Perceived Cushioning Levels of Running Shoes with Different Mechanical Properties

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Abstract. In place of human testing, mechanical shoe tests could be used to save time and costs for shoe manufacturers. This study aimed to compare perceived levels of cushioning with mechanical test results from a new dynamic drop test of running shoes. Nineteen participants were recruited to brisk walk over a 10-m walkway and vertical drop jump from a 30-cm platform. Participants then rated their perceived levels of cushioning of four models of running shoes using the 10cm visual analog scale (VAS). Results showed that the significantly worst perceived cushioned running shoe corresponded with the worst loading rate measured in the dynamic test. On the other hand, perceived levels of cushioning of shoes were not significantly different among shoes with similar loading rates in the dynamic tests. These results suggest that the perceived levels of cushioning only matched dynamic test results if the difference in cushioning properties is sufficiently large.

Keywords: Biomechanics, Heel cushioning, Force plate

1 Introduction

Running is a well-liked sport worldwide but as a result, there is also a substantial number of running-related injuries, amounting to 2.5 to 38 injuries per 1000 running hours [1]. Higher mean vertical loading rates have been associated with running related injury risks among runners [2]. To counter these injury risks, better cushioned footwear could help reduce loading rates by reducing maximum vertical ground reaction force (VGRF), increasing time to the first peak of the VGRF and by allowing more deformation in the cushioned material instead [3]. In fact, studies in 2017 have also found that 67.5% of consumers worldwide consider cushioning of running shoes as ‘very’ to ‘extremely’ critical [4]. This therefore could be a motivating factor for footwear companies to develop materials to help with better cushioning.

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To measure the effectiveness of the cushioning systems, studies have used mechanical tests such as the static shore hardness tests [5,6] to determine the hardness of the midsole of shoes. However, the static shoe harness tests may not adequately simulate dynamic conditions during walking or running. Hence, other studies adopted the ASTM F1976 [7] in testing their shoes dynamically [8,9]. This form of mechanical testing is intended to replicate the dynamic impact forces of a foot strike [7]. Nevertheless, the dynamic impact testing in ASTM F1976 still does not replicate how a shoe with a human load is dropped onto the ground as a person walks or runs. Thus, a new dynamic shoe drop test is proposed in this study to better simulate actual shoe impact conditions.

If mechanical tests could truly reflect actual human perceived levels of cushioning, they would then provide foot manufacturers with a quantitative evaluation of customer satisfaction. This could help footwear companies save costs and time in evaluating their products without the need for human testing. In fact, studies have been conducted to better understand if perceived levels of cushioning and mechanical test results were correlated [6,8,10,11]. However, mechanical test results did not always correspond with perceived levels of cushioning, possibly affected by the type of mechanical test that was carried out. Thus, this study aimed to compare perceived levels of cushioning with results from our newly proposed mechanical test, that might more closely simulate actual dynamic walking or running conditions. It was hypothesized that perceived levels of cushioning matched dynamic test results of the four models of running shoes that were tested.

2 Methodology

2.1 Participants

Nineteen male runners (age: mean 24.7 (SD 1.9) years old; height: mean 1.73 (SD 0.03) m; body mass: mean 67.4 (SD 6.9) kg) participated in this study. Participants ran at least once a week and are heel-strikers. They had no injuries in the lower back, hip, and lower extremities three months before and during the study and had no previous lower-limb surgery in the last three years. As only shoes with US9 sizes were available for this study, participants with only US8.5 to US9.5 were recruited. The study was approved by the Nanyang Technological University Institutional Review Board (IRB-2020-09-045). All participants were briefed of the protocol before signing a written consent form as an agreement to take part in the study.

2.2 Mechanical Test

Dynamic shoe drop tests were conducted on four brands of running shoes using the CADEX Vertical Impactor (Twin-Wire 1000kg Machine, CADEX Inc, Saint-Jean-sur-Richelieu, QC, Canada) (Figure 1). The shoes included in the study were Nike Zoom Fly SP, Asics Gel-DS Trainer 24, Brooks Glycerin 17 and Decathlon Kalenji Run Active.

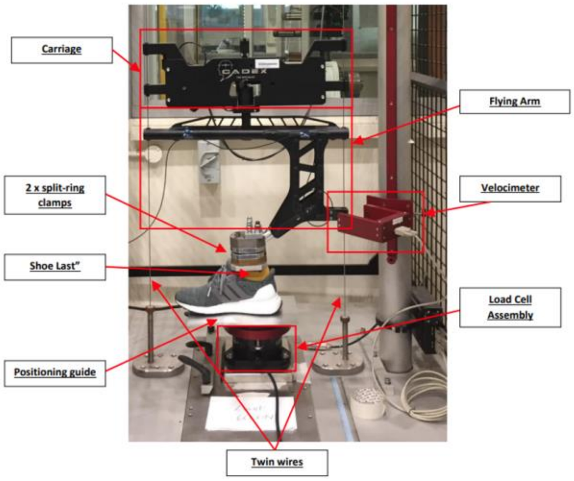

Figure 1 Set up for the dynamic shoe drop test.

Following the ASTM F1976 - Standard Test Method For Impact Attenuation Properties Of Athletic Shoes Using An Impact Test [7], moderate drop energy of 5J was used in this test. Instead of impacting the shoe, each shoe with added weights amounting to around 4kg was raised to a height of 15 cm before dropping onto the force plate below to better simulate dynamic movements during moderate impacts such as in walking. For each of the four shoes (right side, size US9), four drop tests were carried out, and the data collected was put through a Butterworth low-pass 4th order filter of 800 Hz via a MATLAB code. Mean loading rate was calculated as the gradient of the vertical ground reaction force curve between 10% to 90% of the slope from heel strike to the first peak. The loading rate (N/ms) of each shoe was then averaged across the four drop trials.

2.3 Participant Protocol

This is part of a bigger study. Participants were asked to brisk walk over a 10m walkway and to carry out a double leg drop vertical jump from a 30-cm platform in a randomized order while wearing the four different brands of shoes. The order of the shoes was also randomized to prevent any chronological biases. Before the start of the experiment, each participant was briefed and asked to carry out the same stretching exercises. Their fatigue levels were monitored using the Borg Scale [12]. Only the dominant foot was used in the collection of experimental data and participants were asked to identify their dominant foot as the foot which kicked a ball the furthest [13]. Each participant was allowed as many practice trials as required. After which, each participant was asked to rate their perceived levels of cushioning of the running shoes using the 10cm visual analog scale (VAS). Participants were blinded to the mechanical properties of each shoe.

2.4 Data Analyses

Normality assumption was first checked with the Shapiro–Wilk test and data were found to be normally distributed ($p > 0.05$). To compare among the perceived levels of cushioning, a oneway repeated measures Analysis of Variance was conducted at $\alpha = 0.05$ (IBM SPSS 26.0 — IBM Corp., NY, USA). Sphericity could not be assumed when data were tested using Mauchly's test of sphericity and a Greenhouse–Geisser correction was applied. Post-hoc test with Bonferroni adjustment was made with a family-wise $\alpha = 0.05$. Data are presented as mean (standard deviaton).

3 Results and Discussion

The shoe had a significant effect on participants' perceived levels of cushioning (Table 1). Post-hoc tests showed that the Decathlon shoe was perceived to have significantly less cushioning than the Asics ($p < 0.001$), Nike ($p = 0.032$) and Brooks ($p < 0.001$) shoes. On the other hand, dynamic drop test results showed that Nike shoe was rank the best with the least loading rate (associated with relatively better cushioning and force absorption), followed by Brooks and then Asics, finally ending with the Decathlon shoe that relatively had the highest loading rate (Table 1).

Table 1 Perceived cushioning levels in participant trials and loading rates of the shoes based on mechanical testing

(mean (standard deviation)).

	Shoe			
Variable	Asics	Decathlon	Nike	Brooks
Perceived Cushioning Levels (cm)*	6.84 (1.80)	3.34 (2.47)	6.38 (2.79)	6.32 (1.69)
Mechanical Test Result: Loading Rate (N/ms)	148.72 (0.92)	200.73 (4.55)	136.46 (2.03)	140.87 (2.93)

* $p < 0.001$

The Decathlon shoe, which had significantly worst perceived cushioned running shoe, corresponded with the worst loading rate measured in the dynamic test. However, perceived levels of cushioning of shoes were not significantly different among shoes with similar loading rates in the dynamic tests. These results suggest that participants were only able to consistently perceive a similar worst level of cushioning when the increase in loading rate was big enough. In this study, the difference between Nike and Brooks and between Brooks and Asics was around 4 N/ms and 8 N/ms respectively. However, between Asics and Decathlon, the difference jumped to 52 N/ms. In future, more shoes of various cushioning results from our drop test set-up, could be used to determine the minimum difference required for a person to detect a difference in cushioning. Should results fall within the limit, manufacturers could possibly assume that consumers were unable to detect any differences in their shoe cushioning.

On the other hand, the new dynamic drop test proposed in this study was able to correctly identify trends in shoe properties that corresponded with perceived cushioning levels. Shoes perceived similarly as relatively better in cushioning correspond with lower loading rates that are close in the drop test. This suggests that footwear manufacturers might be able to use the test to estimate customer satisfaction and perceived levels of cushioning. In the literature, mechanical tests using the ASTM F1976 was similarly consistent with perceived levels of cushioning especially when the difference was sufficiently large [8]. Thus, to further evaluate the usefulness of the current dynamic test over the ASTM F1976 test, which is easier to conduct, biomechanical test results must be compared with mechanical test results in future. Cushioning of shoes have been found to have an effect on injury risks when 848 healthy runners were followed over six months [9]. With a mechanical test that could correlate with loading rates experienced during running, this could further help footwear manufacturers test the effectiveness of their cushioning materials.

Limitations: Firstly, currently only one shoe size was used in the study. Participants' feet were restricted to US8.5 to US9.5 but some participants might have feet that did not fit the shoes as well. This could affect the results of the perceived cushioning. More shoe sizes could be provided in future studies. Secondly, the CADEX Vertical Impactor was asymmetrical, and weights have been positioned to counter this. However, the shoes may be slightly unbalanced and differ across shoe models due to the shoe design. A more balanced set-up could help in making the test more robust.

4 Conclusion

A new dynamic drop test to better simulate walking or running was proposed in this study. Participants rated their perceived levels of cushioning of four models of running shoes using the 10cm visual analog scale (VAS) after brisk walking and carrying out the drop vertical jump in them. Results showed that the running shoe with the worst perceived level of cushioning corresponded with the worst loading rate measured in the dynamic test. On the other hand, perceived levels of cushioning of shoes were not significantly different among shoes with similar loading rates in the dynamic tests. This suggests that the new dynamic test could be able to determine customer satisfaction only if differences were large enough. Future work could determine the minimum difference that corresponds with a possible perceived level of cushioning for consumers. In doing so, shoe manufacturers could then use mechanical tests to determine consumer perception of cushioning levels in their shoes.

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