JEREMIAH J. TATE, PT, PhD[1] • CLARE E. MILNER, PhD[2]

Sound-Intensity Feedback During Running Reduces Loading Rates and Impact Peak

The association between lower extremity stress fractures and impact loading variables, such as increases in vertical impact peak (VIP) and vertical average loading rate (VALR), has been well established in the literature.[8,9] A recent prospective study also demonstrated that female runners who received a medical diagnosis of injury, compared to runners with no history of injury, had higher impact variables.[5] The linking of VIP and VALR to running injuries has led to the creation of gait retraining programs aimed at reducing impact loading.[3,12] In a recent systematic review on the effects of gait retraining using augmented feedback, Agresta and Brown[1] concluded that real-time augmented feedback was effective in reducing variables related to impact loading. The authors suggested that gait retraining should be considered as a treatment option for both injured runners and healthy runners who display potentially injurious running mechanics.

STUDY DESIGN: Controlled laboratory study, within-session design.

BACKGROUND: Gait retraining has been proposed as an effective intervention to reduce impact loading in runners at risk of stress fractures. Interventions that can be easily implemented in the clinic are needed.

OBJECTIVE: To assess the immediate effects of sound-intensity feedback related to impact during running on vertical impact peak, peak vertical instantaneous loading rate, and vertical average loading rate.

METHODS: Fourteen healthy, college-aged runners who ran at least 9.7 km/wk participated (4 male, 10 female; mean ± SD age, 23.7 ± 2.0 years; height, 1.67 ± 0.08 m; mass, 60.9 ± 8.7 kg). A decibel meter provided real-time sound-intensity feedback of treadmill running via an iPad application. Participants were asked to reduce the sound intensity of running while receiving continuous feedback for 15 minutes, while running at their self-selected preferred speed. Baseline and follow-up ground reaction force data were collected during overground running at participants' self-selected preferred running speed.

RESULTS: Dependent *t* tests indicated a statistically significant reduction in vertical impact peak (1.56 BW to 1.13 BW, $P \leq .001$), vertical instantaneous loading rate (95.48 BW/s to 62.79 BW/s, $P = .001$), and vertical average loading rate (69.09 BW/s to 43.91 BW/s, $P \leq .001$) after gait retraining, compared to baseline.

CONCLUSION: The results of the current study support the use of sound-intensity feedback during treadmill running to immediately reduce loading rate and impact force. The transfer of within-session reductions in impact peak and loading rates to overground running was demonstrated. Decreases in loading were of comparable magnitude to those observed in other gait retraining methods. *J Orthop Sports Phys Ther 2017;47(8):565-569. Epub 6 Jul 2017. doi:10.2519/jospt.2017.7275*

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The sound intensity (in decibels) of a runner's initial contact with the ground may be a useful form of feedback when attempting to reduce impact loading. Feedback with an external focus of attention (directed at the movement effect) has been shown to enhance motor learning,[13] and sound intensity provides a more external focus for biofeedback than focusing on specific body movement. A recent study by Wernli et al[10] demonstrated that landing sound intensity explained 42% of the variability in the magnitude of the vertical ground reaction force during single-leg drop landings. Running can be considered a series of landings from the flight phase. Thus, the sound intensity related to a runner's impact may also be closely related to ground reaction force variables. Feedback based on subjective clinician interpretation of the sound intensity of a runner's impact has been compared to real-time visual feedback of tibial acceleration during running.[2] Results demonstrated that both forms of feedback led to significant reductions in peak tibial acceleration. With recent advances in technology, mobile devices are now capable of providing accurate external feedback related to the sound intensity of a runner's impact.[7] It remains unknown whether gait retraining involving the

[1]Physical Therapy Department, University of Tennessee at Chattanooga, Chattanooga, TN. [2]Physical Therapy and Rehabilitation Sciences Department, Drexel University, Philadelphia, PA. This study was approved by the Institutional Review Board at the University of Tennessee at Chattanooga on September 18, 2014 (number 14-118). The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article. Address correspondence to Dr Jeremiah J. Tate, Physical Therapy Department, University of Tennessee at Chattanooga, 311 Martin Luther King Boulevard, Department 3253, Room 203, Mapp Building, Chattanooga, TN 37403. E-mail: Jeremiah-Tate@utc.edu

sound intensity of a runner's impact at foot strike, provided visually in real time, could result in a meaningful reduction in impact forces during running.

The aim of this study was to determine whether objective real-time sound-intensity feedback during a single 15-minute session of treadmill running would transfer to reductions in impact loading during overground running. It was hypothesized that impact sound-intensity feedback would result in immediate decreases in VIP, peak vertical instantaneous loading rate (VILR), and VALR during overground running.

METHODS

Participants

Participants were recruited from the student body in the Department of Physical Therapy at the University of Tennessee at Chattanooga and by word of mouth. Each participant met the following criteria: (1) currently running at least 9.7 km/wk, (2) running at least 30 minutes continuously at least once per week, (3) familiarity with treadmill running, (4) no known hearing problems, and (5) no current lower extremity injuries. The study was approved by the University of Tennessee at Chattanooga's Institutional Review Board, and informed consent was obtained from each participant.

Baseline Data Collection

Participants wore their own shorts, T-shirt, and usual running shoes. Participants first performed a 5-minute run on a treadmill (Precor Inc, Woodinville, WA) to serve as a warm-up and to establish their self-selected preferred running speed. Baseline data were then collected for overground running immediately following the warm-up. Participants ran along a 10-m runway, landing with the right foot contacting a 40 × 60-cm force plate (Bertec Corporation, Columbus, OH) sampling at a rate of 1200 Hz and centered in the runway. A timing-device system (Brower Timing Systems, Draper, UT) was centered around the force plate, 4 m apart, to determine running speed. Participants were allowed ample practice to ensure that they were able to maintain their self-selected speed (±5%) while making contact with the middle of the force plate, without altering their stride. Trials in which participants targeted or missed the force plate were discarded. Each participant performed 5 acceptable trials.

Gait Retraining

Immediately after baseline data collection, participants underwent gait retraining via impact sound–intensity feedback on the treadmill, while running at the self-selected speed. While running for 15 minutes, participants continuously received real-time visual feedback of sound intensity (in decibels) on an iPad tablet using the application SPLnFFT Noise Meter, Version 5.2 (Fabien Lefebvre), which presents accurate measurements of sound intensity in decibels on a meter.[7] The iPad was placed on the treadmill's console, with the device's microphone oriented to the right to keep it from being muffled by the console. Participants were instructed to decrease the decibel level as much as possible by trying to run as quietly as possible.

Immediate Retention and Transfer Test

After gait retraining, participants immediately performed 5 more acceptable trials of overground running at the self-selected speed, using the same methods that were used during baseline data collection. Participants were reminded prior to data collection to use the running strategy developed during gait retraining.

Data Analysis

Initial data reduction was performed using Visual3D (C-Motion, Inc, Germantown, MD). Data were filtered at 50 Hz using a Butterworth recursive low-pass filter. A threshold of 20 N in the vertical ground reaction force was used to determine stance phase. The VIP, VILR, and VALR were calculated using a custom LabVIEW program (National Instruments, Austin, TX), following established procedures (**FIGURE 1**), and normalized to body weight.[8] Briefly, the VALR was the slope between 20% and 80% of the peak magnitude during the initial loading

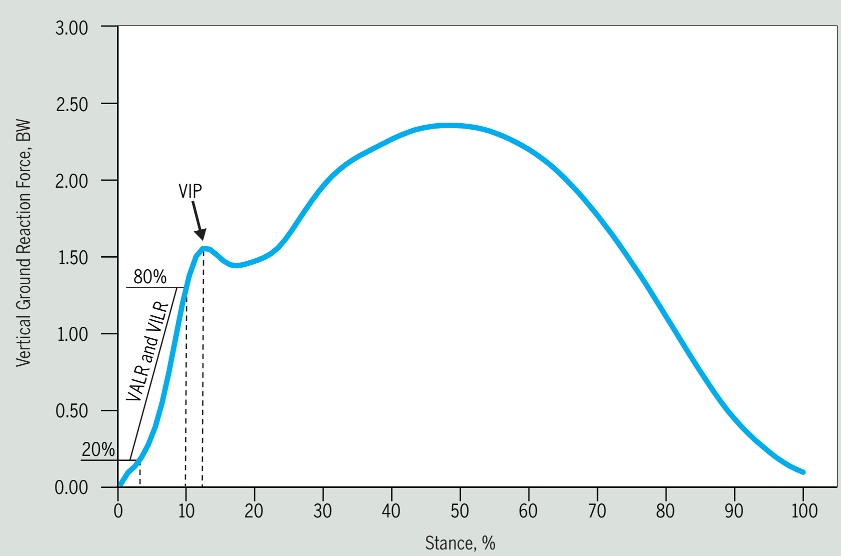

FIGURE 1. Vertical instantaneous loading rate and VALR were calculated between 20% and 80% of the loading period (ie, foot contact to VIP) on the vertical ground reaction force curve, according to established methods (Milner et al[8]). Abbreviations: BW, body weight; VALR, vertical average loading rate; VILR, vertical instantaneous loading rate; VIP, vertical impact peak.

period (from foot strike to VIP) and the VILR was the maximum slope between adjacent data points in the same period. In the absence of a VIP during baseline, 13% of stance phase was used to indicate the end of the initial loading period for determination of the dependent variables.[11] In the absence of a VIP following gait retraining, the same percent of stance that indicated the end of the initial loading during baseline was used. Each dependent variable was calculated for each trial and then averaged across the 5 trials per participant at baseline and during the retention test prior to statistical analysis. A dependent *t* test ($P<.05$) was used to identify any significant differences in these variables following gait retraining. Percent change and effect size were also calculated for each variable. An a priori power analysis ($\alpha = .05$; $\beta = .80$) indicated that a total of 12 participants were needed to detect a change (effect size, 0.8) in impact loading variables from baseline to after gait retraining (G*Power 3.1.5).[6]

RESULTS

Fourteen participants were included (4 male, 10 female). The average ± SD age, height, mass, weekly running distance, and preferred running speed were 23.7 ± 2.0 years, 1.67 ± 0.08 m, 60.9 ± 8.7 kg, 18.7 ± 13.8 km/wk, and 2.96 ± 0.24 m/s, respectively. Statistically significant reductions in VIP, VILR, and VALR were observed after gait retraining (**TABLE**). Review of individual data indicated that 11 of 14 (79%) participants reduced their VIP, VILR, and VALR by 20% or more, whereas 3 participants were unable to achieve similar reductions. Additionally, 11 of 14 (79%) participants demonstrated a VIP prior to gait retraining. In 6 of these 11 participants, the VIP was no longer present following gait retraining (**FIGURES 2A** and **2B**).

DISCUSSION

The purpose of this study was to determine the effects of sound-intensity feedback on impact loading variables in runners. The majority (79%) of our participants were able to reduce each impact variable by at least 20%, indicating that impact variables associated with running injuries can be reduced with a single session of sound-intensity feedback. The results of this proof-of-concept study support further exploration of this approach as a clinically applicable method of reducing loading variables during running.

Our feedback paradigm advances the work of Creaby and Franettovich Smith,[2] in which verbal feedback was provided based on the clinician's subjective interpretation of the sound intensity of impact. Our approach used an objective measure of sound intensity via a decibel meter to provide real-time visual feedback independent of the clinician. Our approach may provide more consistent feedback to the runner than clinician-based subjective feedback. Unfortunately, the results of our study cannot be directly compared to those of Creaby and Franettovich Smith,[2] due to different outcome variables. In their study, peak tibial acceleration was the main outcome variable, and reductions of 24% to 28% were achieved within session. In our study, we demonstrated slightly higher reductions of 28% to 36% in VIP, VILR, and VALR.

The immediate reductions in impact loading variables reported here are comparable to those achieved using more advanced equipment. A 2-week gait retraining program focused on reducing peak tibial acceleration led to reductions in VIP of 19% and in VILR and VALR of 34% and 32%, respectively.[3] Our approach led to a larger reduction of 28% in VIP and similar reductions of 34% and 36% in VILR and VALR. Our method does not require specialized equipment and, therefore, may be more clinically applicable than the methods of Crowell et al.[4] Our method would also allow runners with access to a treadmill to self-manage their retraining after an initial orientation to the protocol.

Sound-intensity feedback may enable runners to experiment with different running mechanics (eg, foot-strike pattern, lower extremity compliance, etc) to decrease the sound intensity of their impact. Other gait retraining methods have specifically aimed at increasing cadence. Willy et al[12] studied the effects of increasing cadence 7.5% in efforts to lead to gait modifications that would lessen loading rates. Following a 2-week gait retraining program, VILR and VALR were reduced by 19% and 18%, respectively. While not tested over an extended period, our method produced greater initial percent changes and may allow runners the freedom to select a gait modification that best suits them.

As is typical in the initial reporting of new approaches, this proof-of-concept study was limited to immediate responses to feedback during a single session. Following the immediate reductions demonstrated in this study, future work is needed to determine whether the

TABLE Loading Variables at Baseline and After Gait Retraining*

Variable	Baseline	After Gait Retraining	*P* Value	Change, %	Effect Size
VIP, BW	1.56 ± 0.31	1.13 ± 0.34	<.001†	–28	1.33
VILR, BW/s	95.48 ± 27.41	62.79 ± 22.35	.001†	–34	1.31
VALR, BW/s	69.09 ± 20.15	43.91 ± 16.14	<.001†	–36	1.39

Abbreviations: BW, body weight; VALR, vertical average loading rate; VILR, vertical instantaneous loading rate; VIP, vertical impact peak.
**Values are mean ± SD unless otherwise indicated.*
†P<.05.

changes can be retained in the long term with additional training. Future studies should include a comparison group that receives the same verbal instructions, without sound-intensity feedback, to determine the effects of verbal instruction alone. This design would determine the additional benefit of augmented feedback over simple verbal instruction. Kinematic and spatiotemporal analyses would also indicate how participants augmented their running gait to achieve these reductions. Additionally, a true control group would indicate whether fatigue contributed to the reductions seen in our study. However, running for 15 minutes during gait retraining and short overground trials with frequent breaks minimized the risk of fatigue. While reductions in loading variables were noted, the short 10-m runway may have impacted the runner's ability to achieve a steady state prior to contact with the force plate. Replication of this study with a longer bout of overground running would confirm that the reductions in loading remain during steady-state running. The current application of this gait retraining method is also limited to healthy runners. It is unknown whether runners who are experiencing pain or recently returning to running after injury could achieve similar reductions. It should be noted that our participants' average VILR was 95.48 BW/s at baseline and that 11 of 14 participants' VILRs were above the 85-BW/s threshold that has been used by previous investigators to denote high-impact runners.[12] Therefore, the majority of our participants could be considered candidates for gait retraining to reduce impact loading. Finally, our participants represent recreational runners in terms of running speed and volume of training. Therefore, caution should be exercised in applying these results to those who run faster or have higher training volumes.

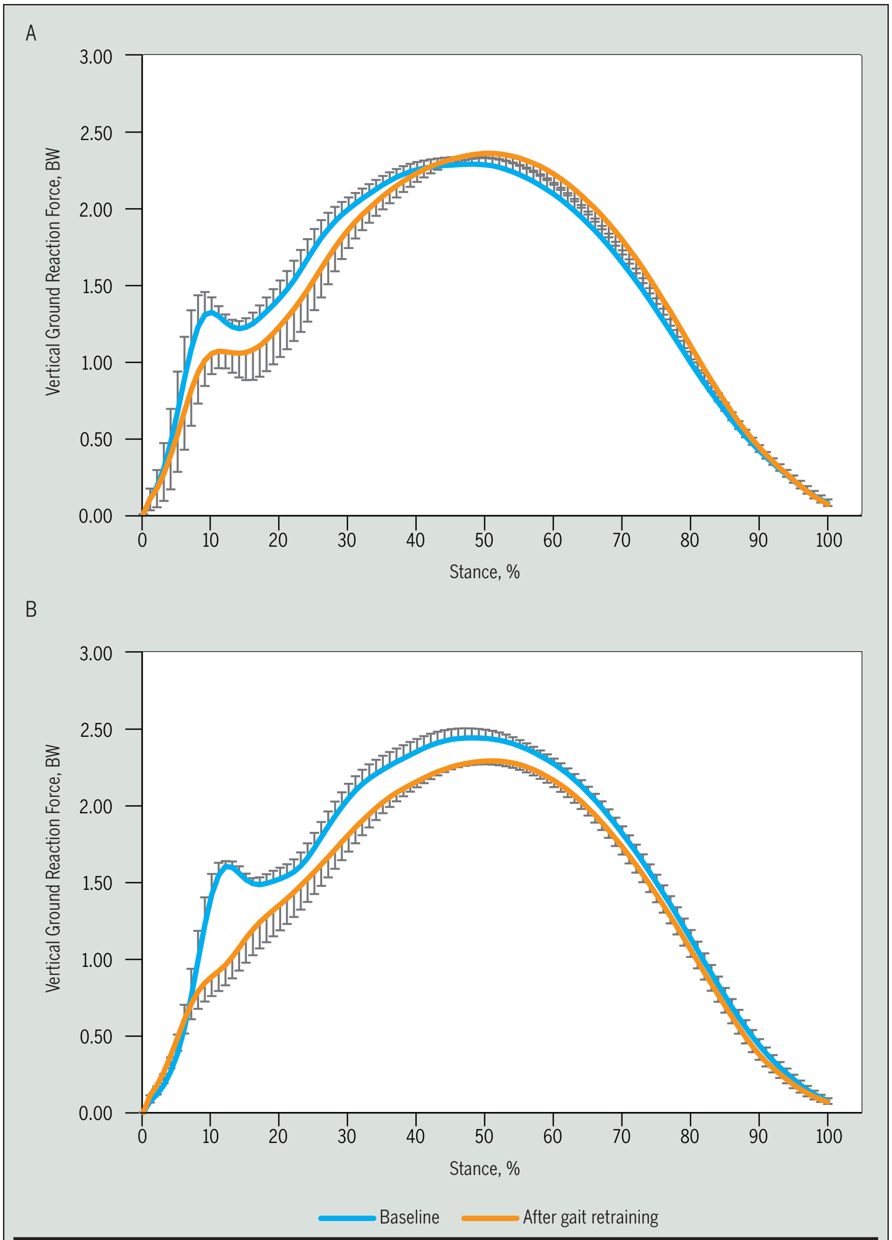

FIGURE 2. Representative vertical ground reaction force curves (mean ± SD) of (A) a participant with a VIP following gait retraining, and (B) a participant without a VIP following gait retraining. Values are ensemble averages of 5 trials by the participant. Abbreviation: BW, body weight; VIP, vertical impact peak.

CONCLUSION

The VIP, VILR, and VALR were reduced significantly following 15 minutes of objective real-time sound-intensity feedback related to foot strike using a decibel meter during treadmill running. About 80% of runners were able to achieve an immediate reduction of 20% or more in all 3 variables. Thus, objective decibel-meter feedback of sound intensity provided via personal portable devices may provide clinicians with a simple way to provide gait retraining to runners. In particular, those at risk of tibial stress fracture due to high-impact loading may benefit. Further work is needed to determine the long-term effects of this approach in return to sport following injury or as a preventative measure in runners who exhibit high-impact loading rates.

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