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Comparison of the linear mechanical deformation of the cushioning material of running shoes between different sizes of the same brand and model

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Abstract

Introduction: Running shoes were the first footwear to successfully incorporate cushioning technologies. The purpose of cushioning is to attenuate the ground reaction force after initial foot contact during running. The cushioning has been shown to provide benefits including the prevention of injury, and improvement in running performance; however, more information is needed in relation to changes in the density of the cushioning material in different shoe sizes. This study aimed to compare the deformation of cushioning under compression between different sizes of shoes from the same model and brand. **Methods:** This is a cross-sectional observational study evaluating eight new identical sports shoes, varying only in color and size (from 6US to 11US). The region of the cushioning of the shoes was submitted to compression through a hydraulic press, which exercised a varying load of 10 kg in increments of 10 kg until 100 kg was reached. The load was monitored by a digital dynamometer. The linear deformation of the cushion was recorded through a millimeter ruler attached to the system. MANOVA was performed using the statistical package SPSS version 18.0. It was considered the level of $P < 0,05$. **Results:** There was no statistically significant difference between the mean of linear displacement and the size of shoes for all strata of loads applied to the pads. **Conclusion:** The material used for the construction of sports shoes shock absorbers of the same brand and model analysed is not differentiated between the sizes, which could compromise their function.

Keywords: Shoes, Running, Biomechanics

Introduction

Running shoes are designed to reduce loading on the lower limb joints caused by the ground reaction force (Frey, 1997). Therefore, efforts have been focused on designing better cushioning materials to dissipate energy and consequently prevent running-related injuries (Frey, 1997; Nigg, Segesser, 1992).

Impact absorption in running shoes is especially required on the rearfoot; since cushioning under the forefoot can produce instability and reduce running performance due to energy loss during the propulsion phase, which is in turn due to the shoe material (Dixon *et al*., 2003; Stefanyshyn, Nigg, 1997). The shoe's cushioning on the rearfoot reduces the magnitude of the ground reaction force during initial contact of running (Dixon *et al*., 2003; Stefanyshyn, Nigg, 1997). In this context, studies have demonstrated that shoe's cushioning can reduce the incidence of bone stress fracture (Scully, Besterman, 1982; Schwellnus *et al*., 1990; Milgrom *et al*., 1985), metatarsal stress fracture and foot overuse injuries in basketball players (Milgrom *et al*., 1992).

Although previous studies have demonstrated the importance of a shoe's cushioning to reduce the occurrence of running-related injuries (Scully, Besterman, 1982; Schwellnus *et al*., 1990; Milgrom *et al*., 1985; Milgrom *et al*., 1992), there is a lack of information supplied by companies regarding the relationship between a shoe's cushioning stiffness or deformation in relation to the shoe's size. Considering a given size of a running shoe, this footwear has to be capable of attending to different user weights with the same foot size.

Big shoe sizes have a bigger rearfoot area to dissipate impact in comparison with small shoes. Consequently, it could be argued that the larger foot support area compensates for the greater loading applied by taller persons, however, body mass is not linearly proportional to height. The same model and brand of running shoe have to cope with the different behavior of the shock absorber material under the rearfoot regardless of shoe size and runner's weight. Therefore the purpose of this study was to compare the linear mechanical deformation of the rearfoot cushioning area of the same brand and model of running shoes when subjected to known compression forces in order to verify if the footwear can adapt the midsole stiffness between different shoe sizes.

Methods

This is an observational cross-sectional study that evaluated eight new running shoes, of the same brand and model, with an average cost of $150.00 each, varying only in color and size. The size number ranged from 6 (US) to 11 (US). The inclusion criteria for the shoes were: A) Be of the same brand. B) Be of the same model. C) Have the same cushion technology. The exclusion criteria were: A) Show any kind of malfunction. B) Have been used. C) Date of manufacture longer than 6 months.

To perform compressions on shoes, a 15-ton hydraulic press (Marcon, Marilia - SP) was used. An aluminum cylinder with a known area of 30 cm2 (11.81 in2) was used to transmit the force exerted by the hydraulic press to the rearfoot area inside the shoe, this was coupled to a metallic rod which was used to measure the linear displacement of the cushioning against a millimeter ruler attached to the hydraulic press. The apparatus itself was composed of a metallic platform to support and stabilize the running shoes during the test, and a portable digital dynamometer (Homis, model 2100, São Paulo-SP) to monitor the compressive load applied by the hydraulic press in real-time (Figure 1). A video camera was mounted on a tripod at a fixed height to record the linear displacement.

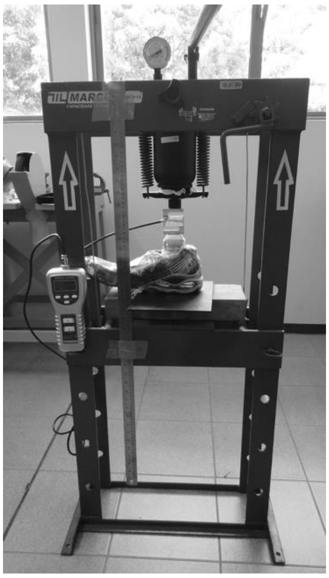

Figure 1: Setup prepared to compress the rearfoot area of running shoes.

The right shoe in each size was prepared by removing to internal insoles to ensure the isolated compression of the shoe cushioning material and the order in which the shoes were tested was randomized. The shoes were positioned on the metal platform support and the compression cylinder was fixed inside the shoe. After positioning the shoe, the load cell was inserted between the compression cylinder and the piston of the hydraulic press. The dynamometer was reset and set to record the force in kilograms (kg), the ruler position was zeroed and the measurements were filmed.

The compression exerted by the hydraulic press was controlled by reading the digital display of the dynamometer and the linear displacement indication in the millimeter ruler through the video. All tests were performed on the same day by the same investigator.

An initial pilot test was carried out to define the number of consecutive compression tests needed. This was achieved by analyzing the mean and standard deviations for a number of compressions. This determined that five compression tests were sufficient to obtain stable data.

Each shoe was then positioned in the hydraulic press. An initial load of 10 kg was applied and the compression was recorded. Then, load increments were performed in sets of 10 kg up to the maximum load of 100 kg, and again the compression was recorded. For the evaluation of the rate of change of a predefined load in relation to the time of compression, in this study defined as viscoelasticity of the cushioning area, the running shoes were positioned in the same way previously described and followed the same order of randomization.

After positioning the shoe in the apparatus, the hydraulic press loads of 100 kg were regulated and the load variation was recorded every second for a total of 300 seconds. After this period, the hydraulic press piston was released and the procedure was repeated for each shoe. Before each cushion viscoelasticity test, the footwear was kept in an unloaded state for at least ten minutes to ensure the return to its initial characteristics.

A Shapiro-Wilk test was used to analyze the data distribution. All data were found to be suitable for parametric analysis. A MANOVA test was then performed followed by Tukey post hoc test with a significant level of $p<0.05$. All analysis was performed using SPSS version 18.0 for Microsoft Windows.

Results

This study explored the effect of compression tests on the rearfoot location of the cushions of running shoes of the same brand and model between sizes ranging from 6 (US) to 11.5 (US). No statistical differences were seen in the linear displacements obtained from the 5 compression tests between different forces applied by the hydraulic press in different sizes of running shoes, Table 1.

Table 1: Mean and standard deviation of angular displacement in millimeters for each load level for each shoe size.

Force (Kgf)	Size 6 US	Size 6.5 US	Size 7 US	Size 7.5 US	Size 8.5 US	Size 9.5 US	Size 10 US	Size 11 US	*P*
10	12 (0.04)	13 (0.03)	09 (0.02)	10 (0.00)	10 (0.00)	11 (0.02)	10 (0.00)	14 (0.02)	0,59
20	25 (0.04)	24 (0.04)	19 (0.02)	20 (0.00)	20 (0.00)	21 (0.02)	20 (0.00)	24 (0.02)	0,38
30	36 (0.05)	34 (0.04)	29 (0.02)	30 (0.00)	30 (0.00)	29 (0.04)	30 (0.00)	31 (0.04)	0,29
40	46 (0.05)	44 (0.04)	39 (0.02)	40 (0.00)	40 (0.00)	36 (0.04)	39 (0.02)	41 (0.04)	0,10
50	56 (0.05)	51 (0.04)	46 (0.02)	48 (0.03)	47 (0.03)	45 (0.04)	48 (0.03)	47 (0.03)	0,18
60	66 (0.05)	58 (0.06)	54 (0.02	56 (0.04)	55 (0.00)	53 (0.04)	56 (0.02)	55 (0.00)	0,16
70	75 (0.04)	68 (0.08)	63 (0.04)	61 (0.02)	64 (0.02)	60 (0.04)	62 (0.03)	65 (0.00)	0,14
80	82 (0.04)	73 (0.08)	70 (0.04)	70 (0.00)	70 (0.00)	67 (0.04)	66 (0.07)	72 (0.03)	0,09
90	88 (0.07)	79 (0.09)	74 (0.02)	73 (0.03)	76 (0.02)	73 (0.04)	75 (0.04)	77 (0.04)	0,14
100	96 (0.08)	83 (0.08)	80 (0.04)	80 (0.00)	85 (0.06)	80 (0.06)	79 (0.04)	83 (0.03)	0,13

Kgf: kilogram-force

The variation of an initial force of 100 kg which was applied and maintained for 300 seconds by the hydraulic press in each size of running shoes in the rearfoot cushioning area showed an adaptative behavior of the viscoelastic material when compressed with a fixed force, Figure 2.

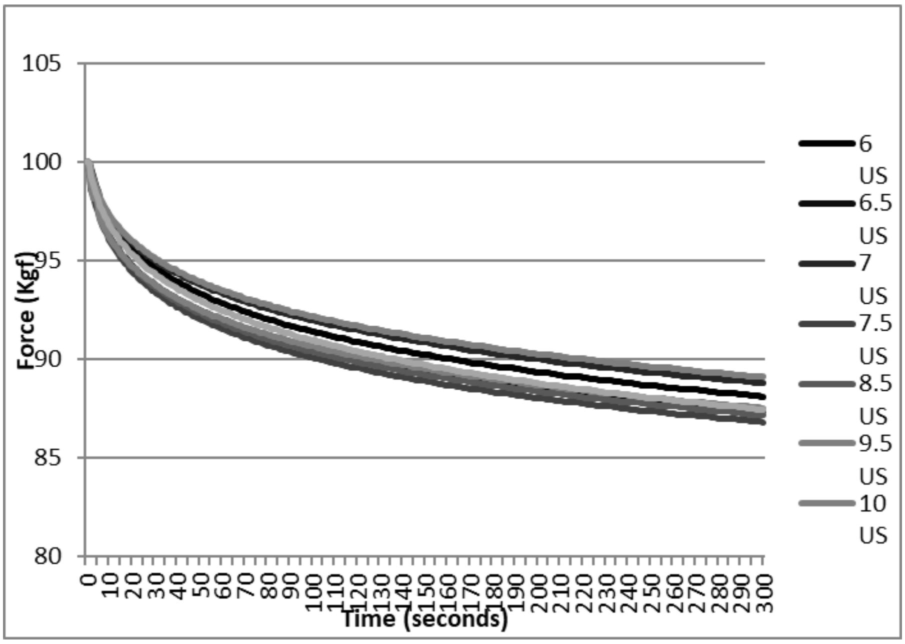

Figure 2: Variation of the initial fixed load over time for each footwear size.

The values of the standard deviations do not exceed 1 kg, the highest value being found, ± 0.81 kgf in time for the second 229, Figure 3.

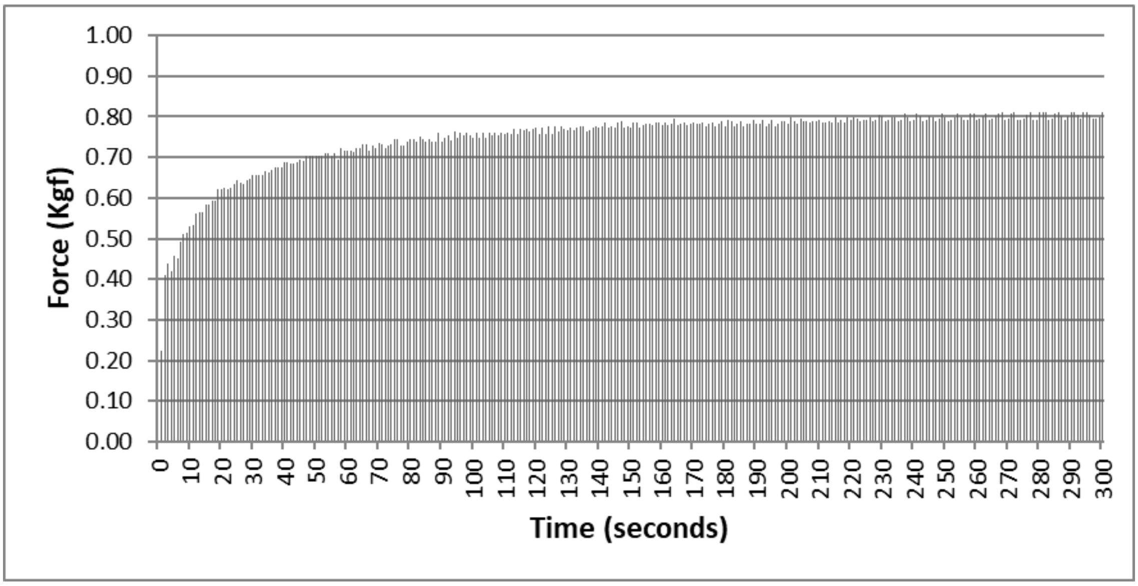

Figure 3: Standard deviation for initial fixed load variation test applied in the rearfoot area of cushioning in relation to time.

Discussion

The aim of this study was to compare the linear mechanical deformation of cushioning between different running shoe sizes of the same brand and model when submitted to a perpendicular compressive force. The hypothesis was that running shoes should present differentiation of cushioning stiffness between sizes when submitted to compression. To analyze the difference in stiffness the same cylinder interface was used in all tests to ensure the same compression area between the samples and the applied load was monitored in real time by the digital dynamometer.

It was expected that larger sizes of shoes would be constructed with more rigid materials to resist greater compression loads and present a less linear deformation when compared to the smaller sizes of shoes. This theory is justified because of the relationship between height, foot size, and body mass. Individuals with larger height have a greater foot length and a greater body mass when compared the individuals of smaller stature (Ozden *et al*., 2005; Ozaslan *et al*., 2012). Contradicting the hypothesis of this study, there was no statistically significant difference between the average of the linear displacement and the sizes of footwear for all strata of loads applied on the rearfoot cushioning area, suggesting the use of materials with similar stiffness between footwear of different sizes.

Any difference in the stiffness of the shock absorbing ability between sizes is important to ensure the effectiveness of the sports footwear, as less rigid materials will tend to deform more when heavier loads are applied which may exceed the resistance point of the material (Mills *et al*., 2003; Sun *et al*., 2008). Controlling the cushioning stiffness becomes critical when the peak of vertical force and loading rate are considered. According to Chang *et al.*, this peak created during the impact of the foot to the ground can reach up to 2.45 times the body mass (Chang *et al*., 2000).

In the present study, the linear compression load ranged from 10 to 100 kilograms force simulating different phases of running and different body loads. The lower loads simulated the initial contact of the foot with the surface, whereas the heavier loads simulated the full acceptance of weight during single limb stance during running. However, this did not examine the effect of loads applied repeatedly over a long period typically executed during the running cycle.

Sun *et al.*, conducted an axial compression test by cyclically loading 70 kilograms applied on materials used in cushioning. They found that the stiffness of the viscoelastic material increased after repeated compression (Sun *et al*., 2008). In this same work, it was identified that after removing the compressive load the material did not completely return to its original thickness (Sun *et al*., 2008). Considering the results presented by Sun *et al.* and the result of this study, it would be important to assess the cushioning efficiency in returning to its original thickness during the running swing phase, where there is no load applied. According to Bartlett, a runner is able to reach 500 to 1200-foot contacts to the ground per kilometer traveled. These results indicate that in addition to the magnitude of the impact and the frequency with which they occur should be considered in the manufacture of shock absorbers (Bartlett, 1999).

The second hypothesis of this study was that after applying a fixed initial load of 100 kg and analyzing the adaptation of the viscoelastic cushioning material during a period of time, the behavior exhibited by the different sizes of footwear would be changed due to the need to differentiate the density of the material in relation to the size of the shoes. As shown in Figure 2, the behavior of all curves was similar for all shoe sizes. When presented with the values of standard deviations in Figure 3, these do not exceed 1 kg, with the highest value ± 0.81 kg. Again, this finding indicates a lack of differentiation of viscoelastic material properties for the construction of cushioning between the different shoe sizes.

The viscoelastic materials used in cushioning tend to have a small elastic recovery undergoing a plastic accommodation after a persistent compression and therefore, the athletic shoe cushioning should be thicker to be free from collapse after heavy use (Costi, 2006). Considering the results indicated in this study, it would be important to differentiate the rigidity of the cushioning between the sizes of athletic shoes. In addition, for better adjustment and individual effectiveness of the cushioning system, athletic shoes should be available in the body load range for the same model and size, thus aiming to maintain the viscoelastic response of the cushioning.

One possible barrier to the implementation of an individualized cushioning system would be the increase in the cost of production of the athletic shoes. A possible solution to this obstacle would be to apply a system similar to footwear to the Rainha System (Alpargatas) designed by Bacchiocchi in the 90s, in Brazil, where different densities are selected by the body mass and added to a cylindrical compartment inside the rearfoot cushioning region (Bacchiocchi, 1992).

Further research is needed to evaluate the linear deformation in different brands of running shoes, accessing the efficiency of recovery in viscoelastic proprieties and original thickness of cushioning during the swing phase of running, and the development and application of custom cushioning for individuals with different body mass.

Conclusion

From this study, it can be concluded that the material used for the construction of sports shoe shock absorbers of the same brand and model analyzed is not differentiated between the sizes, which could compromise their function.

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