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Original Research

Perception of Running Shoe Cushioning: Determining the Correspondence between Subjective Assessment and In-vitro Measurement

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ABSTRACT

International Journal of Exercise Science 17(1): 902-915, 2024. Running shoes, and in particular insoles, are the first interface between runners and running surface. Different insole attenuation properties may vary perception of cushioning and, accordingly, the effect on muscle adaptation. The aim of this study is to find the just noticeable difference between four insole materials, and investigate the parameters of in-vitro measurement of impact testing to predict cushioning comfort. Nineteen (n = 19) male participants were recruited from the sports center at the Technical University of Munich with a mean age of 23.89 (SD = 2.31), weight of 73.52 kg (SD =3.08), and height 178.84 cm (SD =2.81). Four insole samples, one with the highest peak acceleration (EPDM =17.9g), one with the lowest (S.Tk = 8.3g) and the two materials with middle range magnitudes (IP.GL= 11.5g and S.Tn = 12.2g), were selected to use in the subjective measurement. We used the impact testing method to evaluate the in-vitro physical properties of insoles in running shoes. In addition, two parameters of peak acceleration were measured as follows: Jolt α was calculated at a slope of between 5-20 % of inertial impact force and Jolt ß was calculated at a slope of between 0-88 Newtons of inertial impact force. Participants performed six pairwise comparison tests with shoes which were equipped with one of the four insoles in a random order. A minimum 6% increase in cushioning properties, notably between 11.5g (S.Tn) and 12.2g (IP.Gl), was discerned through the paired tests. In simpler terms, participants were able to detect a mere 0.7g as the just noticeable difference. In addition, our findings revealed that an increase of Jolt α and Jolt ß resulted in a reduction in perception of comfort. There was a negative and significant correlation between Jolt α and perceived cushioning and, similarly, between Jolt ß and perceived cushioning r (10) = -0.93, p = 0.00001. No correlation was found between peak acceleration and cushioning comfort (p = 0.1). These discoveries may facilitate a better understanding of how human adaptation can occur with different cushioning.

KEY WORDS: Insole, just noticeable difference, pairwise comparison test

INTRODUCTION

When running, the human body is exposed to repetitive impacts resulting from sudden decelerations (jolt = 'the rate of change of acceleration ' or 'impulsive loading striking') at initial ground contact. These accumulated impacts are considered a risk factor for the development of overuse running injuries (6, 14, 21). To prevent excessive loads and related injuries, three concepts were proposed by Nigg and Segesser (1992), namely, cushioning, support, and guidance (24).

The cushioning system of shoes can be highly related to the certain shoe components e.g. insoles. In the biomechanical measurement using an impact testing device, Chiu et al. (2007) determined that insoles can absorb impact energy up to 24–32% (5), and in the study of O'Leary et al. (2008) such a reduction of impact peak force using insoles reaches 6.8% (26) This would indicate that insoles play a more important role in cushioning properties of sport shoes under low impact energy conditions. An increase in shoe cushioning does not always result in such an impact reduction. Kulmala et al. (2018) determined that increasing cushioning resulted in an increase in the slope of loading rate, i.e., the speed at which forces impact the body (17). Kulmala et al. (2018) and Milani et al. (1997) stated that such excessive cushioning of a running shoe may be responsible for injuries by creating a perceptual underestimation of the actual impact severity (17, 19). An increase or reduction of footwear cushioning may affect the natural frequency of soft tissue vibration, where muscle tuning then occurs (3). The paradigm of muscle tuning determined that runners adapt their muscle responses with each step to minimize the transmission of vibrations through the soft tissues in their lower extremities. Such an adaptation (muscle tuning) raises the question of the extent to which a participant is able to perceive cushioning changes.

The science of psychophysics introduced a threshold as the minimum intensity a subject can perceive, known as the Just Noticeable Difference (JND) (13, 27). Detecting such a threshold can aid in better understanding how muscle adaptation originates when a stimulus occurs (29-31). Other researchers, Henning (1996) and Salzano et al. (2021), attempted to compare the results of subjective assessment with in-vitro physical properties of running shoes using the impact testing method (8, 33). Their findings determined a poor correspondence between the cushioning measured in vitro using peak acceleration (g-Max or g) and wear tester ratings (subjective assessment). The method used in subjective assessments of these studies is the Likert-type scale (1–7). The complexity of this measure can worsen the reliability of assessments. In other words, the number of individuals who reliably assessed the footwear could be increased by reducing the complexity of the measure to simple binary Yes/No questions (11, 20).

Among the methods available for eliciting comparative judgments, binary choice is the easiest for respondents because it compares only two stimuli at a time (11). In addition, the method of paired comparisons uses the inherent familiarity with and ability to make comparisons. Furthermore, the effect of different insole materials on cushioning attenuation has been investigated in only a few studies (4, 23, 32). Insoles with different types of material can react to local pressure peaks in different ways. One way is the absorption of impact energy by compression of the material. Closed cell foams and insoles with integrated air-chambers produce a counter-force when compressed (the inner pressure of the cells rises) and can thus return part of the stored energy during unloading. Open cell foams have a lower energy return capability. The second way of reacting to local pressure peaks is the evasion of the material, occurring in materials with some characteristics of liquids, such as silicones and other viscoelastics. The material moves from an area with high pressure to surrounding areas with lower pressure and thus balances the pressure. Since the mechanism of impact attenuation in both types of material is different (affecting kinetic and kinematic changes in running), it is necessary to investigate the subjective parameters of cushioning at an early stage.

A parameter which has been investigated in past studies (8, 27) is the perception of cushioning measured by rating 'hardness' or 'softness' of the material underfoot in a subjective assessment. However, in these studies, perception of cushioning defined the hardness or softness of the material of the midsole but this parameter cannot indicate in detail the comfortability of the attenuation mechanism (=cushioning comfort). Past studies have not thoroughly investigated whether cushioning comfort in subjective assessment can be linked to the parameter of in vitro physical properties of running shoes using the impact testing method.

In addition to subjective assessments, mechanical testing can provide parameters, such as peak acceleration, for predicting the cushioning properties of insole materials (8, 33). While peak impact acceleration offers insights into initial shock absorption, it may not offer a comprehensive evaluation of overall cushioning, as cushioning may encompass other factors, such as the rate of acceleration change (loading rate), which have been shown in biomechanical measurement (1). Loading rate, in the context of running gait, refers to the rate at which the body experiences an increase in vertical ground reaction force during the initial contact and loading phase of running. However, such a parameter has been overlooked in mechanical testing. For a more precise prediction of cushioning in running insoles, a holistic approach involving multiple factors and testing methods, including mechanical testing and subjective comfort assessments, should be taken into account. Consequently, this study aimed to achieve two objectives: firstly, to determine the just noticeable difference in insole cushioning in running through subjective assessment, and secondly, to explore potential variables in mechanical impact testing to assess their potential as predictors for cushioning comfort.

METHODS

Participants

Nineteen (n = 19) male participants were recruited from the sports center at the Technical University of Munich with a mean age of 23.89 (SD = 2.31), weight of 73.52 kg (SD =3.08), and height 178.84 cm (SD = 2.81). Participants gave written, informed consent prior to the experiment. The consent form declares confidentiality of the objectives, risks of the study, and protection of personal data through appropriate procedures for anonymization according to EU General Data Protection Regulation (28). In addition, the consent form assures participants they are free to withdraw from the research at any time without giving a reason and without penalty for not taking part. This research was conducted according to the ethical standards of the Helsinki Declaration (36) and IJES Ethics Statement (22).

Protocol

Three commercially available insole materials—(i) ethylene-propylene-diene-monomer rubber foam (EPDM), (ii) ipocon-Gel, and (iii) synthetic viscoelastic urethane polymer Sorbothane©, and their combination were prepared in the pilot study. In total, 12 samples were tested using an impactor device (Table 1, Figure 1). In the end, only four insole samples, one with the highest, one with the lowest, and the two materials with middle range magnitudes of the peak accelerations were selected to use in the subjective measurement. These were as follows: EPDM 6 mm (E), Ipocon Gel 3 mm(G), synthetic viscoelastic 3.17 mm (S.Tn), and synthetic viscoelastic 4.7 mm (SB tk). The mean (and standard deviation) of impact peak of E, G, S.Tk and S.Tn were 32.41 g (0.47), 11.54 g (0.25), 12.6 g (1.13), and 7.2 g (0.2), respectively. Drop height 6 mm and weight of impactor was 4.2kg.

Table 1. Samples were tested in the pilot test with impactor device.

ID#	Material	TT	ID#	Material	TT
1	E1	6	7	E+ IP.Gl (2mm+3mm)	5
2	E2	9	8	E+ IP.Gl (3mm+4mm)	7
3	IP.Gl -1	3	9	E+ IP.Gl +E (2mm+3mm+2mm)	7
4	IP.Gl -2	4	10	E+ IP.Gl +E (2mm+4mm+2mm)	8
5	IP.Gl -3	6	11	SBTk	3.17
6	IP.Gl-4	8	12	SBTn	4.76

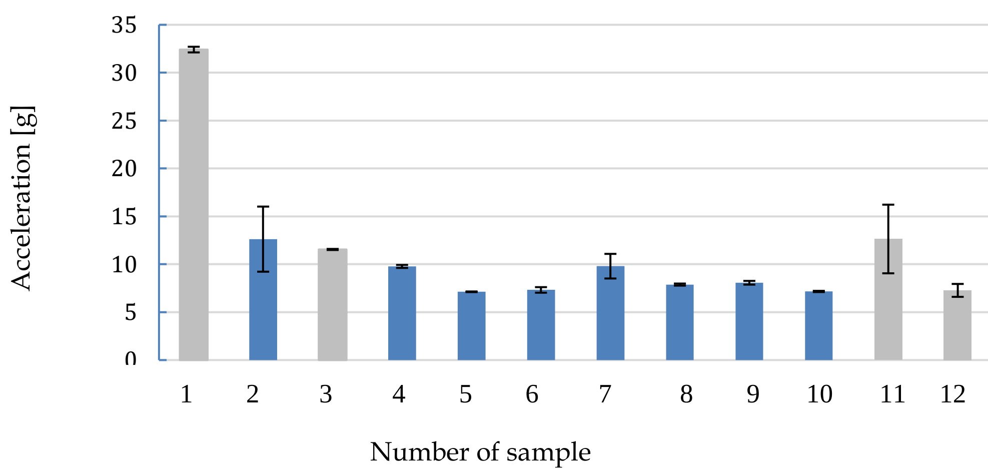
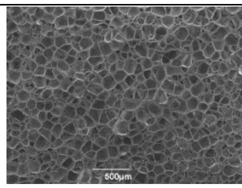
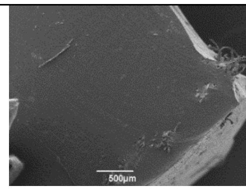
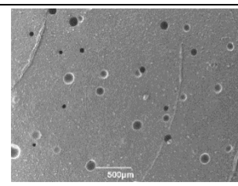
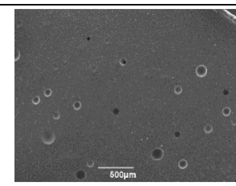


Figure 1. Peak acceleration of twelve samples: Four samples highlighted in gray were used in the main experiment (Error Indicator: 95%-Confidence Interval).

Cross sections of these four samples were prepared for scanning electron microscope through JEOL - Model JSM-6390. Prior to the start of the study, a type A shore durometer (Kern & Sohn

GmbH, Germany) was used to determine the material hardness. The samples are shown in Table 2. Four samples, EPDM, IP.Gl, S.Tk and S.Tn were designed and cut manually to replace original insoles of shoe sizes 42 - 47 (Scott running shoe, model : Palani).

Table 2. Mechanical characteristics of samples.

	EPDM1	IP.Gl2	S.Tn3	S.Tk4
SEM *				
SH **	5.6	23. 2	13. 2	17. 8
Thickness	6mm	3mm	3.17mm	4.7mm

*SEM:Scanning Electon Microscope Machine **SH =Shore hardness 1EPDM= ethylene-propylene-diene-monomer rubber foam; 2IP-Gl: ipocon-Gel; 3Stn = thin synthetic viscoelastic urethane polymer Sorbothane©; 4Stk = thick synthetic viscoelastic urethane polymer Sorbothane©.

A dynamic shock absorption test was used for the measurement of cushioning properties. The pneumatic impactor device consists of a 5 cm diameter indenter and 4.3 kg weight. The machine operates by allowing the weight to fall onto the tested material from a defined height of 7 mm (potential energy of 0.3J). A single axis accelerometer sensor (range of −50 g to 50 g) was attached to the impactor in order to quantify the shock absorption with a measuring frequency of 5000 Hz. The impact tester provides the acceleration-time graph shown in Figure 2a (using Gaussian smoothing, Sigma=5 which is corresponds to 1 millisecond at the measuring frequency 5000 samples per second). Two parameters, G-max and $Jolt_{\alpha}$, were evaluated: G-max is the peak of acceleration of the first impact (Figure 2b). The $Jolt_{\alpha}$ was calculated as the slope between 5-20% in inertial force-curve; and the $Jolt_{ß}$ is the slope from 0-80 Newton in the inertial force-curve below (Figure 2c).

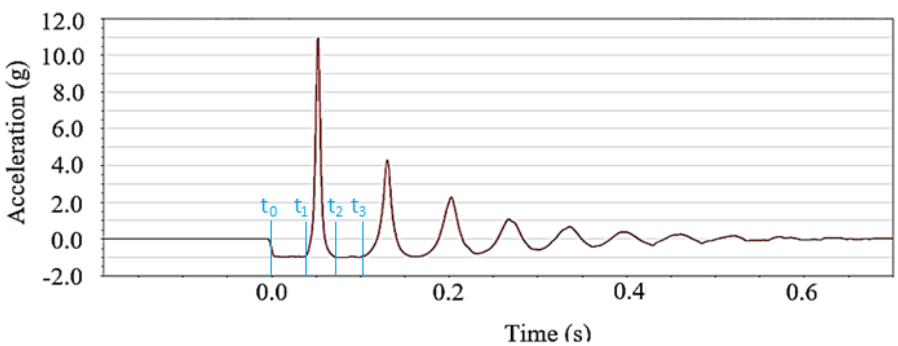


Figure 2a. A schematic of peak acceleration with the Impactor test device (at t0 the device is triggered, from t0 to t1 and from t2 to t3 the impactor is in free-fall). An acceleration value reported in gravitational units (1 g = 9.80665 m s -2).

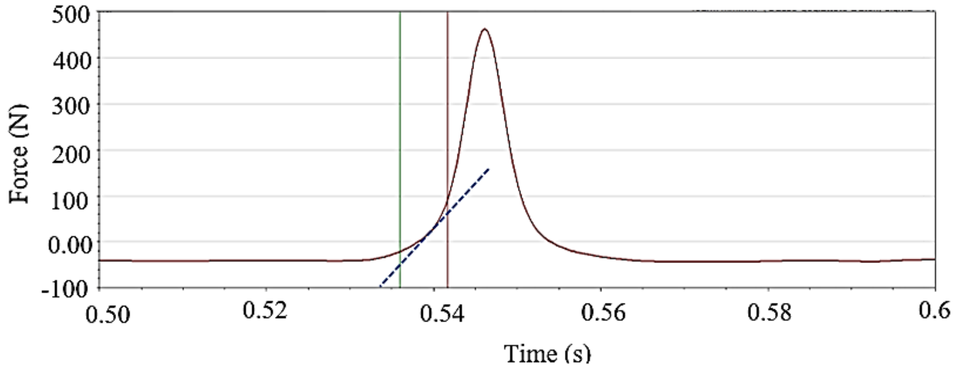


Figure 2b. The Jolt$_{\alpha}$ was calculated the slope between 5-20% of inertial force graph.

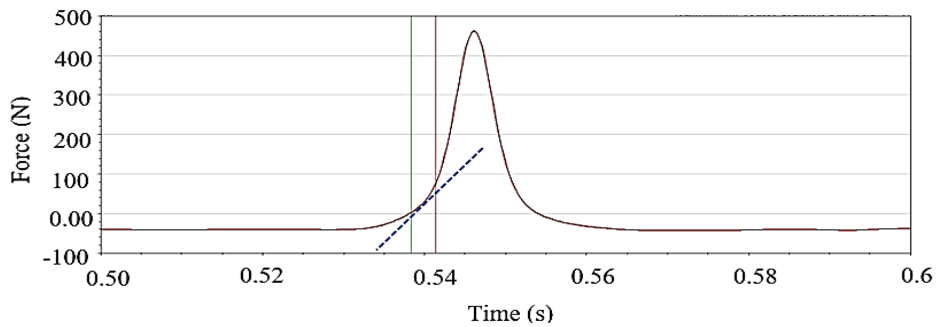


Figure 2c. The Jolt$_{\beta}$ was calculated the slope between 0-80 Newton of inertial force graph.

Subjective assessment: Four samples were compared with pair wise methods. This method on 'n' abilities requires a number of n (n − 1)/2 different combinations, which must be tested by each tester (2). With paired comparisons, respondents select the stimulus, or item, in each pair that had the greater magnitude on the choice dimension they were instructed to use. Pair comparison test (PCT) is a binary test that requires a simple decision between two alternatives. In our study, participants performed six pairwise comparison tests with shoes which were equipped with one of the four abovementioned insoles in a random order, i.e., (EPDM vs. IP.Gl); (EPDM vs. S.Tn); (EPDM vs. S.Tk); (IP.Gl vs. S.Tn); (IP.Gl vs. S.Tk); (S.Tn vs. S.Tk).

At the beginning of the subjective test, the plantar sensitivity of participants was evaluated with 3.61 monofilament = grade 4 (Semmes Weinstein Monofilament Examination), which is equivalent to 0.4 g of linear pressure (15). Nine defined points (distal great toe, third toe, and fifth toe; first, third, and fifth metatarsal heads; medial foot, lateral foot, and heel) (7) on the participant's foot plantar (random foot) were tested three times to detect peripheral neuropathy.

Main experiment: In the first test, participants ran five minutes on the treadmill at their desired velocity with experimented shoe (Scott- model: Palani) with the original insole. They then performed six movements: quad piriform walk, hip opener, arm circles, leg crossover, and inchworm (following the experimenter's instructions). Participants then ran on the treadmill for three minutes with a randomly selected insole, and immediately afterwards, changed into the shoe with a different insole, running for an additional three minutes (in pairwise comparison tests). After accomplishing the first pair test, the following two questions were asked of the participants:

1. Is there any difference between the cushioning features of the two running shoes? Possible answers: Yes/No.
2. Which shoe did you perceive as "…having a better cushioning comfort"? Possible answers: "The first shoe"/ "The second shoe."

After a one-minute rest, participants repeated the same procedure until all pair tests had been accomplished. Participants were informed that the meaning of cushioning is protection against force or shock. Accordingly, cushioning comfort was defined as 'How comfortable was the procedure of reducing shock while running?'

In our study, a number of factors were controlled to determine biases in the experiment. Participants were blind to any information about the selected shoes (type of the shoe and type of the insoles). The experimenter untied and removed the shoes from the participant's feet. Participants were given the option of changing the shoe in the early phase of the experiment (warm up) when they were not convinced of the comfort of the fit.

Based on our previous study (16), participants mostly chose a running pace between 10-12 km/hour. Hence, in our study the running pace was firstly set on 10 km/h, however in case participants could change it according to their desired velocity. To avoid any biases, all participants wore an identical sock during experiment.

RESULTS

The results of the monofilament test determined that the minimum plantar sensitivity of participants (lower range) was 75%, and the maximum (upper range) was 92%. The average plantar sensitivity was 80.3% (SD = 6.8%). These results are based on 513 tests among 19 participants, nine plantar spots, and each of three trials.

In-vitro measurement – Impactor: Peak acceleration, Jolt $_{\alpha}$, and Jolt $_{ß}$ were measured with the impactor and analyzed with self-designed software in visual basic (Table 3). The differences in peak acceleration between samples were as follows: [(IP.Gl vs. $S.T_n$) = 0.7g], [(S.Tk vs. IP.Gl) = 3.2g], [(S.Tk vs. $S.T_n$)= 3.9g], [(IP.Gl vs. EPDM) = 5.4g], [($S.T_n$ vs. EPDM) = 5.7g], and [(EPDM vs. $S.T_k$) = 9.6g].

The impactor results determined that EPDM had the lowest Jolt $_{\alpha}$ equal to lowest inclination and then STK, IP.Gl, and S.Tn, respectively. In Jolt $_{ß}$, EPDM, STK, IP.Gl, and S.Tn also showed lowest to highest inclination (Table 3).

Table 3. Peak acceleration and Jolt $_{\alpha}$ and Jolt $_{ß}$ in 7mm drop height.

	Jolt $_{\alpha}$ (N/S)	Jolt $_{ß}$ (N/S)	G-MAX(g)
	5%-20%	0N-88N	Peak Acceleration
EPDM[1]	23961	34011	17.9
sd	*2224*	*2781*	*1.4*
$S.T_k$[2]	34562	52030	8.3
sd	*2867*	*2756*	*0.3*
IP.Gl[3]	39297	54897	11.5
sd	*1831*	*2166*	*0.4*
$S.T_n$[4]	50535	69162	12.2
sd	*3469*	*4485*	*0.6*

[1]EPDM= ethylene-propylene-diene-monomer rubber foam; [2]IP-Gl: ipocon-Gel; [3]St_n = thin synthetic viscoelastic urethane polymer Sorbothane©; [4]St_k = thick synthetic viscoelastic urethane polymer Sorbothane©.

The inertial forces of insoles were varied from 349N, 485N, 514N, and 754N, respectively, for EPDM, Stk, IP.Gl, and S.Tn. These were calculated using the peak acceleration of each insole multiplied by the weight of impactor.

All participants did choose a velocity of 10 km/h and maintained on such a velocity in their pair-comparison tests. In all 114 pair tests (n=19 × 6 = pair test), participants were able to distinguish the cushioning difference. The just noticeable difference between two samples is indicated when participants compared IP-Gl and Stn. The just noticeable difference between the two sample's G-max was 0.7 g.

The four insoles were evaluated using a 4×4 square decision matrix for each tester. A decision matrix for all testers is shown in Table 4. It was normalized on the number of subjects in Table 5. The transformation of normalized rank data in Table 4 to ratio scaled preference z values were calculated according to the assumption of a standard normal distribution justified by the law of comparative judgment (12) (Table 6). Pair comparison test of samples in scaled values is shown in Figure 3.

Table 4. The specific PCT of all testers. Notice: Read vertically in the columns the quantity of rated preferences. Example: 19 subjects rated insole G as "…having a better cushioning comfort" than insole STk, whereas 6 subjects rated insole S2 as being more comfortable than insole IP.GL

	S.Tk	IP.Gl	EPDM	S.Tn
S.Tk		13	8	15
IP.Gl	6		2	10
EPDM	11	17		15
SoTN	4	9	4	

Table 5. Normalized PCT matrix of all testers by dividing to 19

	S.Tk	IP.Gl	EPDM	S.Tn
S.Tk		0.68	0.42	0.79
IP.Gl	0.32		0.11	0.53
EPDM	0.58	0.89		0.79
S.Tn	0.21	0.47	0.21	

Table 6. Replacement of normalized PCT by corresponding Z-values.

	S.Tk	IP.Gl	EPDM	S.Tn	*AVG*
S.Tk		0.47	-0.2	0.80	0.27
IP.Gl	-0.47		-1.25	0.06	-0.41
EPDM	0.19	1.2		0.80	0.56
S.Tn	-0.80	-0.07	-0.80		0.41

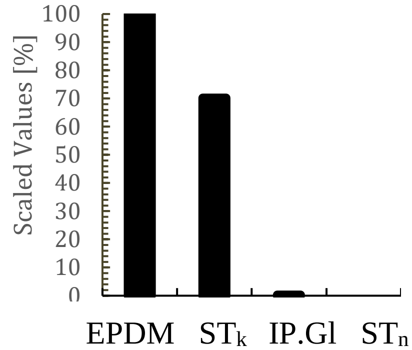


Figure 3. Pair comparison test of samples in scaled values.

To find a statistical difference between the four insole samples, coin theory was applied in the pairwise comparison test. Coin theory is a binomial distribution based on two possible outcomes: heads and tails. In the case of coins, heads and tails each have the same probability of 1/2. In Python, we performed a binomial test using the binom_test() function from the scipy.stats library, which uses the following syntax: binom_test (x, n=None, p = 0.5, alternative='two-sided') and effect size in bionominal data is measured as follow : 1/p0 -pt . Our findings determined a significant difference (P value) in following pair tests:
[(Stk vs. IP.Gl) : 0.013], [(IP.Gl vs. EPDM) : 0.0007], [(EPDM vs. STn): 0.019], and [(Stk vs. STn): 0.019]. However, the cushioning comfort of two pair tests did not differ significantly: [(Stk vs. EPDM): 0.64] and [(IP. Gl VS S.Tn): 1.0]. To calculate the effect size, univariate ANOVA model was used in IBM® SPSS® Statistics 26. The independent variable (insoles) showed medium effect size, 0.43, on dependent variable (preferred cushioning comfort).

The results from the second question were also analyzed by correlation coefficient. Spearman's rank correlation was calculated in Python using the spearmanr() SciPy function. There was a negative and significant correlation between Jolt $_{\alpha}$ and perceived cushioning and, similarly, between Jolt $_{\beta}$ and perceived cushioning [r (10) = = - 0.93, p = 0.00001]. Our findings revealed that an increase of Jolt $_{\alpha}$ and Jolt $_{\beta}$ resulted in a reduction in perception of comfort. No correlation was found between peak acceleration and perception of cushioning (p = 0.1).

DISCUSSION

In this study, we evaluated the JND of cushioning perception and also compared cushioning comfort with an in-vitro measure of impact attenuation's parameters. In our series of 114 paired comparison tests involving 19 participants, it was observed that the participants were capable of detecting differences in insole cushioning stimuli. Notably, the JND was determined between the S.Tn and IP.Gl insoles, amounting to 0.7g. In simpler terms, participants exhibited the ability to discern a minimal increase of 6% in cushioning properties, distinguishing between the 11.5g (S.Tn) and 12.2g (IP.Gel) conditions. This outcome is largely consistent with the results of

Pisciotta et al. (2018) and Isherwood et al. (2021) (13, 27), who identified JND values of 1.4g and 1.12g, respectively, in the context of distinct sole cushioning levels. The heightened precision of the JND observed in the present study, in contrast to the aforementioned investigations, is likely attributable to variances in the subjective assessment methods and experimental designs employed. The earlier studies (13, 27) utilized a visual analogue scale (VAS) for subjective assessment, which lacks comparative reference values for intensity. The cognitive task of estimating attribute intensities within this framework may be more intricate compared to the straightforward comparison of one insole to another, where reference values are not available. Furthermore, differences in methodology, such as the duration of insole wear and its impact on somatosensory perception (34), may yield varying results. In our study, participants engaged in uninterrupted running for two minutes, whereas participants in the earlier studies behaved differently, possibly contributing to the differential effects of wear time on somatosensory perception. Another noteworthy methodological variance concerns the potential energy expended in mechanical testing. In the studies mentioned above, the potential energy utilized was 8J, while in our study, it was restricted to 0.3J, a choice made to serve the specific objective of assessing insole behavior. During a pilot study, we initially employed potential energy levels of up to 8J to test the mechanical properties of all four insoles. However, preliminary findings indicated that such high potential energy levels could damage the insoles. Consequently, we defined the potential energy with a 7mm drop height and a 4.3 kg weight, equivalent to 0.3 J. This limitation of potential energy resulted in peak impact accelerations ranging from 8g to 17.9g (Table 7). Notably, the peak force was defined based solely on interactions with the insoles, in contrast to other studies, which also measured interactions with midsoles or a combination of midsoles and insoles. As per the data presented in Table 7, the current impact force observed in our study falls within a range that aligns with the findings of other studies. This supports the feasibility of conducting insole testing with the chosen potential energy level.

Table 7. Comparisons of impact testing methods used in previous studies and in the present study.

	Material	Impact Mass (Kg)	Impact Energy (J)	Peak Acceleration (g)	m × a (N)
Henning et al. (1991) (9)	m+i*	7.8	3.22	9.1	696
Henning et al. (1993) (10)	m+i	8.5	4.17	11	917
McNair et al. (1994) (18)	m+i	9	4.41	9.6	847
Milani et al. (1997) (19)	M	7.3	3.6	9.6	687
Pisciotta et al. (2018) (27)	m+i	8.5	5	11.1	924
Chiu et al. (2007) (5)	M+i	6.2	1.8-6	9.6-20	584-1229
Current study	i	3.4	0.3	8.3	349-754

m + i* = midsole +insole; i*= insole

These two insoles, which exhibited minimal differences in peak acceleration, belong to the same family of viscoelastic materials and demonstrate similar mechanical behavior (as opposed to EPDM). This discovery holds significance, as it suggests that participants can perceive such differences in peak acceleration (g) not solely based on varying material characteristics, but rather due to their precise JND discernment, even within materials from the same group.

The secondary objective of this research was to enhance our comprehension of the connection between the mechanical characteristics and the cushioning comfort provided by various insoles. Our results revealed that participants rated the EPDM insole, which exhibited the lowest Jolt, as the most comfortable in terms of cushioning. Notably, a statistically significant correlation ($r = 0.9$) was observed between both $Jolt_{\alpha}$ and $Jolt_{ß}$ and the perceived cushioning comfort. Vibrations within the soft tissue compartments of the leg, including muscles, fascia, surrounding tissue, and skin, are initiated during the rapid deceleration of the leg upon landing (25, 35). These vibrations are subject to influence by three key factors: running speed, the hardness or flexibility of the running surface, and the vibration-damping properties of the footwear. For this study, the first two factors remained constant among all participants, with the only variation being the type of insole used. Drawing from the muscle tuning paradigm, it is hypothesized that as the input signal represented by $Jolt_{\alpha}$ (ranging from EPDM = 23 kn/s to S.Tn = 50 kn/s) or $Jolt_{ß}$ (ranging from EPDM = 34 kn/s to S.Tn = 69 kn/s) increases, it moves closer to the resonant frequency of the soft tissue package. In response, the muscles need to adapt and tune to the surface's hardness. This tuning may be most pronounced when using the EPDM insole, followed by the S.Tk, IP.Gl, and S.Tn in descending order. Alternatively, when confronted with harder or softer surfaces, muscles may adapt by increasing damping to minimize resonance. Thus, both $Jolt_{\alpha}$ and $Jolt_{ß}$ serve as input signals, leading to an increase in the damping coefficient of the soft tissues and, subsequently, more intense muscle activity. These dual mechanisms work in harmony to reduce vibrations, potentially resulting in a more robust muscle response when utilizing insoles, ranked in descending order as S.Tn, IP.GL, S.Tk, and EPDM. This, in turn, may have implications for cushioning comfort and motor task performance.

Furthermore, it is plausible that participants employ these mechanisms as a protective response to mitigate the risk of injuries stemming from elevated soft tissue vibrations. Future studies will delve deeper into these assumptions to explore how runners adapt to such changes in a controlled laboratory setting.

Conclusion: In this study, the perception of cushioning and cushioning comfort of four insoles were compared in a pair comparison test among runners. Cushioning attenuation properties of these insoles were compared in vitro measurement using an impactor. Our findings show that runners could detect minimum difference of peak acceleration of 0.7g. In addition, Jolt was shown to be a predictor of cushioning comfort. Any reduction in jolt results in a significant increase of cushioning comfort. In summary, these findings demonstrate that, under controlled conditions, runners were able to distinguish a 6% increase in peak cushioning in insoles while running. Perceived cushioning comfort was therefore consistent with mechanical impact test results. The findings and the methodological framework of this study can be used to enhance the development and design of shoes and prosthetics.

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