EFFECTS OF MIDSOLE HARDNESS AND INSOLE MATERIALS ON SHOCK ABSORPTION IN PROTECTIVE BOOTS

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ABSTRACT. This study aimed to determine the influence of varying midsole hardness and insole materials on cushioning performance of protective boots. Twenty healthy male participants performed running tests with six conditions of protective boots, varying in midsole hardness (50 shore C-soft, 60 shore C-medium, 70 shore C-hard) and insole material (Thermoplastic Polyurethane, Polyurethane). The first peak vertical ground reaction force (1st PVGRF), impact duration (ID), and average vertical loading rate (AVLR) were measured by a force plate. The subjective cushioning evaluation was also conducted using a visual analogue scale. The results showed that midsole hardness had a significant effect on ID ($P = 0.048$, $\eta^2_p = 0.151$) and AVLR ($P = 0.048$, $\eta^2_p = 0.301$) but not on 1st PVGRF ($P = 0.222$, $\eta^2_p = 0.076$). The ID was longer and the AVLR was lower for hard shoes compared to soft shoes. Insole materials had no significant effect on any of the impact variables ($P > 0.05$). Subjective evaluations indicated that the medium-hardness shoes received the highest cushioning scores among the three hardness levels. The findings suggest that midsole hardness influences impact duration and loading rate, while insole materials do not significantly affect the shock absorption performance of protective boots.

KEY WORDS: protective boots, midsole hardness, insole material, shock absorption

INFLUENȚA DURITĂȚII TĂLPII INTERMEDIARE ȘI A MATERIALELOR PENTRU BRANȚURI ASUPRA CAPACITĂȚII CIZMELOR DE PROTECȚIE DE A ABSORBI ȘOCURILE

REZUMAT. Obiectivul acestui studiu a fost de a determina influența diferitelor durități ale tălpii intermediare și a materialelor pentru branțuri asupra capacității de amortizare a cizmelor de protecție. Douăzeci de bărbați sănătoși au efectuat teste de alergare cu cizme de protecție în șase condiții diferite, variind duritatea tălpii intermediare (50 shore C-moale, 60 shore C-mediu, 70 shore C-dur) și materialul branțului (poliuretan termoplastic, poliuretan). Cu ajutorul unei plăci de presiune s-au măsurat primul vârf al forței verticale de reacție a solului (primul PVGRF), durata impactului (ID) și rata medie de încărcare verticală (AVLR). Evaluarea subiectivă a amortizării a fost, de asemenea, efectuată folosind scala analog vizuală. Rezultatele au arătat că duritatea tălpii intermediare a avut un efect semnificativ asupra ID ($P = 0,048$, $\eta^2p = 0,151$) și AVLR ($P = 0,048$, $\eta^2p = 0,301$), dar nu și asupra primului PVGRF ($P = 0,222$, $\eta^2p = 0,076$). Durata impactului a fost mai lungă, iar rata medie de încărcare verticală a fost mai mică pentru pantofii duri, comparativ cu pantofii moi. Materialele branțurilor nu au avut un efect semnificativ asupra vreuneia dintre variabilele de impact ($P > 0,05$). Evaluările subiective au indicat că pantofii cu duritate medie au primit cele mai mari scoruri de amortizare dintre cele trei niveluri de duritate. Descoperirile sugerează că duritatea tălpii intermediare influențează durata impactului și rata de încărcare, în timp ce materialul branțului nu afectează în mod semnificativ capacitatea de absorbție a șocurilor a cizmelor de protecție.

CUVINTE CHEIE: cizme de protecție, duritatea tălpii intermediare, material pentru branț, absorbția șocurilor

L'INFLUENCE DE LA DURETÉ DE LA SEMELLE INTERMÉDIAIRE ET DES MATÉRIAUX POUR LES SEMELLES INTÉRIEURES SUR LA CAPACITÉ D'ABSORPTION DES CHOCS DES BOTTES DE PROTECTION

RÉSUMÉ. L'objectif de cette étude a été de déterminer l'influence de différentes duretés de semelle intermédiaire et de matériaux des semelles intérieures sur la capacité d'amortissement des bottes de protection. Vingt hommes en bonne santé ont effectué des tests de course avec des bottes de protection dans six conditions différentes, en faisant varier la dureté de la semelle intermédiaire (50 Shore C-mou, 60 Shore C-moyen, 70 Shore C-dur) et le matériau de la semelle intérieure (polyuréthane thermoplastique, polyuréthane). À l'aide d'une plaque de pression, la première force de réaction verticale maximale au sol (premier PVGRF), la durée d'impact (ID) et le taux de charge vertical moyen (AVLR) ont été mesurés. Une évaluation subjective de l'amortissement a également été réalisée à l'aide de l'échelle visuelle analogique. Les résultats ont montré que la dureté de la semelle intermédiaire a eu un effet significatif sur l'ID ($P = 0,048$, $\eta^2p = 0,151$) et l'AVLR ($P = 0,048$, $\eta^2p = 0,301$), mais pas sur le premier PVGRF ($P = 0,222$, $\eta^2p = 0,076$). La durée de l'impact a été plus longue et le taux de charge vertical moyen a été plus faible pour les chaussures dures que pour les chaussures souples. Les matériaux des semelles intérieures n'ont eu aucun effet significatif sur aucune des variables d'impact ($P > 0,05$). Des évaluations subjectives ont indiqué que les chaussures de dureté moyenne recevaient les scores d'amortissement les plus élevés parmi les trois niveaux de dureté. Les résultats suggèrent que la dureté de la semelle intermédiaire influence la durée de l'impact et le taux de charge, tandis que le matériau de la semelle intérieure n'affecte pas de manière significative la capacité d'absorption des chocs des bottes de protection.

MOTS CLÉS : bottes de protection, dureté de la semelle intermédiaire, matériau de la semelle intérieure, absorption des chocs

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INTRODUCTION

Lower limb injuries are a prevalent issue among individuals in high-impact professions who are frequently exposed to high-impact forces during activities such as running, landing, and other complex movements [1]. A systematic review reported that the incidence of lower extremity overuse injuries in workers exposed to high physical demands ranges from 27.5% to 61%, with the knee, lower leg, foot, and ankle being the most commonly affected areas [2]. These injuries can impair wearers' physical fitness, operational readiness, and quality of life, while also increasing medical costs and attrition rates [3]. Therefore, identifying risk factors and preventive measures for lower limb injuries in high-impact occupational settings is of paramount importance.

One potential risk factor for lower limb injuries is the impact force transmitted from the ground to the body during foot contact. Such impact forces can cause mechanical stress and damage to the musculoskeletal system, particularly the lower extremities [4]. The magnitude and rate of these impact forces are influenced by various factors, including the speed [5], mass [6], and posture of the runner [7], as well as the surface characteristics [8], and footwear properties [9]. Among these factors, footwear properties are the most modifiable and controllable, which received considerable attention from researchers and practitioners [10, 11].

Footwear properties can influence impact forces by altering the cushioning and biomechanical characteristics of foot-ground interaction [12]. Cushioning refers to the ability of footwear to absorb and dissipate impact energy, thereby reducing the peak and rate of impact forces [13, 14]. Biomechanical characteristics pertain to the kinematic and kinetic parameters of the lower extremity joints and segments, such as foot strike pattern, ankle dorsiflexion angle, knee flexion angle, and joint moments and powers, all of which can affect the distribution and transmission of impact forces along the lower extremity kinetic chain [15].

Protective boots are a specialized type of footwear designed to shield the feet and ankles of wearers from external hazards such as bullets, shrapnel, mines, and chemical agents. These boots are typically constructed from rigid and durable materials like leather, rubber, and steel to provide adequate protection and support. However, these materials may also compromise the cushioning and biomechanical properties of the boots, potentially increasing impact forces and the risk of lower limb injuries [3, 12]. Therefore, optimizing the design of protective boots is necessary to balance the trade-off between protection and cushioning.

The design of protective boots focuses on three primary components: the outsole, midsole, and insole. The outsole, as the outermost layer in contact with the ground, is designed to provide durability, grip, and resistance to environmental hazards. Although the outsole contributes to overall stability, its role in cushioning and shock absorption is limited compared to the midsole and insole, which are in direct interaction with the foot and ground reaction forces. The midsole, located between the outsole and the upper of the boot, serves as the primary shock-absorbing layer [16], typically made from materials such as ethylene-vinyl acetate (EVA), polyurethane (PU), or thermoplastic polyurethane (TPU). Midsole materials are selected based on their cushioning properties, with different hardness levels measured by the Shore C scale to modulate shock absorption and comfort. The insole, as the inner layer in contact with the foot, provides additional cushioning and comfort and is often made from materials like PU, TPU, or gel with varying thicknesses and densities to optimize foot support.

The midsole and insole can interact with each other, affecting the shock absorption performance of protective boots [17, 18]. However, there is a lack of research on the optimal combination of midsole hardness and insole materials for protective boots, and the existing literature presents inconsistent and inconclusive findings. Some studies suggest that cushioning insoles and softer midsoles can reduce impact forces and injury risk by lowering ground reaction forces and loading rates [19, 20]. Conversely, other studies argue that harder midsoles and stiffer insoles can provide better cushioning and stability by increasing the contact area and reducing foot deformation [21].

Therefore, the purpose of this study was to evaluate the effect of different combinations of midsole hardness and insole materials on the cushioning properties of protective boots. The study hypothesizes that: 1) Midsole hardness and insole materials significantly affect shock absorption performance, with shock absorption performance decreasing as midsole hardness increases, and 2) Insole materials significantly influence the shock absorption performance of protective boots.

MATERIALS AND METHODS

Participants

Twenty healthy male participants (age: 19.9 ± 0.8 years, height: 1.77 ± 0.05 m, weight: 67.6 ± 7.8 kg; shoe size: 41-43 French size) volunteered for this study. Participants were recruited from a local university through flyers and online advertisements. The inclusion criteria were: no history of lower limb injury or surgery in the past six months, no current pain or discomfort in the lower limbs, and regular participation in recreational running activities (at least three times per week). Exclusion criteria included any medical condition that could affect the biomechanical performance of the lower limbs, the use of orthotics or braces, and any allergy or intolerance to the materials of the protective boots. All participants provided written informed consent before the experiment commenced.

Footwear Description

The protective boots (Figure 1A) used in this study were custom-made by a local manufacturer, with a total weight of 960g per pair and a shoe upper height of 18 cm. The midsole thickness is 17.4 mm at the heel, while the outsole thickness is 3 mm, with a slip-resistant tread depth of 4 mm. The outsole is constructed from durable rubber material to provide traction and environmental protection, while the midsole is composed of polyurethane (PU) foam for shock absorption. The outsole and midsole are attached to the upper using an adhesive bonding process, which ensures a secure and durable connection that maintains the boots' structural integrity during impact activities. This bonding process was chosen to achieve a balance between flexibility and durability.

The midsoles (Figure 1B) were specifically designed with hardness levels of 50 (soft), 60 (medium), and 70 (hard) Shore C, based on previous research suggesting that these levels are relevant for evaluating the effect of midsole hardness on shock absorption and comfort. The insert insoles (Figure 1C) used in this study were made from Thermoplastic Polyurethane (TPU) and Polyurethane (PU), with thicknesses of 5.5 mm in the forefoot and 7.5 mm in the heel. The material of the main insole in this study was Kevlar with the thickness of 2.5mm. These materials were selected for their common use in protective footwear and their potential to differ in shock absorption and energy return. Figure 1 shows the protective boots and insoles used in the study. A schematic diagram depicting the cross-section of the protective boot, including the upper, lining, insert insole, main insole, midsole, and outsole, is presented in Figure 2.

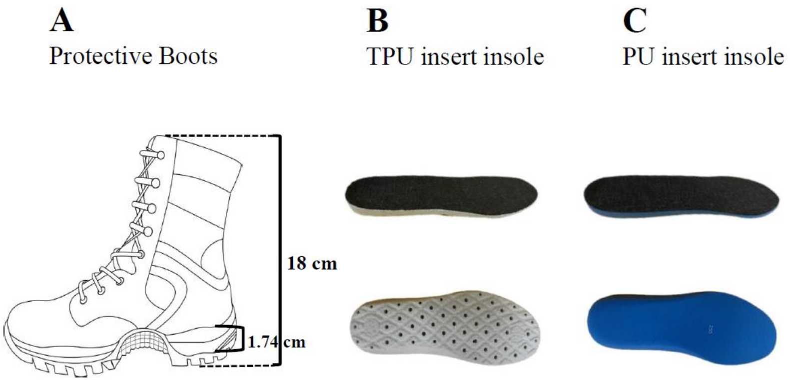

Figure 1. Protective boots and insoles used in this study, TPU: thermoplastic polyurethane; PU: polyurethane

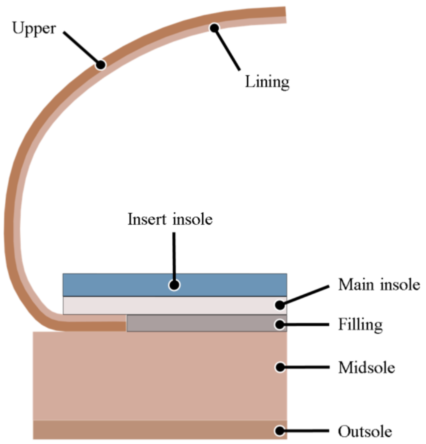

Figure 2. Schematic diagram of the cross-sectional view of the protective boot used in this study

Experimental Set-Up and Procedures

A force plate (Model 9281EA, Kistler Instrumente AG, Switzerland) was used to collect ground reaction forces during running (Figure 3). The force plate was embedded in the middle of a 12 m runway and the sampling frequency was set as 1000 Hz. The speed was monitored using timing gates (Smartspeed; Fusion Sport Inc., Burbank, CA, USA) placed one meter before and after the force plate.

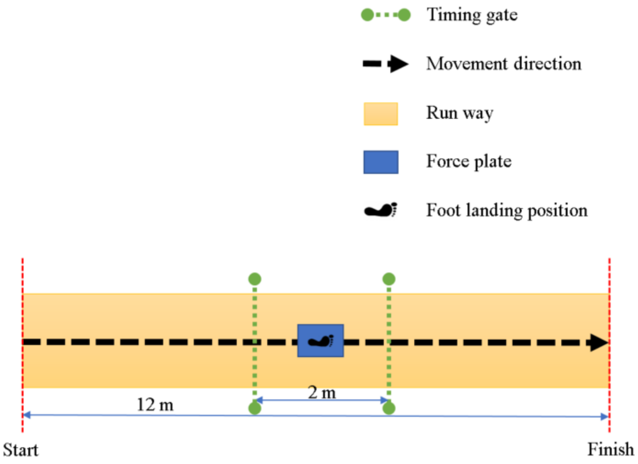

Figure 3. Experimental setup in this study

All experimental testing was conducted on the same day. Participants were first familiarized with the protective boots and the experimental tasks. To acclimate to the weight and feel of the footwear, the boots were worn while walking around the laboratory for 10 minutes. Practice trials of running with the boots were also completed until a comfortable and confident level was reached. After this familiarization period, the running tests were performed under six different conditions: three levels of boot midsole hardness (50-, 60-, 70 Shore C) combined with two different insole materials (PU and TPU). The order of conditions was randomized and counterbalanced across participants.

The running test involved three trials of running at a speed of 3.3 ± 5% m/s along the runway [22], ensuring that the right foot landed on the force plate. Participants were instructed to run naturally while maintaining a consistent speed throughout each trial. Participants were allowed a two-minute rest between trials.

After completing the running tests, participants provided subjective cushioning evaluation of the protective boots based on their experiences with the six different combinations of midsole hardness and insole materials. Using a 15 cm Visual Analogue Scale (VAS) [23], participants rated the cushioning performance for each condition. The left end of the scale represented “Very Poor,” and the right end represented “Excellent.” Participants placed a vertical mark on the scale reflecting their subjective assessment, and the subjective cushioning score for each condition was determined by measuring the distance from the left end of the scale to the marked line.

Data Reduction and Processing

The primary outcome variables were the first peak vertical ground reaction force (1st PVGRF), impact duration (ID), and average vertical loading rate (AVLR). These variables were extracted from the ground reaction force (GRF) data collected during the running trials. The onset and offset of the stance phase were identified as the points where the vertical GRF exceeded and subsequently fell below a threshold of 10 N [14]. This ensured that only the stance phase of running was considered for analysis. Figure 4 illustrates a representative GRF curve and highlights the critical points used to compute AVLR.

Data outliers, such as those caused by irregular foot strikes or missteps, were identified through visual inspection of the force-time curves and were excluded from the analysis to maintain data integrity. The 1st PVGRF was defined as the first noticeable peak in the vertical GRF during the stance phase, representing the initial force impact on the ground. The AVLR was calculated by determining the slope of the vertical GRF between 20% and 80% of the 1st PVGRF [24], capturing the rate at which the vertical force was applied. The impact duration (ID) was defined as the time interval between the initial foot contact and the 1st PVGRF. The following equations were used for these calculations:

$$\boldsymbol{AVLR} = \frac{\mathbf{0.8\times1^{st}\ PVGRF - 0.2\times1^{st} PVGRF}}{(\boldsymbol{t_{0.8}} - \boldsymbol{t_{0.2}})\times \boldsymbol{BW}} \qquad (1)$$

$$\boldsymbol{ID} = \boldsymbol{t_{1st\ PVGRF}} - \boldsymbol{t_{IC}} \qquad (2)$$

where $t_{0.2}$ and $t_{0.8}$ correspond to the time points at 20% and 80% of the 1st PVGRF, respectively, $t_{1st\ PVGRF}$ is the time point corresponding to the 1st PVGRF, and t_{IC} is the time point corresponding to the initial contact, BW is the body weight of the participant.

The ground reaction force was processed using Visual 3d (Version 6.0, C-motion, Inc., USA). The data were filtered using a fourth-order low-pass Butterworth filter with a cut-off frequency of 100 Hz. The GRF data was normalized by the subject’s body weight (BW), and AVLR was expressed in body weight per second (BW/s).

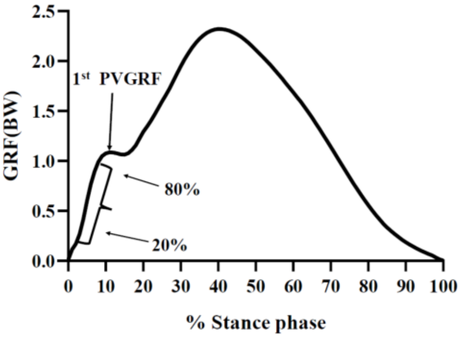

Figure 4. Representative ground reaction force curve showing key points for the first peak vertical ground reaction force and the calculation process of average vertical loading rate; 1st PVGRF: first peak vertical ground reaction force; GRF: ground reaction force; BW: body weight

Statistical Analysis

Descriptive statistics (mean ± standard deviation) were calculated for each condition (three midsole hardness × two insoles). The assumptions of normality and homogeneity of variance were checked using the Shapiro-Wilk test and Levene’s test, respectively. A two-way repeated measures analysis of variance (ANOVA) was performed to examine the main effects and interaction effects of the condition and the test on the outcome variables. The level of significance was set at 0.05. Post-hoc pairwise comparisons with Tukey correction were conducted to identify significant differences between conditions and tests. Partial eta-squared (η^2_p) was used to calculate the effect size, representing the proportion of variance attributed to each factor or interaction. Specifically, η^2_p values of 0.01, 0.06, and 0.14 were interpreted as small, medium, and large effects, respectively [25]. Statistical analyses were performed using SPSS software (Version 26, IBM Corp., USA).

RESULTS

Impact Variables

Table 1 shows the effects of different midsole hardness and insole materials on 1st PVGRF, ID, and AVLR during running. The results showed that there was no significant interaction effect between midsole hardness and insole materials for any of the impact variables ($p > 0.05$). The main effect of midsole hardness was significant for ID ($F_{(1.886, 35.84)} = 3.386$, $P = 0.048$, $\eta^2_p = 0.151$) and AVLR ID ($F_{(1.767, 33.57)} = 3.480$, $P = 0.048$, $\eta^2_p = 0.301$), but not for 1st PVGRF ($F_{(1.922, 36.51)} = 1.571$, $P = 0.222$, $\eta^2_p = 0.076$). The ID was longer for Hard shoes than for Soft shoes ($P = 0.049$), and the AVLR was lower for Hard shoes than for Medium ($P = 0.039$) and Soft shoes ($P = 0.029$). The main effect of the insole materials was not significant for any of the impact variables ($p > 0.05$).

Table 1: Impact variables for different combinations of midsole hardness and insole materials during running

Variables	Insole Materials	Midsole Hardness			Midsole Hardness		Insole Materials		Interaction	
		Soft	Medium	Hard	*P*	η_p^2	*P*	η_p^2	*P*	η_p^2
1ST PVGRF (BW)	TPU	1.34(0.36)	1.37(0.34)	1.30(0.32)	0.222	0.076	0.953	0.001	0.874	0.004
	PU	1.32(0.38)	1.37(0.38)	1.31(0.35)						
ID (ms)	TPU	29.6(5.3)	30.5(6.1)	30.0(7.0)	0.048*	0.151	0.446	0.031	0.125	0.106
	PU	27.6(4.0)	29.8(4.8)	31.1(5.0)						
AVLR (BW/s)	TPU	56.79(18.23)	57.68(22.90)	55.14(18.02)	0.048*	0.301	0.700	0.008	0.209	0.192
	PU	59.80(21.93)	58.82(22.42)	52.92(18.45)						

Note: * p-value <0.05, The difference was statistically significant; TPU: thermoplastic polyurethane; PU: polyurethane; 1st PVGRF: first peak vertical ground reaction force; ID: impact duration; AVLR: average vertical loading rate; Soft, medium, and hard represent midsole hardness levels of 50, 60, and 70 Shore C, respectively.

Subjective Cushioning Performance

Figure 5 shows the subjective cushioning performance across different midsole hardness levels and insole materials. Results showed that there was no interaction between midsole hardness and insole materials for the subjective cushioning performance ($F_{(1.968, 35.420)} = 3.480$, $P = 0.637$, $\eta^2_p = 0.024$), and further main effect analysis found that midsole hardness had a significant effect on the subjective cushioning ($F_{(1.846, 33.220)} = 7.070$, $P = 0.003$, $\eta^2_p = 0.292$). Post hoc analysis indicated that the subjective cushioning scores were significantly lower in the Soft ($P = 0.014$) and Hard ($P = 0.001$) shoe conditions than in the Medium shoe condition. However, there were no insole materials effects on subjective cushioning ($F_{(1, 19)} = 1.101$, $P = 0.308$, $\eta^2_p = 0.058$).

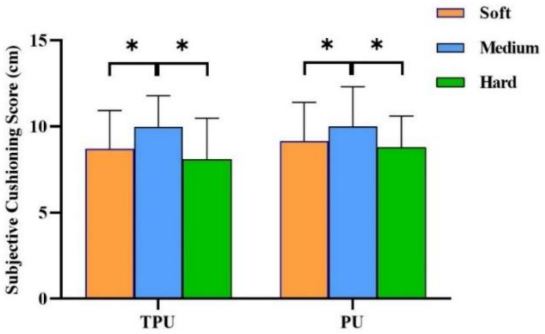

Figure 5. Subjective cushioning performance across different midsole hardness levels and insole materials. Note: TPU: thermoplastic polyurethane; PU: polyurethane. Soft, medium, and hard represent midsole hardness levels of 50, 60, and 70 Shore C, respectively.

DISCUSSION

This study aimed to explore the effects of midsole hardness and insole material on the shock absorption performance of protective boots during running. The findings reveal that midsole hardness significantly influences impact duration (ID) and average vertical loading rate (AVLR), while insole materials do not substantially affect these impact variables. Notably, the subjective evaluation of cushioning performance identified that boots with medium midsole hardness were rated as providing the best cushioning among the three hardness levels, indicating a clear preference for medium hardness over both softer and harder alternatives.

Effect of Midsole Hardness on Shock Absorption

The results of this study underscore the importance of midsole hardness in determining shock absorption performance during running. Our findings indicate that harder midsoles led to a longer ID and a lower AVLR compared to softer midsoles. This is consistent with previous research that suggested harder midsoles can increase the contact area and reduce foot deformation, leading to a decrease in loading rates and an extension of the impact duration [26]. The reduction in AVLR associated with harder midsoles suggests that these midsoles may be more effective in distributing impact forces over time, potentially mitigating the risk of injuries that result from high-impact activities.

Despite these benefits in terms of impact distribution, the subjective assessment revealed a clear preference for medium midsole hardness in terms of perceived cushioning. This preference aligns with earlier studies that found participants generally favor footwear that strikes a balance between softness and firmness [27]. In contrast, harder midsoles, while beneficial for prolonging the impact duration and reducing loading rates, might compromise the perceived comfort due to their stiffer nature, which can lead to a less cushioned feel during running [28, 29].

On the other hand, softer midsoles, which intuitively might seem to offer better cushioning, did not perform as well in this study. The shorter ID and higher AVLR observed with softer midsoles suggest that they may allow more rapid and forceful impacts, which could result in increased discomfort and potentially higher injury risk over time [30, 31]. These results suggest that while softer midsoles may initially feel more cushioned, they might not effectively reduce the overall mechanical stress on the body during repetitive high-impact activities such as running.

Effect of Insole Material on Shock Absorption

Contrary to our second hypothesis, the study found no significant effects of insole material (TPU vs. PU) on the measured impact variables, including 1st PVGRF, ID, and AVLR. These results imply that, within the context of the protective boots used in this study, the choice of insole material does not significantly alter the mechanical shock absorption properties during running. This finding diverges from some previous research that highlighted the potential of shock-absorbing insoles to reduce peak impact forces and lower the risk of injury by modulating ground reaction forces [30, 32].

A possible explanation for this discrepancy could lie in the design characteristics of the protective boots used in this study. The relatively thick and rigid outsole of these boots might have diminished the potential benefits of softer insole materials by limiting their ability to deform and absorb shock effectively [33]. Additionally, the overall construction of the boots, which includes a focus on protection and durability, may have led to a more uniform distribution of force that reduced the influence of insole material on the measured outcomes.

Moreover, the protective boots may have influenced the runners' biomechanics, including foot strike patterns and joint kinematics, which in turn could have affected the distribution and transmission of impact forces along the lower extremity kinetic chain [14, 21]. These biomechanical alterations might have overshadowed any potential differences between TPU and PU insoles, rendering their impact on shock absorption negligible in this particular setup.

Subjective Cushioning Performance

The subjective evaluations conducted in this study revealed a strong preference for medium midsole hardness in terms of perceived cushioning. Participants consistently rated the medium hardness as offering superior shock absorption compared to both softer and harder alternatives. This finding is particularly important as it highlights that subjective comfort does not always correlate directly with objective mechanical measures of shock absorption [34, 35].

The preference for medium midsole hardness could be attributed to its ability to provide an optimal level of cushioning that balances the firmness needed for stability with the softness required for comfort. Participants may have perceived the medium hardness as cushioning enough to absorb impacts effectively, without the excessive softness that could lead to instability or the excessive firmness that could result in discomfort [26]. These subjective assessments are critical in footwear design, as they directly impact user satisfaction and, by extension, the likelihood of long-term use and adherence to wearing protective boots in various settings.

Interestingly, the lack of a significant effect of insole material on subjective cushioning scores further reinforces the idea that midsole hardness plays a more dominant role in determining perceived comfort. Despite the theoretical differences in material properties between TPU and PU insoles, participants did not perceive a notable difference in comfort. This outcome suggests that the mechanical properties of the midsole, such as its hardness, may have a more substantial influence on overall cushioning and comfort perceptions in protective footwear.

However, the study also highlighted discrepancies between objective measures (1^{st} PVGRF, ID, AVLR) and subjective assessments. While harder midsoles reduced AVLR and prolonged ID, they were less preferred by participants, who favored the medium hardness for its perceived cushioning. These differences underscore the complexity of assessing footwear effectiveness, as objective metrics may not fully capture the dynamic interactions between the foot, the boot, and the ground during movement [34, 36]. Factors such as individual biomechanics, running technique, and environmental conditions—elements that differ between controlled laboratory settings and real-world scenarios—can influence these interactions and lead to variations in comfort perception [35].

Moreover, subjective evaluations are inherently influenced by personal factors like past footwear experiences, preferences, and psychological biases, which can affect how cushioning and comfort are perceived, even when objective data suggests otherwise [36]. The controlled conditions of this study, while ensuring consistency, may not reflect the diverse environments where protective boots are typically used. Future research should explore these subjective-objective discrepancies by incorporating more varied testing environments and considering additional biomechanical factors, such as joint kinematics and muscle activation, to gain a comprehensive understanding of footwear performance.

Limitations

This study offers valuable insights into how midsole hardness and insole material affect shock absorption, but several limitations must be noted. The small, homogeneous sample of male university students limits the generalizability of the results to other groups, such as female or older personnel, who may respond differently to footwear. The controlled laboratory setting, while consistent, does not fully mimic the varied conditions of real-world field scenarios. Future studies should examine these factors in more diverse environments, such as different terrains and climates, to better understand their impact on injury risk. Additionally, this study focused mainly on vertical ground reaction forces and loading rates, but other biomechanical factors like joint angles and muscle activation should also be considered for a more comprehensive understanding of footwear performance.

CONCLUSIONS

This study investigated the effects of midsole hardness and insole material on the shock absorption performance of protective boots during running. The results showed that midsole hardness influenced the impact duration and loading rate, while insole material did not affect the shock absorption. The subjective cushioning evaluation also revealed that medium midsole hardness was preferred by the participants over soft or hard midsole hardness. These findings suggest that midsole hardness is an important factor to consider in the design of protective boots, and that medium midsole hardness may provide the optimal balance between protection and cushioning. Future studies should include other biomechanical and physiological variables, such as joint kinematics, muscle activation, and tissue stress, to further evaluate the influence of footwear properties on lower limb injury risk in demanding operational environments.

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