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Effect of overground vs treadmill running on plantar pressure: Influence of fatigue

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ABSTRACT

The differences produced when running on a treadmill vs overground may call into question the use and validity of the treadmill as a piece of equipment commonly used in research, training, and rehabilitation.

The aim of the present study was to analyze under pre/post fatigue conditions the effect of treadmill vs overground on plantar pressures. Twenty-seven recreational runners (17 men and 10 women) ran on a treadmill and overground at two speeds: S_1 = 3.33 m/s and S_2 = 4.00 m/s, before and after a fatigue protocol consisting of a 30-min run at 85% of their individual maximal aerobic speed (MAS). Contact time (CT in seconds), peak pressure (PP in kPa), and relative load (RL in %) were analyzed under nine foot zones of the left foot using an in-shoe plantar pressure device.

A two-way repeated measures ANOVA showed that running on a treadmill increases CT (7.70% S_1 and 9.91% S_2), modifies the pressure distribution and reduces PP (25.98% S_1 and 31.76% S_2), especially under the heel, medial metatarsals, and hallux, compared to running overground. Moreover, on both surfaces, fatigue (S_2) led to a reduced stride frequency (2.78%) and reduced PP on the lateral heel and hallux (15.96% and 16.35%, respectively), and (S_1) increased relative load on the medial arch (9.53%). There was no significant interaction between the two factors analyzed (surface and fatigue). Therefore, the aforementioned surface effect, which occurs independently of the fatigue state, should be taken into account when interpreting the results of studies that use the treadmill in their experimental protocols, and when prescribing physical exercise on a treadmill.

1. Introduction

Properties of different surfaces provoke biomechanical modifications in running gait [1], making the running surface an essential aspect to consider when designing the methodology of gait analysis. Within this area of research, the use of treadmills is becoming ever commoner [2–5] since it provides numerous methodological advantages – less space required, repeatability, and better control of climatological aspects, speed, slope, etc., as well as easier instrumentation of the runner [2–4,6–8]. However, the generalization of results from studies that analyze running on a treadmill may become controversial if treadmill and overground running biomechanics are not proven to be equivalent [4,8]. In this sense, there is evidence showing differences when running on a treadmill and overground in several variables – stride frequency [3,5,8,9], contact time [5,8,10], ankle, knee, and hip kinematics [3,5,7,8,11], muscular activity [5,6], energy expenditure [12], shock attenuation [13], and plantar pressures [6,14]. These differences could be due to treadmill familiarization [2], intra-stride treadmill speed variations because of the interaction between the runner and the device [4], air resistance [12], and the runner trying to reach a stable and safe running pattern on the treadmill [5–7]. Another factor that can affect the comparison between overground and treadmill is the running speed. According to Williams (1985) (cited by Nigg et al. [7] and Riley et al. [3]), the differences observed between treadmill and overground increase as the speed increases, but, contrary to that observation, Nigg et al. [7] find biomechanical differences between surfaces at 3 m/s, 4.5 m/s, and 5 m/s, but not at 6 m/s. The heterogeneity of the effects of the running surface when measured at different speeds and the well-known alterations

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of biomechanical measurements caused by speed changes [15,16] suggest that treadmill and overground running biomechanics should be compared taking into account different ranges of speeds.

The differences found when comparing treadmill and overground running may cast doubt on their equivalence as running surfaces [4–7,9,13,14]. Nonetheless, several authors consider running on a treadmill to be a representative expression of running overground [3,8,11].

Besides the controversy involving the behaviour of biomechanical variables for the two surfaces, such an important factor during running as is the fatigue state has yet to be taken into account when comparing treadmill vs overground running. The aforecited studies do not take fatigue into account, even though a fatigued runner may alter the biomechanics of their running by decreasing the angle of the foot with the running surface at initial contact [17], changing the plantar pressure distribution [18–20], and modifying reaction forces [20,21]. In addition, fatigue may affect the biomechanical pattern of running differently on a treadmill and overground if, as cited by Baur et al. [6], these are different muscle activity patterns with specific neuromuscular control mechanisms for each surface. Therefore, given that plantar pressures during running are analyzed on both surfaces since they constitute important variables for the development of sports materials [1], for injury prevention [21,22], and for athletic performance [18,19,21], the aim of the present study was to analyze under pre- and post-fatigue conditions the effect of the surface (treadmill vs overground) on plantar pressures. It is hypothesized that (a) treadmill running may alter the runner's plantar pressure pattern compared to overground running; and (b) the effect of the running surface on the plantar pressure pattern might be affected by the runner's fatigue state.

2. Methods

2.1. Participants and experimental protocol

An a priori analysis of effect size and sample size was made for a desired power of 0.9. Effect size was estimated by means of Cohen's f [23], calculated from the results of published work which studied similar dependent variables (plantar pressures, contact times), with fatigue [24] or surface [14] as independent variables. Sample size was calculated using the G*Power 3 software [25]. The result was an estimated minimum sample size of 26 subjects.

Accordingly, the study group comprised 27 healthy recreational runners: 17 men and 10 women (34.0 ± 7.8 years, 173.0 ± 8.0 cm, 66.2 ± 9.4 kg). They were informed about the experimental characteristics of the study, and subsequently provided their written informed consent.

The participants performed three running tests on different days. First, each participant underwent a maximal effort 5-min run on a 400-m track in order to determine their individual maximal aerobic speed (MAS) [26]. Second, a treadmill run (400 m on an Excite Run 700, TechnogymSpA, Gambettola, Italy) and an overground run (400-m track) were carried out at random. For both surfaces, the participants warmed-up "ad libitum" for 15 min (which also served as familiarization time on the treadmill [2]), and subsequently plantar pressures at two different running speeds (S_1 = 3.33 m/s, S_2 = 4.00 m/s) randomly chosen were measured before and after a fatigue protocol consisting of a 30-min run at 85% MAS. The running speeds chosen (S_1 and S_2) cover the range of speeds most commonly used in studies comparing treadmill vs overground running [5–7,11,14], and are typical speeds for recreational runners. Plantar pressure variables were measured under the left foot using instrumented insoles (Biofoot 2001®), registering data at 500 Hz for 3 s. In addition, after the fatigue protocol, the runners completed a scale of perceived exertion [27].

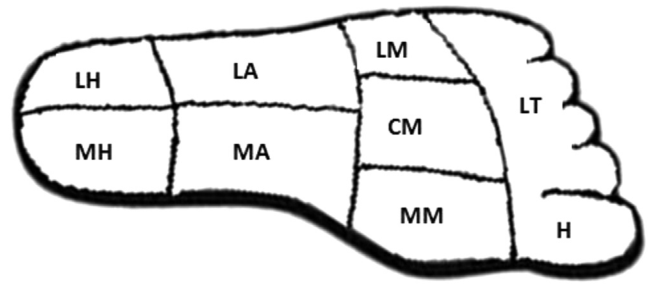

Fig. 1. Distribution of the nine zones of the foot distinguished in the analysis: LH (lateral heel), MH (medial heel), LA (lateral arch), MA (medial arch), LM (lateral metatarsal), CM (central metatarsal), MM (medial metatarsal), LT (lesser toes), and H (hallux).

The time between the treadmill and 400-m track tests was 7 days. Both runs were carried out at similar times of the day under non-adverse climatic conditions, with each participant using their own running shoes (the same footwear for all three tests), using an acoustic signal system which marks the running rate by means of cones placed around the track to monitor and control the running speed in the 400-m track test.

2.2. Plantar pressure measurement

The foot was divided into nine zones (Fig. 1), similar to those measured in previous studies [14,18,19,21]. Contact time (CT in s), stride frequency (SF in steps/min), and mean peak pressure under each foot zone (PP in kPa) were measured. Stride length (SL in m) and relative load (RL in %, representing the peak pressure observed for each zone compared to the whole foot peak pressure [28]) were also calculated and analyzed.

2.3. Statistical analysis

The mean value of two consecutive left stances was calculated for each variable and running condition (treadmill vs overground running; pre-fatigue vs post-fatigue). The data gathered were exported to the statistics software package SPSS.18®, to perform the corresponding statistics treatment for each running speed independently. After checking the variables for normality (Kolmogorov–Smirnov), they were subjected to a descriptive analysis and a two-way repeated-measures ANOVA considering fatigue (pre-fatigue, post-fatigue) and surface (treadmill, overground) as intra-subject factors. Mauchly's test was applied to check the sphericity assumption of the repeated-measures ANOVA. When sphericity was satisfied, the analysis of variance was performed using a univariate approach. When it was violated, the most powerful correction among the following was applied to adjust the degrees of freedom: Greenhouse–Geisser, Huynh–Feldt, or lower-bound. The Bonferroni post hoc correction was applied, with alpha set at 0.05 for all the tests.

3. Results

The 5-min run test resulted in a MAS of 4.48 ± 0.45 m/s, allowing the determination of the individual speed for the fatigue protocol (4.11 ± 0.39 m/s).

3.1. Effect of treadmill vs overground running

Contact times were significantly greater ($p < 0.05$) in treadmill vs overground running, but no significant differences were observed in stride frequency or stride length (Table 1). With respect to peak pressures, the pattern was similar for the two running surfaces (Fig. 2), with the highest values under the heel,