Journal of Science and Medicine in Sport 18 (2015) 93–97

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Biomechanical variables and perception of comfort in running shoes with different cushioning technologies

Roberto C. Dinato[a], Ana P. Ribeiro[a], Marco K. Butugan[a], Ivye L.R. Pereira[a], Andrea N. Onodera[b], Isabel C.N. Sacco[a,*]

[a] University of Sao Paulo, School of Medicine, Physical Therapy, Speech and Occupational Therapy Department, Brazil
[b] Biomechanics Laboratory, DASS Sport & Style Inc., Ivoti, Brazil

ARTICLE INFO

Article history:
Received 1 February 2013
Received in revised form 4 November 2013
Accepted 20 December 2013
Available online 1 January 2014

Keywords:
Plantar pressure
Ground reaction force
Comfort
Running
Biomechanics

ABSTRACT

Objectives: To investigate the relationships between the perception of comfort and biomechanical parameters (plantar pressure and ground reaction force) during running with four different types of cushioning technology in running shoes.
Design: Randomized repeated measures.
Methods: Twenty-two men, recreational runners (18–45 years) ran 12 km/h with running shoes with four different cushioning systems. Outcome measures included nine items related to perception of comfort and 12 biomechanical measures related to the ground reaction forces and plantar pressures. Repeated measure ANOVAs, Pearson correlation coefficients, and step-wise multiple regression analyses were employed ($p \leq 0.05$).
Results: No significant correlations were found between the perception of comfort and the biomechanical parameters for the four types of investigated shoes. Regression analysis revealed that 56% of the perceived general comfort can be explained by the variables push-off rate and pressure integral over the forefoot ($p = 0.015$) and that 33% of the perception of comfort over the forefoot can be explained by second peak force and push-off rate ($p = 0.016$).
Conclusions: The results did not demonstrate significant relationships between the perception of comfort and the biomechanical parameters for the three types of shoes investigated (Gel, Air, and ethylene-vinyl acetate). Only the shoe with Adiprene+ technology had its general comfort and cushioning perception predicted by the loads over the forefoot. Thus, in general, one cannot predict the perception of comfort of a running shoe through impact and plantar pressure received.

1. Introduction

The popularity and the practice of running have considerably increased worldwide over the last 30 years.[1–3] This has initiated much scientific interest for the development of new products and technologies to reduce potential risk factors of injuries associated with running, such as improvement of running shoes. Up until the1980s, research focusing on the development of running shoes adopted only approaches related to the results of mechanical tests of the shoes midsole materials.

In addition to the mechanical tests usually performed, more complex biomechanical analyses were included with the purpose of developing better cushioning technologies after the 80s. The comprehension of how the body interacts with the running shoes material, obtained by analyzing the resultant external forces produced by this interaction, was believed to be important for the development of specific technologies to attenuate the impact forces. The measurement of the ground reaction forces[4] and the calculation of loading rates,[5–7] both used as indirect methods for assessing these impacts during running, were found to be effective to identify how the these loads are attenuated by the use of various running shoes, and what is their relationship with histories of running injuries.[7–9]

In addition to the ground reaction force, measurement of plantar pressure appeared to be efficient in distinguishing differences between the characteristics of shoe cushioning,[10] and thus, became a potential approach for the appropriate prescriptions of running shoes.[11] Some researchers have recommended this approach to investigate the risk of running injuries.[11,12] Recently, Clinghan et al.[13] concluded from the measure of plantar pressures during gait, that the capacity of attenuating the loads was not related to the cost of the shoes. Considering that the indicators of impact,

* Corresponding author.
E-mail address: icnsacco@usp.br (I.C.N. Sacco).

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http://dx.doi.org/10.1016/j.jsams.2013.12.003

measured by means of biomechanical approaches, could help the prescription of appropriate running shoes,[11] it would be important to investigate if runners are capable of perceiving if the running shoes attenuates impact forces, similarly to the biomechanical assessments. These perceptions of comfort are closely related to the sense that the runners have regarding the loads imposed on their bodies during running practices.

The perception of load attenuation (perception of cushioning) has been the focus of studies.[14–16] Milani, Hennig, and Lafortune[14] andHennig, Valiant, and Liu[17] observed strong association between the runners' perception of the shoe's cushioning properties and the indicators of resultant impacts, assessed by ground reaction forces and plantar pressures, while using shoe with various ethylene-vinyl acetate (EVA) midsole densities. Interestingly, based on these results, a better perception of cushioning was related to a higher magnitude of impact forces. Some authors suggested that the body perceptive–sensory systems are able to distinguish impacts of various frequencies and magnitudes, as a function of the characteristics of the shoe, particularly in the stiffness of their midsole. Thus, the runners adopted kinematic adjustments in their running techniques to reduce impact levels on the anatomical structures of their feet.[14,17]

It is important to note that previous studies[13,16] only investigated how the different levels in stiffness of the EVA midsole altered the users' perception and the biomechanical variables, and did not include nor specify the cushioning technologies of the running shoes. Wegener, Burns, and Penkala[15] investigated in-shoe plantar pressure loading and comfort during running in two cushioning technologies running shoes, Gel and Hydro Flow only for athletes with cavus feet. Some technologies, such as air, gel, wave, amongst others, have been introduced in the midsole of the shoe with the purpose of optimizing the reductions of the impact forces. Therefore, it is important to conduct a biomechanical investigation that seeks potential relationships between the perception of impact modifications and load reductions in running shoes with technology cushioning midsoles.

The objective of this study was to investigate the relationship between the perception of comfort and biomechanical variables related to impact during running with four different shoe cushioning technology types. The study's hypotheses were: (i) running shoe with EVA midsole would lead to lower load rates, but lower levels of comfort; (ii) Gel, Air, and Adiprene shoes would result in lower load rates and higher levels of comfort, since the aggregate midsole materials would have the potential of optimizing load attenuation; and (iii) there would be significant correlations between rearfoot impacts and forefoot forces and the perception of comfort with these cushioning technology running shoes.

2. Methods

Twenty two men, who were recreational runners with mean age of 39.4 ± 6.6 years; body mass of 76.1 ± 9.2 kg; height of 1.73 ± 0.04 m were evaluated, according to the following criteria: Were aged between 18 and 45 years; had running experience of at least one year; a training volume of at least 20 km per week; a shoe size of 40; rearfoot contact running technique; a neutral static foot alignment, as determined by the *Foot Posture Index*-6[18] (FPI-6), evaluated by a trained physiotherapist; and had not suffered any musculoskeletal injuries over the last six months. All participants provided written consent, based upon approval by the Ethics Committee of the School of Medicine of the University of Sao Paulo (329/11).

All of the acquired running shoes were of known market brands, cost between (BRL 200–300), and to the characteristics of available shoes (Table 1). The shoes were masked with a black adhesive tape, so that any brand identification was eliminated, and were randomly numbered after being blinded, so neither the runners nor the examiners could identified them. In this way, the assessments of both comfort and biomechanical parameters were double blinded. Simple drawing randomized the order of assessments for each runner and this order was kept for the both comfort and biomechanical evaluations.

The runners underwent a pre-trial adaptation phase for the each shoes for 10 min.[17] Visual Analog Scale (VAS) evaluated the perception of comfort for each shoe characteristic evaluated. After each pre-trial adaptation, the runner rated nine aspects of the shoe related to its comfort perceived. The comfort scale used lengths 100 mm with the left end labeled 'not comfortable at all' (0 comfort point) and the right end 'most comfortable condition imaginable' (10 comfort points). Since many aspects of footwear may influence comfort, specific comfort ratings were included: forefoot cushioning, heel cushioning, arch height, heel height, shoe heel width, shoe forefoot width, shoe length, medio-lateral control and overall comfort, following Mundermann et al.[19] study.

The biomechanical measurement was carried out in two phases after the comfort evaluation. The first phase consisted of the acquisition of the plantar pressures during running on a flat asphalt surface at the University campus. The second phase consisted of measuring the ground reaction forces inside the laboratory. In both locations, the participants ran at 3.3 m/s (±5%) and were monitored by means of two photoelectrical sensors (Speed Test Fit Model, Nova Odessa, Brazil).

The asphalt track was 40 m long and the plantar pressures were acquired in the intermediate 20 m. The plantar pressure was recorded at 100 Hz with the Pedar® in-shoe pressure measurement system (Novel, Munich, Germany), with a spatial resolution of approximately one sensor/cm.[2] Three running trials were obtained for each shoe condition. The ground reaction forces were acquired with an AMTI force plate (AMTI OR-6-1000, Watertown, EUA) at 1 kHz. Before data acquisition, all participants were familiarized with the equipment, the laboratory setting, and the required speed. Nine valid trials were analyzed.

The peak pressure (kPa), contact area (cm^2), and the pressure time-integral (kPa s) were measured over three plantar areas: rearfoot (30% of foot length), midfoot (30% of foot length), and forefoot and toes (40% of foot length).[20]

Table 1
Specifications of the investigated footwear.

Specifications	Air	Gel	Adiprene	EVA
Sole material	Rubber	Rubber	Rubber	Rubber
Density of the rearfoot EVA (g/cm^3)	0.160	0.153	0.164	0.238
Impact absorption system on the rear and forefoot	Uretano-based chamber with capsulated gas under pressure	Gel cushioning units (silicon/polyurethane composite)	Adiprene in the rearfoot and Adiprene+ in the forefoot (viscous elastic foam)	EVA layers of various densities
Type of footstep	Neutral	Neutral	Neutral	Neutral
Mass (g)	309	263	322	320

EVA: ethylene-vinyl acetate.