Gait & Posture 42 (2015) 91–95

Contents lists available at ScienceDirect

Gait & Posture

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

The effect of shoe type and fatigue on strike index and spatiotemporal parameters of running

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ARTICLE INFO

Article history:
Received 10 December 2014
Received in revised form 17 April 2015
Accepted 20 April 2015

Keywords:
Pressure insole
Running style
Foot strike pattern
Detrended fluctuation analysis

ABSTRACT

We aimed to observe differences in running style parameters and the stride-to-stride coefficient of variation and correlative patterns using detrended fluctuation analysis (DFA) between conventional and first-time minimalistic shoe use. We also aimed to study the effect of fatigue on these parameters. 26 recreational runners were tested using a pressure insole device on a treadmill whilst wearing conventional (CONV) and minimalistic (MIN) shoes. They then performed a prolonged running bout simulating a fatiguing training session, before being tested a second time in both shoe types. Average values of strike index (initial ground contact point on the footsole expressed as a percentage of total sole length) were not significantly different between CONV [25.7 ± 14.6% (unfatigued), 23.1 ± 11.1% (fatigued)] and MIN [28.9 ± 19.1% (unfatigued), 26.7 ± 17.6% (fatigued)] ($p = 0.501$). The fatigued state also yielded a similar strike index compared to the unfatigued state ($p = 0.661$). An overall trend in decreased inter-stride correlative patterns of strike index was observed in MIN compared to CONV ($p = 0.075$). No differences in contact time, flight time, stride time, duty factor, stride length and stride frequency were found between shoe types. A trend in reduced flight time ($p = 0.078$) and therefore increased duty factor ($p = 0.053$) was observed due to fatigue. We conclude that in recreational runners, no meaningful, acute adaptation in running style occurs as a result of first-time MIN use. Similarly, runners were able to maintain their running style after a prolonged running bout.

1. Introduction

Shoe type has been thought to affect the running style, and a handful of studies comparing minimalistic (MIN – low profile, flexible sole, reduced or zero drop, wide toe-box and no motion control or heavy cushioning) and conventional (CONV) running shoes have been published [1–4]. Popular belief is that MIN encourage a non-rearfoot strike (non-RFS) running pattern [5], thereby lowering vertical loading rates which have been associated with the occurrence of injuries [6]. However, Willy et al. (2014) observed higher vertical loading rates when MIN were used compared to CONV, and interestingly a more dorsiflexed foot at footstrike [3]. Similarly, a study comparing the ground reaction forces between racing flats and CONV found that loading rates and peak vertical impact force were significantly higher when male runners used racing flats [7]. A shorter stride length (S_{length}) and higher stride frequency ($S_{frequency}$) have been found with MIN compared to CONV [4]. Squadrone and Gallozzi [1] found a significantly reduced contact time ($T_{contact}$) and increased strike index (SI) with MIN. SI is a continuous measure of strike pattern expressing the initial contact point on the foot sole as a percentage of the total sole length, with 0% at the heel [8,9]. In contrast to the above-mentioned studies [3,4,7], Squadrone and Gallozzi [1] tested habitually barefoot runners, a minority among modern runners. Indeed it has been observed that 88–94% of recreational, shod runners adopt a rearfoot strike (RFS) pattern [10,11]. Therefore a consensus on the effect of shoe type on running style, especially foot strike pattern and temporal parameters, has not yet been reached.

The effect of physical fatigue on running style also remains elusive. Fatigue due to training and extended bouts of running has

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http://dx.doi.org/10.1016/j.gaitpost.2015.04.013
0966-6362/

been theorised as a potential mechanism of injury [12–15]. Researchers have looked into identifying biomechanical differences between measurements taken before and after a fatiguing running bout, yielding conflicting results for vertical loading rate [12,15], S_{length} [13,16] and $S_{frequency}$ [16,17] for example. Willems et al. [18] concluded that several plantar pressure patterns change as a result of a 20 km race and could contribute to the development of injuries, whereas Alfuth and Rosenbaum [19] found no differences in plantar pressure measurements before and after a 10 km run. These conflicting findings could be due to the variations in protocols used to fatigue the runners. The importance of recreating typical training conditions (i.e. duration and intensity) has been highlighted and recommended as these are the conditions during which most injuries occur [20].

Our main aim was to observe any differences in SI and spatiotemporal parameters between first-time MIN, and CONV use. A second aim was to identify any fatigue effect, induced by a prolonged running bout designed to mimic typical running activity, on running style parameters. Finally, we tested the interaction of the shoe type and fatigue and its influence on running style. We hypothesised that running in MIN would increase the SI whereas fatigue would decrease it.

2. Methods

2.1. Participants

A sample size calculation with a power of 80%, a significance level set at $p = 0.05$ and an expected SI mean difference based on minimal detectible change of 4.9% [9] between shoe conditions yielded a required 20 participants for this study. Runners over the age of 18, injury-free during the previous 12 months, running a minimum of twice a week on average and with an average session duration of ≥45 min with CONV were included. Runners were contacted via leaflets at races, sport shops and public training locations as well as through direct contact with participants of previous cohort studies from our laboratory. Runners already familiar with MIN, unfamiliar with treadmill running, deemed unfit to undertake strenuous exercise (by way of a standardised cardiovascular screening questionnaire) or requiring orthopaedic insoles for running were excluded. Written informed consent was acquired; the study was approved by the National Research Ethics Committee of Luxembourg (CNER N°: 201403/06).

2.2. Protocol

Participants declared their preferred running speed (PRS) defined as the speed they could maintain for a typical running session, and average session duration over the last 12 months. They provided details regarding past and current running shoe use. All testing was performed on a treadmill (Woodway, PPS70 Plus, Germany) in two different shoe types: MIN (0 mm drop, 5 mm overall stack height, 158 ± 15 g average shoe mass, very flexible) and CONV (10 mm drop, 26 mm heel stack height, 284 ± 25 g average shoe mass). The order of shoe testing was randomised, and runners were equipped with the Runalyser (TNO, Eindhoven, The Netherlands), a pressure-sensitive insole device which is inserted into the shoe and designed to measure pressure location and temporal parameters [9]. The pre-fatigue acquisition protocol started with a 5-min warm-up at 85% of the PRS. Then treadmill speed was increased to the PRS and participants continued running for another 5 min. This resulted in 10 min of running, enough time to provoke short-term adaptation to shoe type [21]. Pressure data was acquired during the final 2 min at the PRS along with heart rate (HR) and rate of perceived exertion (RPE) using the visual analogue scale from 6 to 20 [22]. After a 5-min recovery period, the procedure was repeated with the other shoe type. After a 2-min break, participants completed a fatiguing running bout using their own, habitual running shoes. Duration was defined as 120% of a typical running session duration minus the 20 min pre-fatigue acquisition period. If participants felt they could not complete the predefined duration, slight adjustments in speed were made according to the RPE and HR which were recorded every 5 min. We ensured that RPE remained <17 throughout. After completing the fatiguing running bout, the acquisition protocol for both shoe types was repeated (in the same order) with 2-min breaks for the participant to change shoes and install the Runalyser.

2.3. Data analysis

Data of both feet were averaged for all acquisitions, and SI, contact time ($T_{contact}$), flight time (T_{flight}), stride time (T_{stride}), duty factor (DF, $T_{contact}/T_{stride} \times 100$), S_{length} and $S_{frequency}$ were calculated using custom-made MATLAB (Mathworks Inc., USA) algorithms as previously described [9]. Based on previously published cut-offs [9], runners were subdivided as RFS (SI < 43.9%) or non-RFS (SI > 43.9%) runners using their pre-fatigue, CONV data. Using the full 2-min data acquisitions, coefficient of variation (CV) of each parameter was calculated providing information on the stride variability. Detrended fluctuation analysis (DFA) was performed on all parameters, to detect any presence of stride-to-stride correlative patterns within each time series [23,24]. This technique calculates a scaling exponent value known as α, which can be interpreted as follows: $\alpha = 0.5$ represents white noise or the absence of any correlation, $\alpha > 0.5$ signifies that long-range correlations are present (as α increases, so does the strength of the correlation), meaning that a given stride is correlated with one or more previous strides. Finally, an $\alpha < 0.5$ signifies the presence of anti-correlations, meaning that a shorter stride is more likely to be followed by a longer one, for example.

2.4. Statistics

Linear mixed models with "shoe type" and "fatigue" as fixed effects and "subject" as random slopes and intercepts were used to test all variables measured with the unstructured term applied. The statistical software package SPSS for Windows version 20 was used. Statistical significance was accepted at $p < 0.05$.

3. Results

27 runners were tested, and data for one participant who was unable to complete the fatiguing running bout due to pain in the lower extremity was discarded. Table 1 provides a description of the 26 runners retained for the analysis. Four runners (15.4%) were identified as non-RFS runners (no significant differences in demographics were observed between non-RFS and RFS runners). The average running duration between acquisitions of the same shoe type was 73.7 ± 13.1 min,

Table 1
Descriptives and training characteristics of the 26 participants.

RFS runners	$n = 22$ (84.6%)
Sex (male)	14 (63.6%)
Age (y)	40 ± 8
Height (m)	1.75 ± 0.08
Weight (kg)	70 ± 10
BMI (kg/m^2)	22.9 ± 2.0
Running experience (years)	9.8 ± 7.8
Average number of sessions/week	3.3 ± 1.1
Average session duration (min)	63.2 ± 13.2
Preferred running speed (km/h)	10.7 ± 1.3
Total mileage last 12 months (km)	1352 ± 758
Months run last 12 months	11.8 ± 0.6

RFS: rearfoot strike; BMI: body mass index; values are mean ± SD.