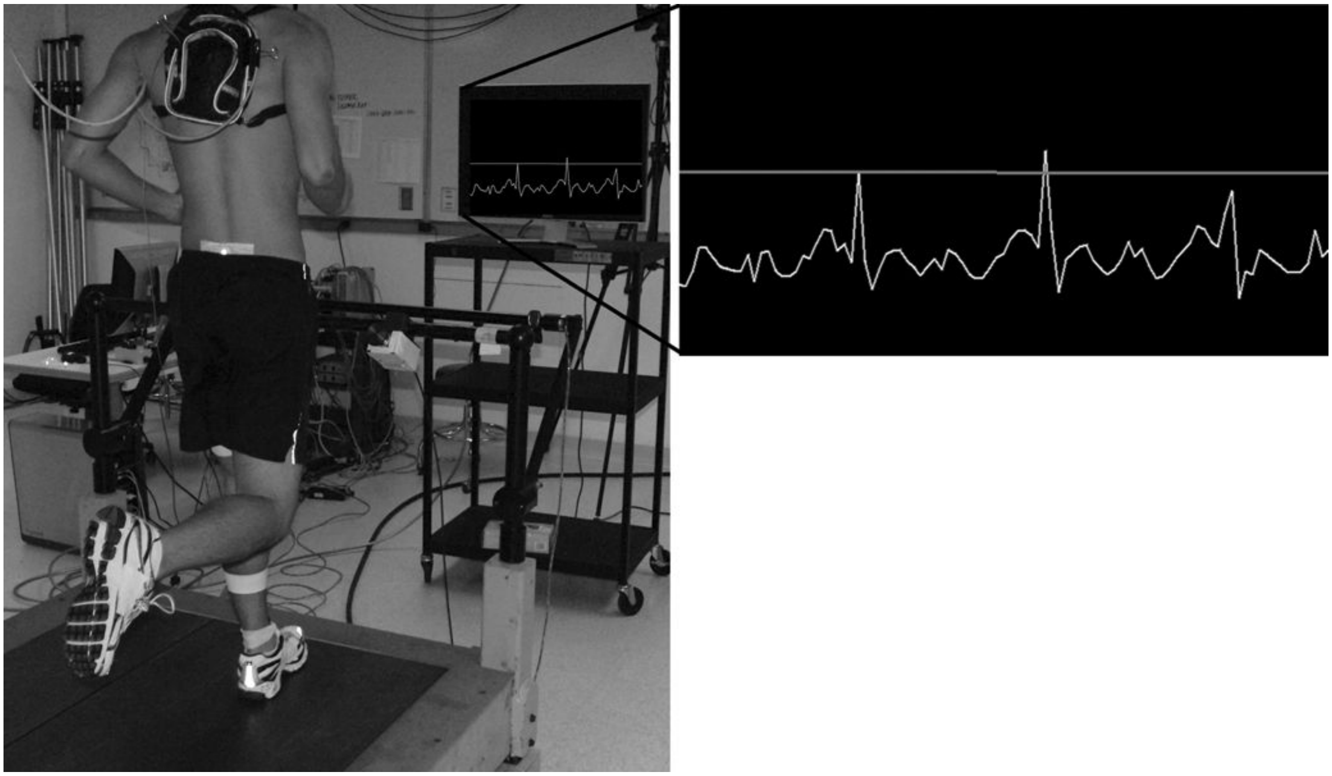

Figure 2:
Set up for the retraining sessions. Real-time accelerometry data was provided on a screen as the participant ran on the treadmill.

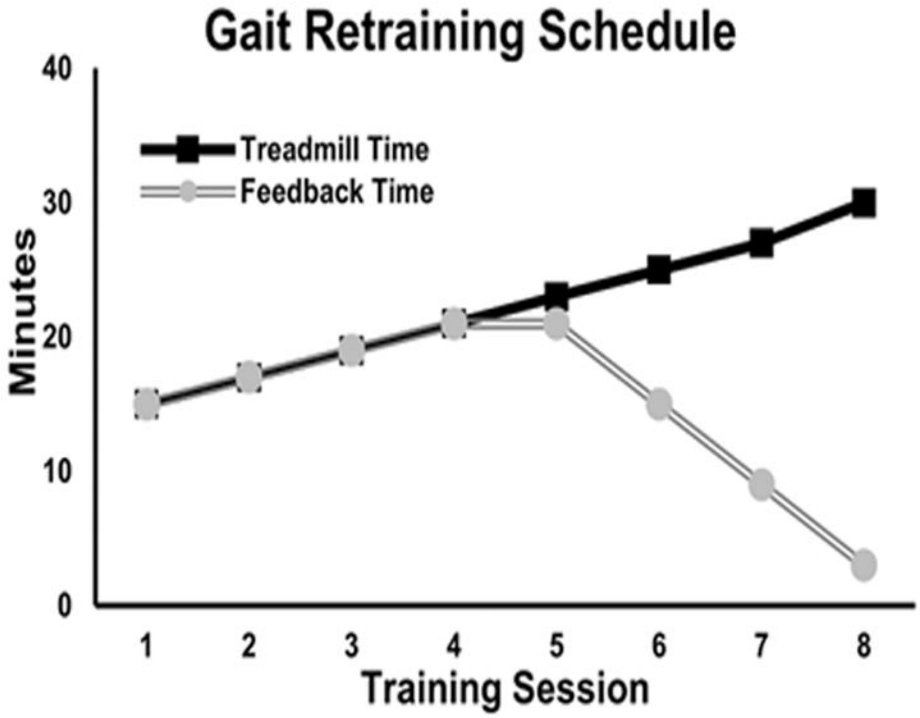

Figure 3:
Running and feedback times across the 8 retraining sessions.

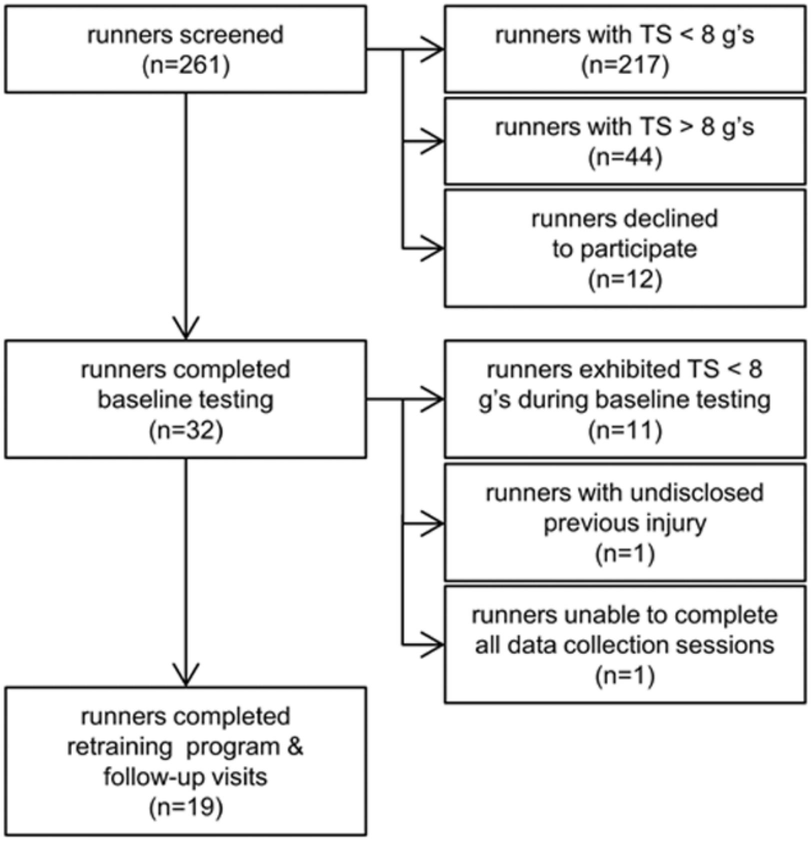

Figure 4:

Flow chart of participant inclusion in the study

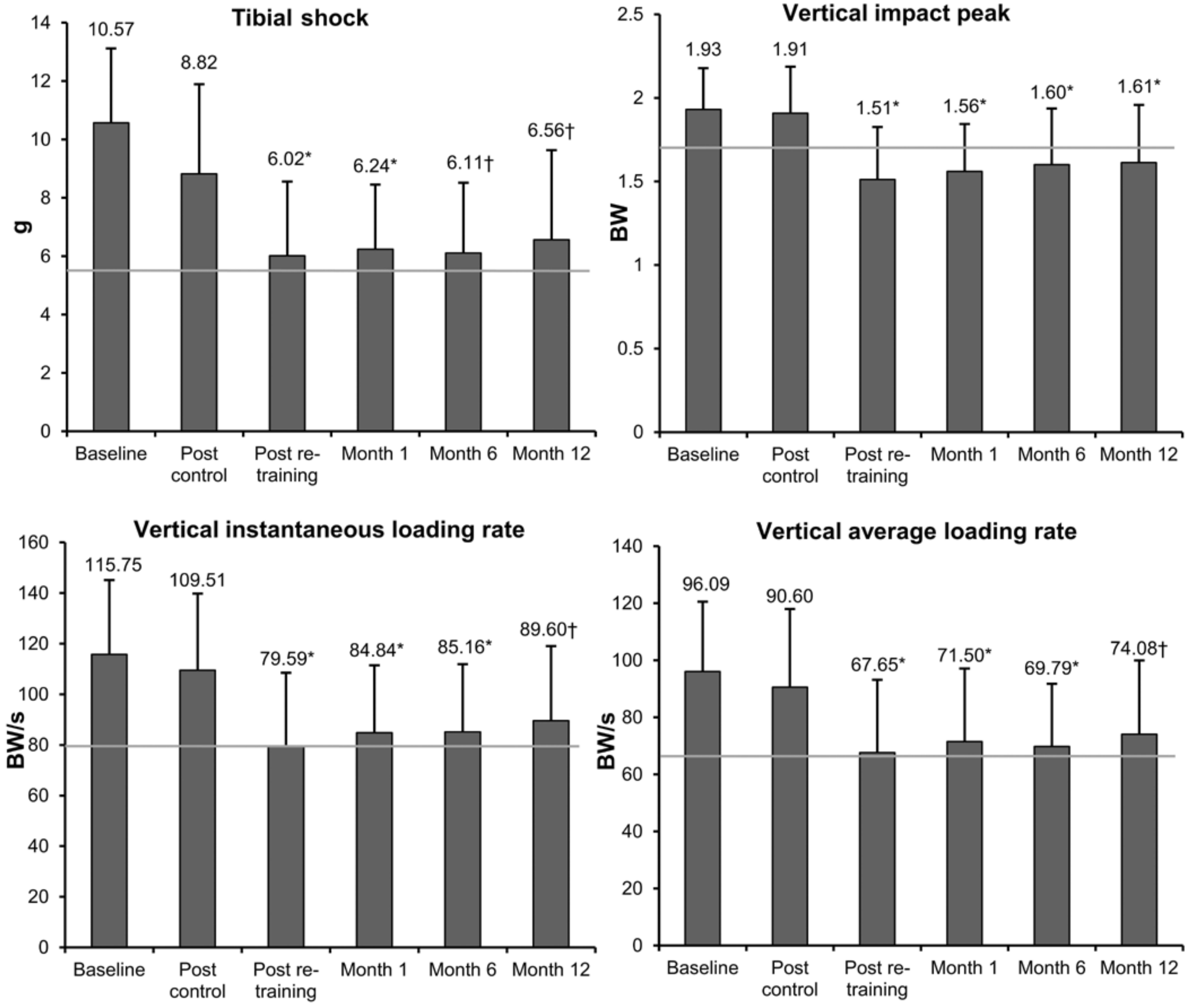

Figure 5:

A comparison of tibial shock, vertical impact peak, and vertical load rates at the baseline, post control, post re-training, and 1, 6, and 12 month follow up visits. The gray line represents normal values for these measures as reported by Milner et al., (10). * and † indicates significantly different from post control ($p < 0.05$ and 0.01 respectively).

Table 1.

Vertical loading variables during running

Variable	Repeated Measures ANOVA	Planned Comparisons		Mean Difference (SEM)	*p*-value	Cohen's *d*	Percent Reduction
Tibial Shock (g)	F(2.94, 52.92)=17.36 p<0.001* $\eta_p^2 = 0.49$	Baseline	-Post control	1.75(0.55)	0.010*	0.74	17
		Post control	-Post retrain	4.56(0.60)	<0.001*	1.16	32
			-Month 1	2.58(0.60)	0.002*	0.99	29
			-Month 6	2.70(0.81)	0.011†	0.77	31
			-Month 12	2.25(0.89)	0.021†	0.58	26
Vertical impact peak (BW)	F(2.97, 53.48)=14.64 p <0.001* $\eta_p^2 = 0.45$	Baseline	-Post control	-0.02(0.04)	0.618	0.12	1
		Post control	-Post retrain	-0.42(0.09)	<0.001*	1.02	21
			-Month 1	0.35(0.07)	<0.001*	1.13	18
			-Month 6	0.31(0.07)	<0.001*	1.05	16
			-Month 12	0.30(0.08)	0.002*	0.90	16
Vertical instantaneous loading rate (BW/s)	F(2.42, 50.80)=15.18 p <0.001* $\eta_p^2 = 0.46$	Baseline	-Post control	-6.24(4.23)	0.158	0.34	5
		Post control	-Post-retrain	-36.16(6.86)	<0.001*	1.12	27
			-Month 1	24.67(6.02)	0.003*	0.94	23
			-Month 6	24.34(6.40)	0.004*	0.87	22
			-Month 12	19.91(6.63)	0.015†	0.69	18
Vertical average loading rate (BW/s)	F(2.67, 57.26)=13.81 p <0.001* $\eta_p^2 = 0.43$	Baseline	-Post control	-5.49(4.10)	0.197	0.31	6
		Post control	-Post-retrain	-28.45(5.44)	0.002*	1.00	25
			-Month 1	19.11(5.60)	0.009*	0.78	21
			-Month 6	20.81(5.40)	0.005*	0.88	23
			-Month 12	16.52(5.90)	0.024†	0.64	18
Peak vertical force (BW)	F(2.04, 41.54)=3.19 p =0.052 $\eta_p^2 = 0.15$	Baseline	-Post control	0.01(0.02)	1.00	0.09	<1
		Post control	-Post-retrain	-0.09(0.05)	0.18	0.52	4
			-Month 1	0.06(0.04)	0.46	0.41	2
			-Month 6	0.09(0.04)	0.16	0.53	4
			-Month 12	0.05(0.03)	0.45	0.41	2

* and † indicates significant difference from Post control ($p < 0.01$ and 0.05 respectively); SEM=standard error of the mean difference