Effect of Cushioned Insoles on Impact Forces During Running

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Background: The use of cushioned or shock-absorbing insoles has been suggested as a mechanism to reduce the impact forces associated with running, thereby protecting against overuse injuries. The purpose of this study was to determine whether the use of cushioned insoles reduced impact forces during running in healthy subjects.

Methods: Sixteen recreational runners (9 females and 7 males) ran at a self-selected pace for five trials with and without the use of cushioned insoles. During each trial, ground reaction forces, tibial accelerations, lower-extremity kinematics, and subject-perceived comfort were recorded. All variables were tested with the level of statistical significance set at $\alpha = .05$.

Results: The use of cushioned insoles resulted in significant reductions in mean vertical ground reaction force peak impact (6.8%) and ground reaction force loading rate (8.3%), as well as peak tibial acceleration (15.8%). Spectral analysis of the tibial acceleration data in the frequency range associated with impact accelerations (12–25 Hz) revealed no change in the predominant frequency or the power of the predominant frequency. The knee flexion angle at initial contact and perceived comfort were similar for the two conditions.

Conclusions: This study demonstrates the effectiveness of one type of cushioned insole in reducing peak impact force and tibial acceleration at initial foot-ground contact during running. The impact reduction observed was independent of knee kinematic adjustments or changes in perceived comfort. Further study is required to determine whether the reduction in loading that accompanied the use of the cushioned insoles can affect the incidence of running-related injuries. (J Am Podiatr Med Assoc 98(1): 36-41, 2008)

During running, loads equaling 1.5 to 5 times body weight are repetitively absorbed through each leg.[1] It has been suggested that this repetitive loading and associated impact shocks cause microtrauma to the underlying tissues and may eventually cause enough damage to impair function.[2, 3] Some common overuse injuries resulting from this repeated microtrauma include stress fractures, shin splints, and plantar fasciitis.[2, 3] The use of cushioned or shock-absorbing insoles has been suggested as a mechanism to reduce the impact forces associated with running, thereby protecting against these overuse injuries.[4]

Some investigations have found that the use of cushioned insoles reduces the risk of stress fractures and overuse injuries,[5-7] while other research has shown no protective effect.[8, 9] In the studies by Schwellnus et al[5] and Mundermann et al,[7] shoe inserts were found to decrease the frequency of overall injuries during military training. Shock-absorption measurements were not included, however, so the mechanism of injury prevention remains unclear. The use of cushioned insoles remains a promising protective intervention for lower-extremity overuse injuries but requires further investigation.[7, 10, 11]

Controversy exists regarding the effectiveness of cushioned insoles in reducing impact loading and lower-extremity accelerations associated with foot-ground contact. Reduced vertical impact force, tibial accelerations, and plantar pressures at heel strike have been observed with the use of cushioned in-

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soles during running compared with no insole.[12-14] Other authors, however, have found no reduction in impact force during running with the use of cushioned insoles.[4, 15] This discrepancy in findings may be partially explained by kinematic adjustments made by the runner. Specifically, increased knee flexion angle at foot-ground contact can reduce running-related impacts. Additionally, kinematic adjustments during running in response to the presence of an insole have been correlated with the perceived comfort of the insole.[16] The interaction of cushioned insoles, perceived comfort, and knee kinematic adjustments has not been well described.

The purpose of this study was to determine whether the use of cushioned insoles significantly reduced impact forces during preferred-speed running in healthy subjects. Additionally, knee kinematic adjustments and perceived comfort scores were assessed as subjects ran both with and without cushioned insoles.

Methods

Subject Selection

Sixteen healthy individuals (7 males and 9 females) were recruited from the University of Wisconsin–Madison community. Subject age ranged from 20 to 36 years, the mean height was 1.73 ± 0.09 m, and the mean mass was 68.4 ± 12.0 kg. All subjects were self-described recreational runners and were screened before study participation with the following exclusion criteria: lower-extremity injury in the past 6 months; history of hip, knee, or ankle surgery; lower-extremity or back pain during running; and significant cardiovascular, pulmonary, or neurologic impairment limiting the ability to run comfortably at a self-selected pace. The protocol was reviewed and approved by the University of Wisconsin Health Sciences Institutional Review Board, with all subjects providing written consent to participate in the investigation. The sample size estimation was performed for a pair-wise comparison using a desired power of 80% at $\alpha = .05$, based on published effect sizes concerning these dependent variables under related conditions.[17]

Procedures

Subjects ran 15 m at their preferred speed (mean, 3.2 ± 0.3 m/sec) on level ground while wearing a standardized running shoe (model M635 or W630; New Balance Athletic Shoe, Inc, Boston, Massachusetts). Subjects performed five running trials with the running shoe only and five trials with the running shoe and a cushioned insole (SorboAir; Sorbothane, Inc, Kent, Ohio). The sock liner of the shoe remained in place for the shoe-only condition but was removed when the cushioned insole was added. This insole is constructed of gray polyurethane foam molded into the shape of a footbed (6 mm thick at the center of the heel and 3 mm thick at the forefoot) with a textured Poron (Rogers Corp, Rogers, Connecticut) foam top cover (1.5 mm thick), and is available commercially. The insole mass was 62.4 g (2.2 oz) for men's size 9.5 to 10.5 (women's size 12). The viscoelastic properties of Sorbothane have been previously tested and described.[18]

The order of the running conditions was randomized across subjects, with each subject allowed several practice runs to accommodate to the fit of the shoe with and without the insole. The velocity of a reflective marker located on the sacrum was used to monitor running speed; only trials within 5% of each subject's preferred speed were accepted. To prevent targeting, subjects were not aware that the right foot needed to contact a force plate. The running assessment continued until five trials were obtained in each condition that met the above-mentioned criteria for speed and foot placement. Immediately after each condition, subjects indicated their perceived overall comfort during running using a 10-cm visual analog scale, with 0 being least comfortable and 10 being most comfortable.[19]

Bilateral lower-extremity kinematics were recorded at 200 Hz with an optical, passive marker motion-capture system (Motion Analysis Corp, Santa Rosa, California) that tracked the three-dimensional positions of 31 reflective markers, with 17 located on palpable anatomical landmarks. The remaining markers were fixed to a polypropylene shell and secured to the lateral aspect of each thigh and shank. In addition, ground reaction forces and right tibial vertical accelerations were synchronously recorded at 2,000 Hz. Ground reaction forces were measured by one of two force plates (model BP400600; AMTI, Watertown, Massachusetts) positioned flush with the runway. A uniaxial accelerometer (model U353B16; PCB Piezotronics, Inc, Depew, New York) with signal conditioner (model 480E09 ICD; gain = 10) was used to measure tibial accelerations. The accelerometer was secured to the distal anteromedial surface of the right tibia and aligned with its longitudinal axis. Coban self-adherent wrap (3M, St. Paul, Minnesota) and athletic tape were tightly wrapped around the accelerometer and lower leg to minimize skin movement artifact.

Data Reduction

Kinematic and kinetic analyses were limited to the right leg, because only right tibial accelerations were recorded. Vertical ground reaction force data were low-pass filtered at 100 Hz with a bidirectional fourth-order Butterworth filter. Foot-ground contact was determined at a vertical ground reaction force threshold of 10 N. Impact peak was identified from the first peak of the vertical ground reaction force. Impact loading rate was calculated from the slope of the vertical ground reaction force from foot-ground contact to the impact peak.

Before analysis, the average tibial acceleration value and any linear trend from the signal were removed.[20] Tibial accelerations were low-pass filtered at 100 Hz with a bidirectional fourth-order Butterworth filter. The magnitude and timing (relative to foot-ground contact) of peak positive acceleration were determined. A frequency analysis of the tibial acceleration signal was conducted with a fast Fourier transformation. As the frequencies associated with impact accelerations range from 12 to 25 Hz, the predominant frequency of the acceleration signal and the power of the predominant frequency within this range were determined.[20-22]

Kinematic marker coordinate data were low-pass filtered at 9 Hz with a bidirectional fourth-order Butterworth filter. Three-dimensional joint angles were calculated with a scaled 6-*df* musculoskeletal model (Visual3D; C-Motion, Rockville, Maryland). Knee flexion angle at foot-ground contact was recorded.

Statistical Analysis

Differences in knee flexion angle at initial contact, peak tibial acceleration, peak vertical ground reaction force impact, and vertical ground reaction force loading rate between the two conditions were determined with paired *t* tests. A paired *t* test was also used to compare the predominant frequency and the power of the predominant frequency of the tibial acceleration signal. Perceived comfort scores were compared for the two conditions with a Wilcoxon signed rank test. The level of statistical significance for all tests was set at $\alpha = .05$. In addition, effect sizes (Cohen's *d*) were calculated for all statistically significant variables to help determine the clinical significance of the difference.

Results

Vertical Ground Reaction Force Impact

The use of the cushioned insoles during running significantly reduced the mean vertical ground reaction force peak impact (6.8%; $P = .004$; Cohen's $d = 0.29$) compared with the shoe-only condition (Table 1, Fig. 1). The mean vertical ground reaction force loading rate was also significantly lower with the cushioned insole (8.3%; $P = .005$; Cohen's $d = 0.46$).

Tibial Accelerations

The mean peak tibial acceleration was significantly reduced (15.8%; $P < .001$; Cohen's $d = 0.48$) when the cushioned insoles were used (Table 1, Fig. 1). The time to peak tibial acceleration following foot-ground contact was similar for the two conditions ($P = .052$). Within the 12 to 25 Hz band, the use of the cushioned insoles did not change the predominant frequency ($P = .603$) or its power ($P = .866$).

Knee Angle at Initial Contact and Perceived Comfort

Despite the reductions in vertical ground reaction force impacts and tibial accelerations, the knee flexion angle at initial foot-ground contact was similar for the two conditions ($P = .290$). The subjects' perceived comfort during running without insoles (7.2 ± 1.1) did not change significantly ($P = .717$) when the cushioned insoles were used (6.8 ± 2.4).

Discussion

Vertical ground reaction force peak impact and loading rate, as well as peak tibial acceleration, decreased significantly with the use of cushioned insoles. The shock-attenuation effect of the cushioned insoles was not accompanied by a change in knee flexion angle at initial foot-ground contact or subject perception of comfort. Frequency analysis of the foot-ground contact impulse wave component (12–25 Hz)[20, 23] of the tibial acceleration signal did not reveal any change in the predominant frequency or its magnitude between the two running conditions. Although the predominant frequencies and magnitudes observed in our study are consistent with values reported in the literature,[20, 21] the reduction in peak tibial acceleration observed in the time domain did not influence the predominant frequency characteristics.

The moderate effect sizes observed with the vertical ground reaction force loading rate and peak tibial acceleration suggest that the observed reduction in each variable that occurred with the use of cushioned insoles may be of clinical significance. Similar effect sizes were observed in a comparison of the loading rates and tibial accelerations of female runners with and without a history of tibial stress fractures.[3] The authors concluded that a history of tibial stress fractures was associated with higher loading rate and

Table 1. Vertical Ground Reaction Force Peak Impact and Loading Rate, Tibial Acceleration, and Knee Flexion Angle at Foot-Ground Contact With and Without Insoles

Variable	Without Insoles		With Insoles		*t*	*P* Value
Vertical GRF impact						
Peak impact (%BW)	1.32	(0.30)	1.23	(0.32)	–3.34	.004
Loading rate (%BW/sec)	40.9	(6.6)	37.5	(8.0)	–3.26	.005
Tibial acceleration						
Peak (g)	4.81	(1.45)	4.05	(1.69)	–4.28	<.001
Time to peak (ms)	29.7	(5.7)	30.9	(5.7)	2.11	.052
Predominant frequency (Hz)	15.4	(2.0)	15.7	(2.9)	0.53	.603
Power of predominant frequency (g^2/Hz)	0.114	(0.046)	0.112	(0.031)	–0.17	.866
Knee flexion angle at foot-ground contact (°)	15.6	(7.9)	15.1	(7.6)	–1.10	.290

Abbreviations: GRF, ground reaction force; %BW, percentage of body weight.

Notes: Timing variables are calculated relative to foot-ground contact. Variables were compared between conditions using a paired *t* test (α = .05). Values are given as mean (SD).

greater tibial accelerations. The observed reduction in loading secondary to the use of cushioned insoles in this study is comparable to the differences observed between runners with and without a history of tibial stress fracture.

Our results are in agreement with the reported decrease in loading with the use of cushioned insoles during walking[12, 13] and running.[14] The magnitude of this effect, however, appears to be material-specific, as Windle et al[14] demonstrated that Sorbothane caused a

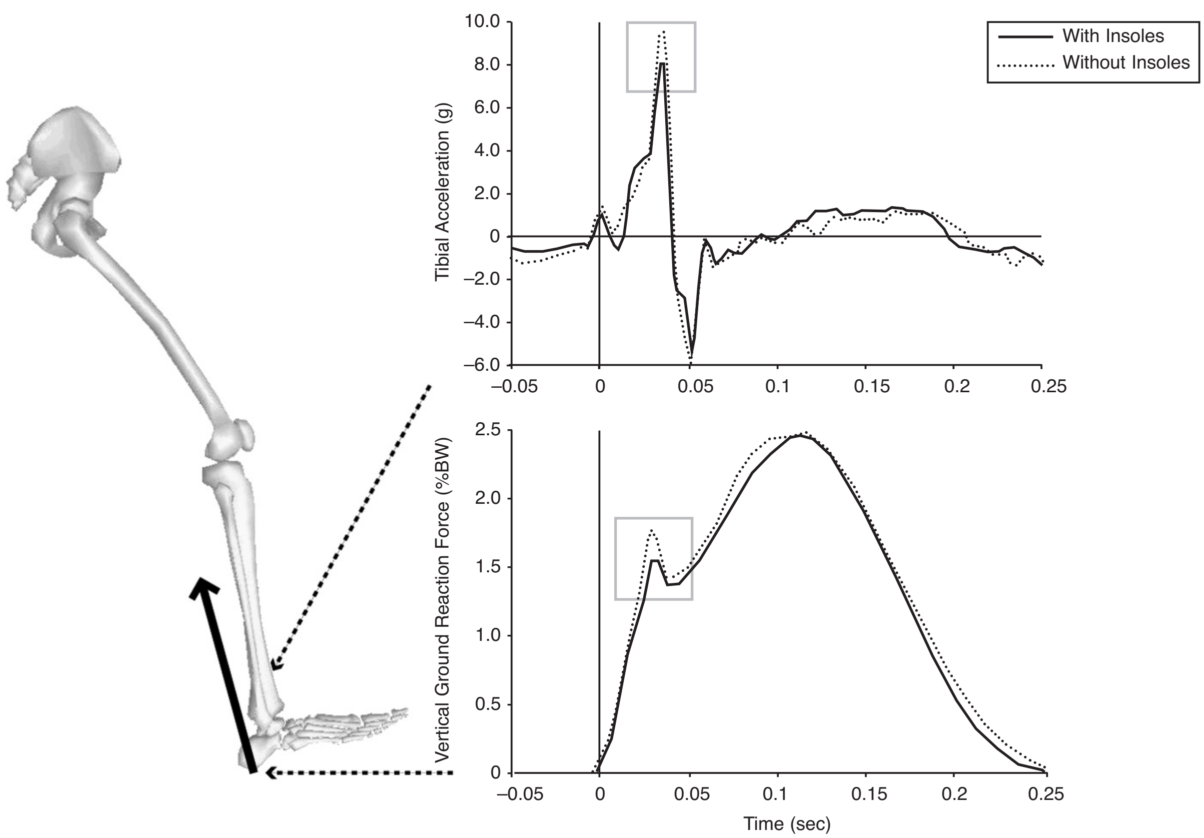

Figure 1. Tibial accelerations and vertical ground reaction force impacts of a representative subject during the stance phase of running with and without insoles. The peak values are boxed. Foot-ground contact occurs at 0 sec (vertical line). Knee flexion angle at contact (depicted at left) was similar for the two conditions. %BW indicates percentage of body weight.

greater reduction in peak heel and forefoot pressures than did other insoles classified as shock-absorbing (eg, Cambion, [Magister Corporation, Chattanooga, Tennessee], PPT, [Langer, Inc, Deer Park, New York], and saran [Asahi Kasei Chemicals, Inc, Tokyo, Japan]). Similarly, Dixon et al[24] reported a difference in the effectiveness of four different cushioned insoles in reducing vertical ground reaction force impacts and loading rate. The insole constructed of polyurethane foam with an ethyl vinyl acetate (EVA) heel cup resulted in a greater reduction in loading rate than either Saran insoles or insoles constructed only of polyurethane. Interestingly, 3-mm-thick insoles and 6-mm-thick insoles were found to have similar impact-attenuating properties.[25]

The consistent knee flexion angles between test conditions suggest that the reduced shock that occurred with the use of cushioned insoles was not a result of altered knee kinematics. Increased knee flexion angle at initial foot-ground contact has been shown to decrease the effective mass and ground reaction force impact while increasing tibial acceleration.[26] Although such kinematic adjustments have been observed under fatiguing conditions as a potential impact-controlling mechanism,[22] the addition of cushioned insoles did not appear to necessitate changes in knee flexion angle at initial contact. Thus it is likely that the observed reductions in vertical ground reaction force impact and tibial acceleration are due to the energy-absorbing properties of the cushioned insoles.[18]

Our study investigated the immediate shock-attenuation abilities of new cushioned insoles. The material degradation that occurs with regular use may influence the insoles' effectiveness. A previous study found that insoles constructed only of polyurethane foam underwent a significant deterioration in shock-absorbing ability after a few weeks of daily walking.[27] Another study, however, found that cushioned insoles made of polyeurethane foam with an EVA heel cup maintained their shock-attenuation abilities throughout 18 weeks of military training.[25] In addition to material property changes with continued wear, kinematic adjustments by the runner may also occur during the initial period of use. Although our results did not reveal any changes in knee flexion angle at foot-ground contact with the use of cushioned insoles, such changes may not appear before several hours or days of use.

Our study supports the use of cushioned insoles to reduce impact forces during running; their ability to reduce running-related injuries, however, remains in question. The use of shock-absorbent neoprene insoles among a cohort of military recruits was found to reduce the incidence of overuse and traumatic injuries compared with a control group, but the reduction was not statistically significant.[5] In addition, two randomized controlled trials that investigated the injury-reducing ability of Sorbothane during military training found no reduction in lower-limb injury rates (specifically bone stress reactions) among recruits.[8, 9] Recent investigations have highlighted the importance of comfort and fit of insoles in preventing injury.[7, 16] When recruits used the shoe insert they found most comfortable, the incidence of foot stress fractures was reduced by 13.4% compared with recruits who used no insert.[7] We are unaware of any randomized controlled trials that have assessed the effectiveness of cushioned insoles for injury prevention in a nonmilitary population. Despite the controversy that remains regarding the effectiveness of such insoles in reducing running-related injuries, two recent systematic reviews concluded that cushioned insoles show promise for reducing the incidence of shin splints[10] and stress fractures.[11]

Conclusion

The use of cushioned insoles during running resulted in significant reductions in mean vertical ground reaction force peak impact and loading rate, as well as peak tibial acceleration. Knee flexion angle at initial foot-ground contact and perceived comfort ratings were not significantly altered with the use of insoles, which indicates that the reduction in impact forces was not a result of kinematic adjustments or perceived comfort. The reduction in both the magnitude and rate of loading for the kinetic parameters achieved with over-the-counter cushioned insoles makes them a promising injury-prevention modality. Further studies should investigate the use of cushioned insoles for injury prevention and performance enhancement in a nonmilitary population.

Acknowledgments: Zach Barber for assistance with data collection and analysis; New Balance Athletic Shoe, Inc, Boston, Massachusetts, for donation of shoes used in the study; and Sorbothane, Inc, Kent, Ohio, for donation of insoles used in the study.

Financial Disclosures: This study was supported by the Graduate and Medical Schools of the University of Wisconsin–Madison.

Conflict of Interest: None reported.

References

1. Hreljac A: Impact and overuse injuries in runners. Med Sci Sports Exerc **36:** 845, 2004.
2. James SL, Bates BT, Osternig LR: Injuries to runners.

Am J Sports Med **6:** 40, 1978.
3. Milner CE, Ferber R, Pollard CD, et al: Biomechanical factors associated with tibial stress fracture in female runners. Med Sci Sports Exerc **38:** 323, 2006.
4. Nigg BM, Herzog W, Read LJ: Effect of viscoelastic shoe insoles on vertical impact forces in heel-toe running. Am J Sports Med **16:** 70, 1988.
5. Schwellnus MP, Jordaan G, Noakes TD: Prevention of common overuse injuries by the use of shock absorbing insoles: a prospective study. Am J Sports Med **18:** 636, 1990.
6. Milgrom C, Finestone A, Shlamkovitch N, et al: Prevention of overuse injuries of the foot by improved shoe shock attenuation: a randomized prospective study. Clin Orthop Relat Res **281:** 189, 1992.
7. Mundermann A, Stefanyshyn DJ, Nigg BM: Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. Med Sci Sports Exerc **33:** 1939, 2001.
8. Gardner LI, Jr, Dziados JE, Jones BH, et al: Prevention of lower extremity stress fractures: a controlled trial of a shock absorbent insole. Am J Public Health **78:** 1563, 1988.
9. Withnall R, Eastaugh J, Freemantle N: Do shock absorbing insoles in recruits undertaking high levels of physical activity reduce lower limb injury? a randomized controlled trial. J R Soc Med **99:** 32, 2006.
10. Thacker SB, Gilchrist J, Stroup DF, et al: The prevention of shin splints in sports: a systematic review of literature. Med Sci Sports Exerc **34:** 32, 2002.
11. Jones BH, Thacker SB, Gilchrist J, et al: Prevention of lower extremity stress fractures in athletes and soldiers: a systematic review. Epidemiol Rev **24:** 228, 2002.
12. Shiba N, Kitaoka HB, Cahalan TD, et al: Shock-absorbing effect of shoe insert materials commonly used in management of lower extremity disorders. Clin Orthop Relat Res **310:** 130, 1995.
13. Johnson GR: The effectiveness of shock-absorbing insoles during normal walking. Prosthet Orthot Int **12:** 91, 1988.
14. Windle CM, Gregory SM, Dixon SJ: The shock attenuation characteristics of four different insoles when worn in a military boot during running and marching. Gait Posture **9:** 31, 1999.
15. Butler RJ, Davis IM, Laughton CM, et al: Dual-function foot orthosis: effect on shock and control of rearfoot motion. Foot Ankle Int **24:** 410, 2003.
16. Mundermann A, Nigg BM, Humble RN, et al: Orthotic comfort is related to kinematics, kinetics, and EMG in recreational runners. Med Sci Sports Exerc **35:** 1710, 2003.
17. Laughton CA, Davis IM, Hamill J: Effect of strike pattern and orthotic intervention on tibial shock during running. J Appl Biomech **19:** 163, 2003.
18. Cinats J, Reid DC, Haddow JB: A biomechanical evaluation of sorbothane. Clin Orthop Relat Res **222:** 281, 1987.
19. Miller JE, Nigg BM, Liu W, et al: Influence of foot, leg and shoe characteristics on subjective comfort. Foot Ankle Int **21:** 759, 2000.
20. Shorten MR, Winslow DS: Spectral analysis of impact shock during running. Int J Sport Biomech **8:** 288, 1992.
21. Yingling VR, Yack HJ, White SC: The effect of rearfoot motion on attenuation of the impulse wave at impact during running. J Appl Biomech **12:** 313, 1996.
22. Derrick TR, Dereu D, McLean SP: Impacts and kinematic adjustments during an exhaustive run. Med Sci Sports Exerc **34:** 998, 2002.
23. Lafortune MA, Henning E, Valiant GA: Tibial shock measured with bone and skin mounted transducers. J Biomech **28:** 989, 1995.
24. Dixon SJ, Waterworth C, Smith CV, et al: Biomechanical analysis of running in military boots with new and degraded insoles. Med Sci Sports Exerc **35:** 472, 2003.
25. House CM, Dixon SJ, Allsopp AJ: User trial and insulation tests to determine whether shock-absorbing insoles are suitable for use by military recruits during training. Mil Med **169:** 741, 2004.
26. Derrick TR: The effects of knee contact angle on impact forces and accelerations. Med Sci Sports Exerc **36:** 832, 2004.
27. Pratt DJ: Medium term comparison of shock attenuating insoles using a spectral analysis technique. J Biomed Eng **10:** 426, 1988.