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The effect of footwear and footfall pattern on running stride interval long-range correlations and distributional variability

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ABSTRACT

The presence of long-range correlations (self-similarity) in the stride-to-stride fluctuations in running stride interval has been used as an indicator of a healthy adaptable system. Changes to footfall patterns when running with minimalist shoes could cause a less adaptable running gait. The purpose of this study was to investigate stride interval variability and the degree of self-similarity of stride interval in runners wearing minimalist and conventional footwear. Twenty-six trained habitual rearfoot footfall runners, unaccustomed to running in minimalist footwear, performed 6-min sub-maximal treadmill running bouts at 11, 13 and 15 km·h^{-1} in minimalist and conventional shoes. Force sensitive resistors were placed in the shoes to quantify stride interval (time between successive foot contacts). Footfall position, stride interval mean and coefficient of variation (CV), were used to assess performance as a function of shoe type. Long-range correlations of stride interval were assessed using detrended fluctuation analysis (α). Mean stride interval was 1-1.3% shorter ($P = 0.02$) and 27% of runners adopted a midfoot footfall (MFF) in the minimalist shoe. There was a significant shoe effect on α and shoe*speed*footfall interaction effect on CV ($P < 0.05$). Runners that adopted a MFF in minimalist shoes, displayed reduced long-range correlations ($P < 0.05$) and CV ($P < 0.06$) in their running stride interval at the 15 km·h^{-1} speed. The reduced variability and self-similarity observed for runners that changed to a MFF in the minimalist shoe may be suggestive of a system that is less flexible and more prone to injury.

1. Introduction

It has been suggested that conventional cushioned running shoes may reduce performance [1] and contribute to injury [2]. Minimalist shoes, with reduced heel drop and cushioning, have been suggested as an alternative footwear option for distance running [2]. Investigations into the effects of running in minimalist shoes have shown reductions in stride length [3,4] and the amount of ankle dorsiflexion at initial contact [4] and that minimalist shoes can promote the adoption of a forefoot or midfoot footfall (MFF) pattern [5,6]. These changes to running gait can reduce loading at the knee and vertical ground reaction force (GRF) loading rate [2,7]. Reduced knee loading and vertical GRF loading rate could be protective against running injury and this has been suggested as a mechanism for minimalist shoes to reduce injuries [2,8]. However, Ryan et al. [8] found that transitioning to a minimalist shoe over a 3-month training period was associated with increased rates of injury. Characteristics of running gait other than knee loading and vertical GRF may be responsible for these transition injuries.

Previous investigations of minimalist shoe running gait have focussed on the analysis of average stride properties that are derived from consecutive strides or trials [3–6]. This analysis assumes that stride-to-stride fluctuations in gait simply represent uncorrelated (white) noise [9]. However, analysis of stride-to-stride fluctuations in running stride interval (time between successive foot contacts) has shown that these fluctuations are not just white noise where one stride is completely uncorrelated from any previous strides [10]. Instead, stride intervals at any point in time are dependent upon stride intervals at remote previous times, and this dependence decays in a scale-free, power law fashion [9]. The persistence of this pattern over a large number of strides indicates the presence of long-range correlations in stride interval [10]. The presence of long-range correlations in stride

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interval has been previously used as an indicator of a healthy adaptable system [11].

Meardon et al. [12] observed that runners with a recent musculoskeletal injury displayed weaker stride interval long-range correlations throughout a run to exhaustion than runners without a recent injury [12]. Accumulation of fatigue throughout the run also caused weaker long-range correlations [12]. These findings suggest that adaptability of running gait is impaired as a result of injury and fatigue. Interestingly, although injury and fatigue changed the stride interval correlation properties, the stride interval average and coefficient of variation (CV) did not change [12]. Long-range correlations could be sensitive to changes in function that more traditional measures of running gait are not.

There is growing interest in the potential performance advantages of running in minimalist footwear from both runners and scientists [3,5,8,13], but there are concerns about injury risk. It remains unclear why some runners get injured transitioning to minimalist shoes while others do not [8]. The effect of minimalist shoes and changes to footfall pattern on stride interval long-range correlations is not known and could provide valuable insight into the risk of injury. A decline in long-range correlations when changing shoes or footfall pattern could impair a runner's ability to adapt their gait to changes in the running environment. This loss of adaptability could be a mechanism predisposing to injuries sustained by runners transitioning to minimalist shoes [8] and warrants investigation.

The purpose of this study was to investigate the effect of minimalist shoes and changes to footfall pattern on stride interval long-range correlations in trained rearfoot footfall (RFF) runners, accustomed to conventional running footwear. It was hypothesised that long-range correlations in stride interval would be reduced when running in the minimalist shoe as a result of changes to footfall pattern. It was anticipated that mean stride interval would be reduced in the minimalist shoe due to a reduced stride length and stride interval variability (CV) would be greater for runners that changed footfall pattern due to their lack of familiarity with the gait pattern.

2. Methods

2.1. Participants

Twenty-six trained male distance runners (age 18-40 years, height 1.69-1.90 m, body mass 61.7-88.2 kg and weekly running distance 15-70 km) took part in the study. Participants provided their written informed consent to participate in this study, which had institutional ethical approval. Runners were required to run a minimum of 15 km per week, have no prior experience running in minimalist shoes, run with a habitual RFF gait pattern at the time of enrolment in the study (typical of 89% of runners [14]) and have no current or recent (<3 months) musculoskeletal injury. Footfall pattern eligibility was determined from over-ground running trials in the runners usual shoes at self-selected running speed filmed using a high-speed digital camera at 200 Hz (Basler Pilot, Ahrensburg, Germany).

2.2. Study protocol

This study used a cross-over design with order of conditions randomised and counterbalanced across participants (Fig. 1). Eligibility of participants was assessed in the week prior to their anticipated start date. During this eligibility assessment participants completed a 30-minute treadmill (Model 645, Quinton Instrument Co., Washington, USA) familiarisation. On separate days, eligible runners then completed an experimental testing session in a conventional running shoe (Asics Gel Cumulus-14;

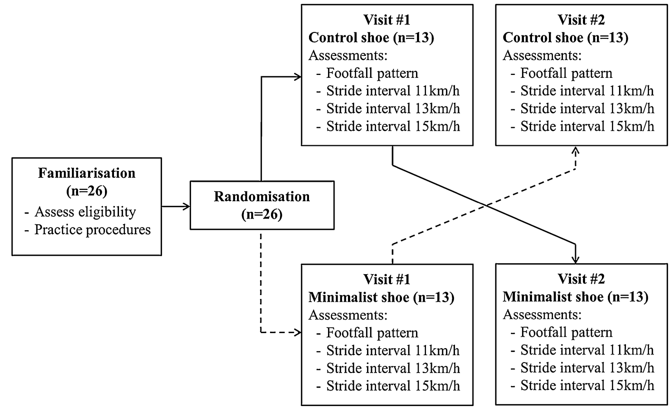

Fig. 1. Study crossover design.

mass 318 g per shoe; heel drop 9 mm) and a minimalist shoe (Asics Piranha SP4; mass 125 g per shoe; heel drop 5 mm) during which treadmill running stride interval and overground running biomechanics were assessed.

2.3. Running biomechanics

A 12 camera VICON MX-F20 system (Vicon, Oxford, UK) and four force platforms aligned in series were used to determine footfall pattern, in each of the shoe conditions, during experimental sessions. Overground running trials were performed at 18 km·h^{-1} $\pm$ 10% over a 40 m straight track. Spherical retro-reflective calibration markers placed over the 1st and 5th metatarsal head, lateral and medial malleolus, and lateral and medial femoral epicondyle were used to define the position and orientation in space of the foot and shank [15]. Marker trajectories and GRF data were sampled at 300 and 1200 Hz, respectively.

Force platform and motion data were synchronised using Vicon Nexus software (version 1.8, Vicon, Oxford, UK) and data were imported into Visual3D (Version 5, C-Motion, Maryland, USA) for post-processing. Marker trajectory and GRF data were filtered using a recursive fourth order low-pass Butterworth filter at a cut-off frequency of 25 Hz and 50 Hz, respectively. Cut-off frequency for the marker trajectories was determined using a residual analysis [16]. Footfall pattern was classified using the average strike index from five running trials [17]. Strike index was calculated using the location of the centre of pressure at initial contact along the long axis of the foot, expressed as a percentage of total foot length [17]. A strike index of 0-33% was considered a RFF, 34-67% a MFF and 68-100% a forefoot footfall [17].

2.4. Stride interval time series

After a 5-minute running warm-up on the treadmill at 8 km·h^{-1}, runners completed three 6-minute sub-maximal running bouts at 11 km·h^{-1}, 13 km·h^{-1} and 15 km·h^{-1} in a fixed order. Force-sensitive resistors (FSR) were placed underneath the forefoot and heel regions of each shoe insole. This allowed the moment of initial foot contact to be recorded wirelessly at 2000 Hz using a Delsys Trigno system (Delsys Inc, Massachusetts, USA) (Fig. 2A). Foot contacts were defined as the peak signal and were transformed to binary data (Fig. 2B). Stride intervals were calculated as the time between foot contacts (Fig. 2 C). Data were processed in MATLAB (R2013a, MathWorks, Natick, MA). Because there was no *a priori* reason to expect differences between right and left sides, analysis was limited to the right leg only [18]. The length of each time series was approximately 500 strides. No filters were applied to the time series.