

Gait Retraining in Runners

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Running is a popular fitness activity with over 15 million Americans engaging in the sport. Due to its aerobic nature, it has tremendous cardiovascular benefits. However, it is a sport that also involves repetitive loading. For example, a typical runner will strike the ground approximately 1000 times per mile with each foot. Therefore, even minor malalignments and/or abnormal movement patterns can accumulate into an overuse injury. In fact, it has been reported that 50% to 87% of runners will sustain an injury over a one-year period. With 15 million runners in the United States, the number of running related injuries is in the millions. This is associated with substantial medical costs. In addition, cessation of running as a fitness activity can impact one's overall fitness level. The Healthy People 2010 initiative has linked one's fitness level with longevity and productivity.

The etiology of running injuries is multifactorial and each runner has their own threshold for injury. This threshold is dependent on their structure, their mechanics, and their dosage. These factors are interactive and determine how close one functions to their injury threshold. For example, one runner may have poor structural alignment resulting in abnormal mechanics, but only run 10 miles per week. They may continue to run uninjured until they decide to increase their dosage and train for a half-marathon. This increased dosage, in concert with their poor structure and mechanics, may now place them at or above their injury threshold. On the other hand, another runner may have excellent alignment and mechanics, but run ultramarathons, placing him or her at their injury threshold. Therefore, these factors can interact in numerous ways.

While some aspects of structure, such as flexibility, can be altered, basic anatomy is considered relatively unchangeable. Of the 3 factors described, dosage is clearly the most modifiable. However, runners become accustomed to certain running dosage, typically measured by miles run per week. They are reluctant to significantly reduce this mileage as they

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feel they lose the conditioning effects of the exercise. This leaves mechanics which are also modifiable. It is generally believed that mechanics play a significant role in the development of running related injuries. Therefore, altering these mechanics should help to reduce injury risk. In addition, if one has already sustained an injury thought to be related to their mechanics, the risk for reinjury is high unless these mechanics are altered.

The idea of altering one's movement patterns is not new. Therapists are trained to alter abnormal patterns in their patients to reduce injury risk. They do this in their daily practice. For example, they often train their patients to change the manner in which they lift objects in order to reduce spinal loads. However, gait is often thought of as an automatic skill that some believe is driven by central pattern generators. Therefore, the notion that these automatic actions can be changed through conscious thought is often questioned. However, if we believe that movement patterns can be changed, then there is some hope that gait patterns also can be changed to help reduce injury risk.

There is emerging evidence in the literature that kinematic adaptations are indeed possible through neuromuscular reeducation. A recent study by Hewett et al¹ reported lower extremity mechanics during landing from a jump could be significantly altered through a plyometric training program. The program was designed to teach athletes to land softer and with better lower extremity alignment. Reductions in ground reaction forces and knee moments were noted. In a follow-up study, these same authors reported a significant reduction in serious knee injuries among female athletes

who had undergone this training program.²

Gait may be more difficult to alter given its repetitive and automatic nature. However, there have been numerous reports in the literature documenting the success of using some type of real time feedback training to alter walking gait. The majority of these report on patients with neurologic involvement, such as adults who have sustained a stroke or children with cerebral palsy. The earliest forms of feedback were limb load monitors placed within the shoe of a patient.^{3,5} The aim of this type of feedback was to produce an equal load distribution between lower extremities during gait. Electromyography is one of the most widely used forms of feedback reported in the literature. Reports of improvements in gait symmetry in terms of spatio-temporal parameters and joint motion patterns have been reported.^{6,10} Feedback on joint angles has been provided through the use of electrogoniometers for patients with genu recurvatum.¹¹⁻¹³ An overwhelming majority of these studies have reported successful results.

Reports of real-time feedback training are beginning to emerge in the orthopaedic literature. White et al¹⁴ first demonstrated that providing real time visual feedback from an instrumented treadmill could be used to train healthy individuals to exhibit asymmetrical limping strategies. Using the same protocol, they then provided real time feedback, 3 times a week for 8 weeks, to patients who had undergone a hip replacement.¹⁵ They reported a significant improvement in symmetry of reaction forces at weight acceptance. In a related study, Dingwell¹⁶ used an instrumented treadmill to improve the gait of a group of unilateral, trans-tibial amputees. Prior to the training, asymmetries in the measured parameters were 4.6 times greater in the amputee group compared to the control group. These asymmetries were significantly reduced following the training.

However, studies involving feedback during running are sparse. Messier et al¹⁷ provided verbal and visual feedback to a group of female novice runners over a 5

week, 3 sessions per week, running program. Prior to each training session, runners were shown a videotape of their running and were instructed on the features of their gait that they were to try to modify. These were subject-specific mechanics and included characteristics such as excessive vertical oscillation, over-striding, excessive trunk lean, and excessive arm rotation. This group of runners significantly altered the desired kinematic gait variables compared to a control group who received no feedback prior to their training sessions. While this study did not involve the use of real-time feedback, it demonstrates that runners are able to alter their mechanics with training.

Prior to making changes in one's movement patterns, it is important to identify those patterns that are to be related to injury. This can only be done through prospective investigations. We have been engaged in prospective studies to identify biomechanical factors associated with stress fractures, as well as those associated with anterior knee pain. Both of these injuries are among the top 5 most common injuries that runners sustain.¹⁸ In addition, females are at least twice as likely to sustain these injuries compared to their male counterparts. Therefore, our prospective studies were focused on female runners between the ages of 18 and 45 years. In order to eliminate the influence of fitness in our study, all subjects had to be running a minimum of 20 miles per week. Following the instrumented gait analysis, runners are followed monthly for a period of 2 years. Running mileage, as well as any injuries that are sustained are reported. Our preliminary data suggests that female runners who go on to develop a stress fracture exhibit significantly higher peak tibial shock, as well as increased vertical loading rates compared to a group of uninjured age and mileage matched group. Runners who go on to develop anterior knee pain exhibit increased hip adduction and internal rotation. These findings provide the rationale needed to alter these mechanics in runners.

We began our realtime feedback training with the use of a treadmill and a mirror. We have since further developed our realtime feedback to include realtime accelerometry and realtime motion analysis feedback. The following prelimi-

nary and case studies will hopefully demonstrate how realtime feedback can be used to retrain abnormal gait patterns in runners.

STUDY 1

Gait Retraining in a Runner with Plantar Fasciitis

A 40-year-old female runner with right plantar fasciitis served as the subject for this study. She had discontinued running as a result of her pain. Prior to her injury, she had been running an average of 15 to 20 miles per week. She had been treated unsuccessfully with foot orthotic devices and was seeking additional advice. A visual analysis of the patient's running revealed the following (Figure 1a): the right hip was in excessive internal rotation and the knee in genu valgum throughout the support phase. In addition, excessive midfoot pronation was observed. Weakness of the right hip abductors and external rotators was noted (4/5 on a manual muscle test), as well as excessive hip internal rotation range of motion (0-70°). The left side exhibited normal hip strength and range of motion.

An instrumented gait analysis was performed to quantify the gait deviations that were noted visually. The frontal and transverse plane motions of the hip and knee are shown in Figure 2 (left panel) and compared to that of a group of healthy runners. Hip adduction and internal rotation and knee abduction and external rotation were found to be greater in the injured runner. It was hypothesized that the plantar fasciitis this runner was experiencing was related to the internally rotated hip and medially deviated position of the knee, placing

greater stress on the arch of the foot. The subject agreed to undergo an 8-week training program to address these gait mechanics. Visual feedback was provided as the patient ran on a treadmill in front of a full-length mirror. The patient was instructed verbally to "keep your knees apart" to address the hip adduction. In addition, she was asked to "keep your patella pointed forward" to address the internal rotation of the femur. She ran for 10 minutes and gradually progressed to 32 minutes by the end of the 8-week session. She was seen 3 times a week for the first 3 weeks, 2 times a week for the next 3 weeks, and once a week for the last 2 weeks. The mirror and verbal feedback were progressively removed. She reported soreness in the external rotators and abductors of her right hip during the initial training, which resolved within 2 weeks. She also reported a progressive reduction in the effort required to maintain the aligned posture of her right lower extremity. The subject underwent another instrumented gait analysis to assess any changes that occurred as a result of the training.

Following the gait re-training program, there was a significant reduction in hip internal rotation, hip adduction, and knee abduction and increase in knee internal rotation (as a result of the decreased femoral internal rotation) (Figure 1b & Figure 2 right panel). The runner returned for a 6 month follow-up gait analysis. She was running 30 minutes, 3 to 4 times per week without pain. The analysis revealed that hip external rotation and abduction were maintained, but knee frontal plane patterns showed a shift towards pretraining levels (Figure 2 right panel).

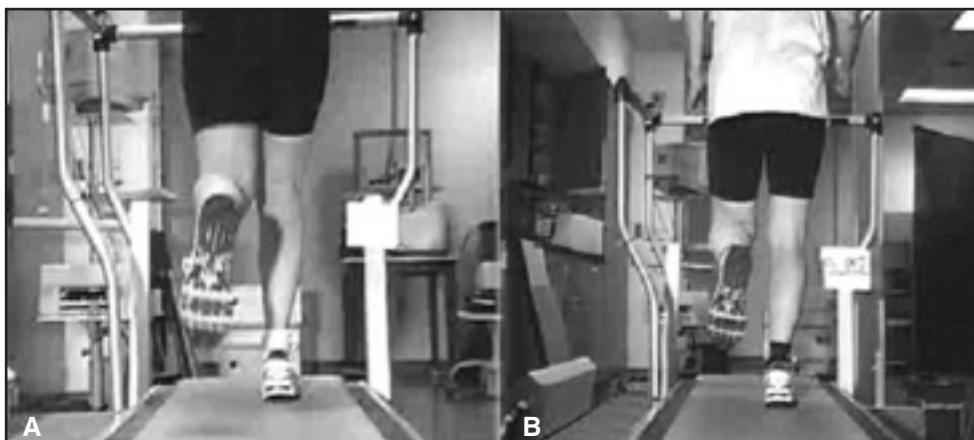


Figure 1. (a) Pretraining gait. Note the genu valgum and hip adduction position. (b) Post-training gait. Note the reduced genu valgum and hip adduction.

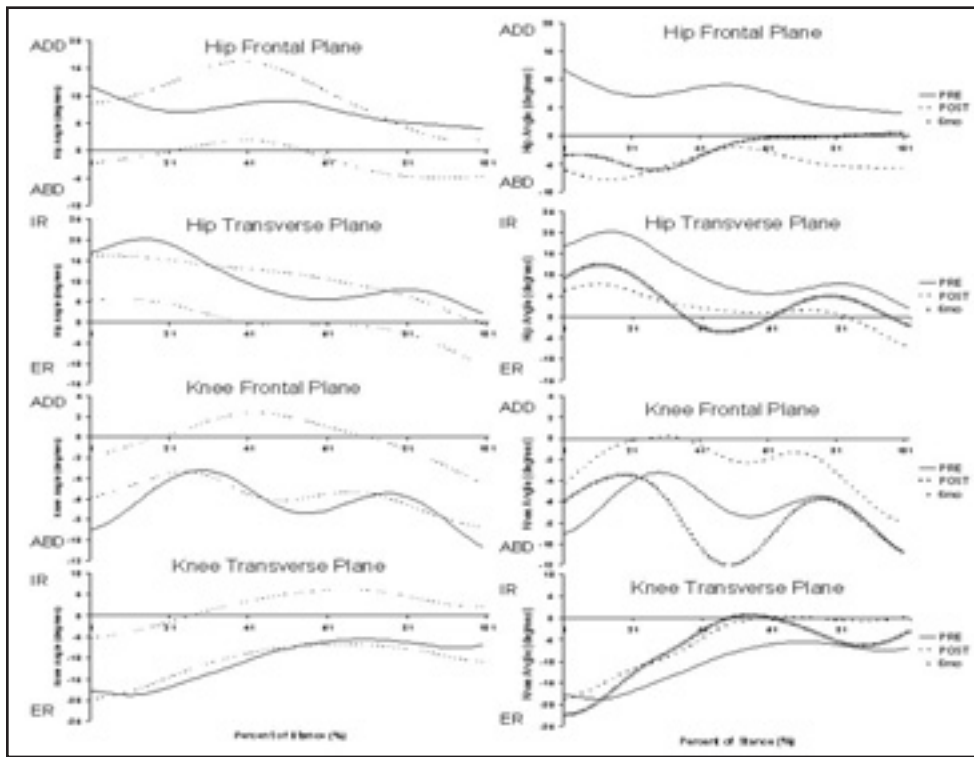


Figure 2. Hip and knee frontal and transverse plane pretraining angular position curves compared to the $\pm 1SD$ of the normative database (left) and compared to post-training and 6 month follow-up (right).

Results of this study clearly suggest that the patterns of running gait can be modified. These modifications led to a resolution of the patient's symptoms. However, she reported that the symptoms would return when she became fatigued and reverted to her old pattern. This further supports the hypothesis that the abnormal mechanics were causing the symptoms. Finally, this case study demonstrates the ability of the runner to maintain these new patterns over a 6-month period.

STUDY 2 Gait Retraining in a Runner with Patellofemoral Pain

The subject was a 46-year-old female runner who had been running for 15 years and had been averaging 15 miles per week. She had recently been training for a marathon when she developed left anterior knee pain, prompting her to seek physical therapy advice. Upon evaluation, it was noted that this runner exhibited weakness of the hip abductors and external rotators (4/5 on a manual muscle test). Upon performing a lateral stepdown, she exhibited excessive knee valgum, hip adduction, and femoral internal rotation. A visual gait analysis during running revealed increased hip adduction and internal rotation, knee valgus,

and rearfoot pronation during stance (Figure 3a). An instrumented gait analysis revealed excessive hip internal rotation. It was hypothesized that this runner's patellofemoral pain was due to an excessively internally rotated femur and would be resolved if her gait mechanics could be altered so that she exhibited greater hip external rotation during stance. Thus, this runner was placed in a gait retraining program consisting of visits twice a week for 10 weeks.

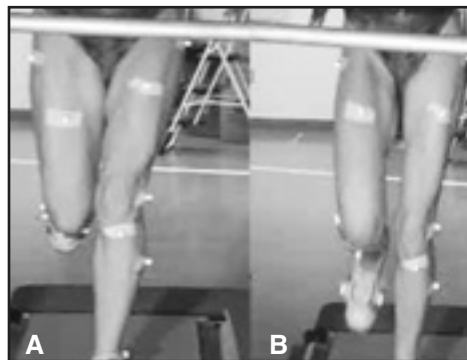


Figure 3. Pre (left) and post (right) training Hip IR. Note the reduction following gait retraining.

A real time motion analysis system was used for this retraining. Retroreflective markers were placed on the left leg. The motion was recorded in real-time with 6 cameras sampling at 120 Hz. The Vicon

370 (Oxford Metrics, UK) 120 Hz 6-camera motion analysis system was used to collect bilateral lower extremity 3D joint kinematic data while the subject ran on a treadmill for 30 minutes (Figure 4). The processed 3D kinematic data collected by the Vicon DataStation were transferred to the Vicon Real-Time Engine which output marker and segment positions and rotations. This information was then on-line transferred to Polygon software where lower extremity segment and marker position data were displayed on a monitor for the subject to observe. Data were only presented during the stance phase of gait by selecting triggers based on heel and toe marker kinematic data. The patient was asked to alter her gait mechanics by shifting the chosen angular curve in the appropriate direction to provide more normal alignment. A real-time display of her hip internal rotation angle was provided as the subject ran on the treadmill at her self-selected pace (Figure 4). The subject was asked to lower her hip internal rotation curve (without altering her foot placement angle).



Figure 4. Subject running on the treadmill with retro-reflective markers placed on her pelvis, thighs, shanks, and feet. A video monitor (right) was provided for real-time feedback.

Over the 10-week training period, the runner was able to reduce her amount of hip internal rotation as she ran. This subject also experienced muscle soreness in her hip abductors and external rotators following training. Again, this soreness resolved over the first 2 weeks of gait retraining. By the 5th week of training, the visual feedback was periodically withdrawn. The patellofemoral pain this runner had experienced was resolved and she was able to reduce the amount of hip internal rotation throughout stance (Figure 3b and 5).

This study demonstrates the effective use of the integrated real-time video feed-

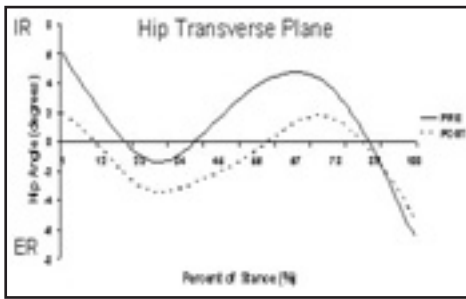


Figure 5. Pre and post-training Hip IR – note the decrease after gait retraining.

back system. The Vicon motion analysis company has just released their first version of their realtime analog feedback system. This will allow us to provide kinetic feedback on variables such as tibial shock, as well as vertical impact peaks measured on the instrumented treadmill.

STUDY 3

Preliminary Study of the Effect of Realtime Feedback During Running on Tibial Shock

The purpose of this preliminary study was to determine whether a runner could reduce their tibial shock while running on a treadmill and receiving a simple real-time feedback display of their shock levels. Four healthy recreational runners (age 25-35 yrs) volunteered to participate in this pilot study. Subjects were all rearfoot strikers without any current lower extremity injuries or conditions that might influence their running mechanics. An accelerometer was attached to their right distal tibia in an anteromedial position. Each subject ran on the treadmill at their own comfortable speed (range 6.0 - 7.0 mph) for 5 minutes. Data were then collected for 5 seconds to establish the subject's baseline values for tibial shock. A monitor, placed in front of the treadmill, then provided a real time visual display of their shock pattern as the subject ran. A horizontal line was placed on the video display at a position that was approximately 50% of each individual's peak shock value. Subjects were instructed to reduce the size of the peaks to below the horizontal target on the screen. They were simply told to try to "run more softly." They were allowed to practice this new pattern with the continuous visual feedback from the tibial shock curve for a period of 5 minutes, after which a second 5-second trial was again collected. The mean peak positive acceleration (tibial shock) was determined over 5 foot

strikes for each trial. A one-tailed paired t-test was used to determine whether tibial shock was reduced following the real time feedback. Based on the preliminary nature of this study, an alpha of $P < 0.10$ was used to determine significance.

Following the 5 minutes of feedback, each participant was able to reduce their mean tibial shock. The group mean reduction was 30%, which was significant at the $P = 0.08$ level (Table 1).

This preliminary study demonstrates that runners are able to reduce the loading of their lower extremity by an average of 30% with a very brief training session. Only one of these subjects exhibited a baseline tibial shock value in the high risk range (> 8.89 g's, which was 1.0 standard deviations above the mean of a healthy reference population of runners). There was a considerably lower range of post retraining values for tibial shock compared to the baseline values. This may indicate that there is a floor effect in the potential for those with a normal or low shock value to reduce their shock further. It is notable that the subject with the highest baseline shock produced the greatest reduction. This suggests that we may see large reductions in our proposed study when using a population of high risk runners.

STUDY 4

Preliminary Study of the Short-Term Retention of Gait Changes Developed during Realtime Feedback to Reduce Tibial Shock

The purpose of this preliminary study was to assess the effect of realtime feedback of tibial shock on both tibial shock and ground reaction forces. Therefore, the study was conducted at the University of Massachusetts where an instrumented treadmill is available. Three healthy recreational runners (age 23-28 yrs) volunteered to participate in this pilot.

An accelerometer was attached to their right distal tibia in an anteromedial position. Subjects ran on a force-measur-

ing instrumented treadmill to monitor concurrent changes in ground reaction force. Each subject ran on the treadmill at their own comfortable speed (range 5.4 - 5.9 mph) for 5 minutes. Data were then collected for 5 seconds to establish the subject's baseline values for tibial shock and ground reaction force. A monitor, placed in front of the treadmill, then provided a real time visual display of their shock pattern as the subject ran. A horizontal line was placed on the video display at a position that was approximately 50% of each individual's peak shock value. Subjects were instructed to reduce the size of the peaks to below the horizontal target on the screen. They were simply told to try to "run more softly." They were allowed to practice this new pattern with the continuous visual feedback from the tibial shock curve for a period of 10 minutes, after which a second 5-second trial was collected. This period of training was followed by a second 10-minute period during which no feedback was provided. The subjects were instructed to continue running in the new way that they had been practicing. No further verbal feedback was given. At the end of this period, a further 5 second trial was collected. The subject then cooled down for 5 minutes. The mean peak positive acceleration (tibial shock) was determined over 5 foot strikes for each trial. The variables considered were peak tibial shock, average vertical loading rate and impact peak. All of these have been associated with tibial stress fracture retrospectively in our previous studies.

Following the 10 minutes of feedback, each participant was able to make a sizeable reduction in their mean tibial shock (Table 2). Average loading rate and impact peak were also reduced.

Following the 10-minute period without feedback, the participants were able to maintain their reduction in tibial shock. Average loading rate and impact peak also remained reduced, compared to baseline values (Table 3).

Table 1. Baseline and Post-training Peak Tibial Shock Values (* $P = 0.08$)

Subject	Normal (g)	Post Training (g)	Reduction (%)
1	4.51 ± 0.89	3.92 ± 0.67	13.22
2	3.71 ± 0.73	3.44 ± 0.43	7.19
3	4.77 ± 0.26	2.64 ± 1.67	44.54
4	9.41 ± 0.48	4.05 ± 1.27	57.00
Mean	5.60 ± 2.58	3.51 ± 0.63*	30.49

Table 2. Baseline and Post-training Peak Tibial Shock Values

Variable	Baseline	Post-training	Reduction (%)
Tibial shock (g)	7.29 ± 1.25	3.83 ± 0.37	47.51
Ave load rate (BW/s)	28.39 ± 3.72	20.05 ± 1.14	29.37
Impact peak (BW)	1.50 ± 0.12	1.11 ± 0.16	25.71

Table 3. Baseline and Maintenance Period Peak Tibial Shock Values

Variable	Baseline	Maintenance	Reduction (%)
Tibial shock (g)	7.29 ± 1.25	3.77 ± 0.17	49.33
Ave load rate (BW/s)	28.39 ± 3.72	21.35 ± 4.39	24.82
Impact peak (BW)	1.50 ± 0.12	1.13 ± 0.25	24.52

This preliminary study demonstrates that runners are able to reduce the loading of their lower extremity by an average of more than 25% with a very brief training session, with a particularly large decrease in tibial shock, the variable used to provide feedback. All of these subjects had baseline values of tibial shock within the normal range and were still able to make large reductions following a brief training period. This effect was maintained in the short-term when feedback was removed, indicating the potential for runners to learn a modified running gait.

STUDY 5

Gait Retraining Case Study of Patient with High Tibial Shock

This subject was a 20-year-old female collegiate runner with a history of multiple overuse injuries of her left lower extremity. Evaluation of her gait mechanics (session 1) revealed high loading variables (especially tibial shock) with the left being greater. This subject lived 2 hours from the university and could not undergo a prolonged course of retraining. However, she was provided verbal instruction in softening her landing while running on a treadmill. She was given the opportunity to practice this technique for approximately 20 minutes during treadmill running. She returned in one year and asked to be reassessed. At that visit, we tested her while running over-ground again (session 2a), provided her with 30 minutes of realtime feedback on her tibial shock during treadmill running and then tested her again (session 2b).

Table 4 and Figure 6 demonstrate the reduction in the magnitude of the loading variables from her baseline to her 1 yr follow-up. In addition, her loading was further reduced with additional feedback training that day. There was a reduction

in all variables with the exception of the impact force, all other variables decreased. This subject now reports being able to run competitively and remain injury-free.

FUTURE DIRECTIONS

While these preliminary and case studies have demonstrated that gait patterns can be changed, there is much work to be done in this area. Research is needed to determine the optimal gait retraining protocols. This includes determining the feedback variables that provide the most effective results. In addition, work needs to be done in optimizing the feedback training schedules. Finally, we need more follow-up studies to determine the permanence of these

gait related changes and their influence on future injury incidence. These are the investigations that we are currently engaged in. It is hoped that by further understanding the etiology of running-related injuries, we can better direct interventions towards minimizing them. In this way, we can help runners remain healthy throughout their lifetime.

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Table 4. Comparison of Loading Variables Across Sessions

Variable	Tibial shock (g)	Fz Impact (bw)	Inst. Load Rate (bw/s)	Av Load Rate (bw/s)
Session 1	11.13	1.8	140.2	128.4
Session 2a	9.5	2.0	93.6	63.2
Session 2b	8.43	1.9	85.9	52.8

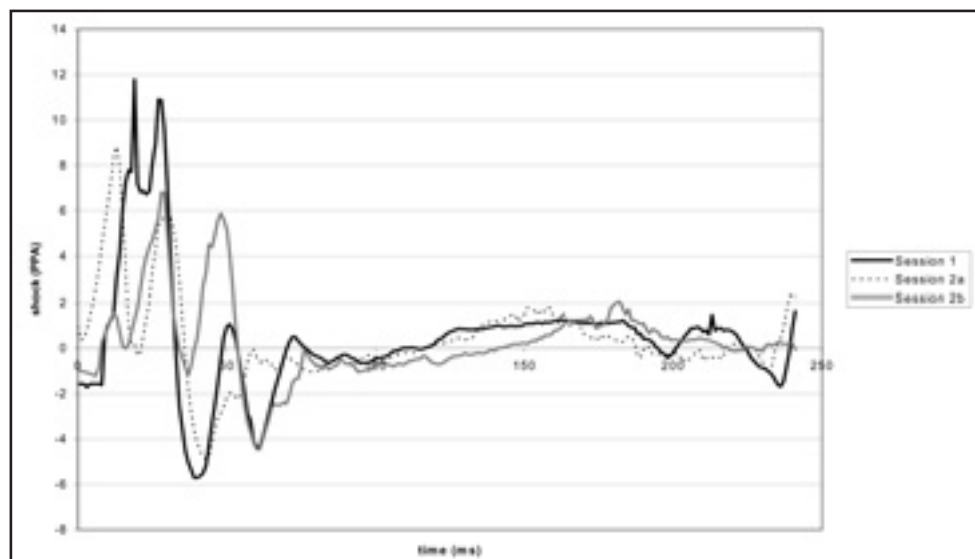


Figure 6. Progressive reduction in peak tibial shock from baseline (session 1) to 1 year follow-up (session 2a) to post-training at the 1 year follow-up.

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