BIOMECHANICAL AND METABOLIC EFFECTS OF A LEAF SPRING STRUCTURED MIDSOLE IN OVERGROUND RUNNING

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A leaf spring structured midsole shoe (LEAF) increases stride length and reduces stride rate by a horizontal foot shift during stance phase in heel-toe running and leads to an enhanced economy in treadmill running. The purpose of this study was to investigate whether these effects can also be seen in overground running. Ten male runners ran with a LEAF and a standard foam midsole shoe (FOAM) at 2 mmol/l blood lactate. Stride rate and stride length were measured by an inertial measurement unit combined with a 2D video. Running economy was quantified via spirometry. The LEAF revealed a reduction in stride rate (-0.01±0.00Hz; $p<0.03$) and an increase in stride length (9±4mm; $p<0.04$). VO_2 tend to be reduced (-0.38±0.19; $p<0.08$). This study demonstrates that the effects of a LEAF observed on treadmill are similar in overground running.

KEYWORDS: economy, running, shoe design.

INTRODUCTION: Running economy, defined as the oxygen consumption at a submaximal speed, is a key determinant of endurance performance (Saunders, Pyne, Telford, & Hawley, 2004). Shoe design and more specifically the midsole of a running shoe can alter running economy (Worobets, Tomaras, Wannop, & Stefanyshyn, 2013). Following this concept, recently a new midsole construction for a heel-striker specific running shoe has been developed. The concept of this leaf spring structured midsole shoe (LEAF) is based on using the vertical force to shift the shoe anteriorly during the first part of the stance phase in running. The vertical force is the highest loading component in running and reaches peak values of up to three times body weight (Munro, Miller, & Fuglevand, 1987). Typically, the effect of redirecting the vertical force on the anterior movement of the shoe is small for a standard ethylenvinylacetat foam midsole shoe (FOAM). During vertical compression the midsole of a FOAM deforms homogeneously in all directions (Fig. 1a), whereas the LEAF provokes a deformation of the midsole both in the vertical and anterior direction (Fig. 1b). When treadmill running at a constant speed of 3 m/s, the enlarged anterior shift of a LEAF compared to a FOAM results in an increase in stride length (21 ± 26 mm) and a decrease in stride rate (-0.02 ± 0.02 Hz). In terms of running economy, a reduction in oxygen consumption of about 2.5 % was measured (Wunsch, Kröll, Strutzenberger, & Schwameder, under review). These findings are in line with Tartaruga et al. (2012) showing that an increase in stride length and a decrease in stride rate account most for enhanced running economy. According to the literature, treadmill running is a well-established method to allow for a controlled environment and a constant running speed over many stride cycles (Fellin, Manal, & Davis, 2010; Kluitenberg, Bredeweg, Zijlstra, Zijlstra, & Buist, 2012; Saunders et al., 2004). Despite great similarities in locomotion patterns between treadmill and overground running, also differences can be detected, e.g. smaller sole angle at touchdown (Nigg, De Boer, & Fisher, 1995), higher ankle joint moment (Riley et al., 2008), shorter ground contact times (Kluitenberg et al., 2012), changes in the push-off phase (Riley et al., 2008) and a decrease in stride length and an increase in stride rate (Elliott & Blanksby, 1976; Riley et al., 2008; Schache et al., 2001) during treadmill running when compared to overground running. Thus, it is unclear whether the effects of the LEAF observed in treadmill running also occur in overground running. Therefore, the aim of this study was to compare LEAF and FOAM in overground running with respect to spatio-temporal variables and running economy.

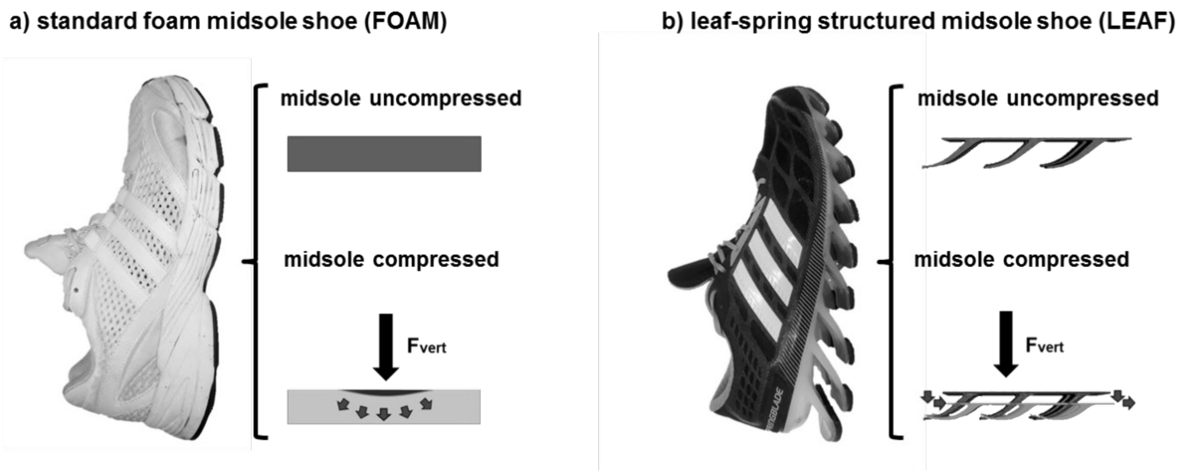

Figure 1: a) Reference shoe with a standard foam midsole (FOAM) and schematic view of the midsole under vertical compression b) Leaf spring structured midsole shoe (LEAF) and schematic view of the midsole under vertical compression

METHODS: Ten male, non-professional long-distance runners of middle-proficiency level (mean ± SE: age 33.1 ± 2.3 yrs, height 1.78 ± 0.02 m, mass 73.0 ± 2.1 kg) with an annual training of more than 240 km volunteered to participate in the study. All runners were heel-strikers with a foot-ground angle at touch-down of at least 10 degrees, which was checked beforehand as an inclusion criterion. The runners were free from injuries at time of testing. Written informed consent was signed. The participants ran on a 400 m track with the FOAM (size: US 9; mass: 340 g; Fig. 1a) and the LEAF (size: US 9; mass: 340 g; Fig. 1b). Each participant had to perform four runs of 15 min plus the time to finish the last lap. The runs followed the sequence 'shoe1–shoe2–shoe2–shoe1' starting with FOAM or LEAF in randomized order. Between each shoe condition a 5 min break was provided for shoe changing and for reducing fatigue effects. The running speed was kept constant throughout all trails according to the running speed at 2 mmol/l blood lactate, determined by a preceding incremental test till exhaustion (start: 2 m/s; step: 0.5 m/s every 5 min). The participants' running speed was audio controlled (signal/50m). Kinematic data of more than 900 strides per run and participant were recorded using an inertial measurement unit (IMU; 4000 Hz) fixed above the right ankle joint and a 2D video (50 Hz) at the finish line. Thus, right heel-strike was detected by the peak vertical acceleration of the IMU. Stride rate (f) and stride length (d) were calculated by the means of f_i [1] and d_i [2].

$$f_i=n_i/t_i \quad [1]$$

(n_i = number of strides from right heel-strike behind the finish line to right heel-strike behind the finish line of the consecutive lap; t_i = time from right heel-strike behind the finish line to right heel-strike behind the finish line of the consecutive lap; i = number of laps from the second up to the second to last lap)

$$d_i=s_i/n_i \quad [2]$$

(s_i = distance from right heel-strike behind the finish line to right heel-strike behind the finish line of the consecutive lap)

VO_2 and RER were measured continuously during the entire test using a portable breath-by-breath spirograph (K4b^2, Cosmed, Rome, Italy). The gas analyser was calibrated prior to each test with a high precision gas mixture (15.8 % O_2, 5 % O_2 in N; Praxair, Düsseldorf, Germany) and a 1L syringe (nSpire, Oberthulba, Germany). The mean value during the last five minutes of each trial for VO_2 and RER was used for further analysis. Group differences for all variables were statistically tested using paired t-tests setting the level of significance at $p<0.05$. Cohen's d_z was used to describe the relevance of differences (Cohen, 1992).

RESULTS: On average, the running speed of the participants was 2.95 ± 0.48 m/s. Biomechanical and physiological data of all measurement conditions are summarized in Table 1. Stride rate was reduced while stride length was enlarged when running with LEAF compared to FOAM ($p < 0.05$). Individual response to running with LEAF vs. FOAM is presented in Fig 2. No difference in RER and a trend towards a reduction in VO_2 ($p < 0.1$) was found between running with LEAF compared to FOAM.

Table 1
Stride rate, stride length, VO_2 and RER for running with a leaf spring structured midsole shoe (LEAF) and a standard foam midsole shoe (FOAM). (mean ± SE)

	LEAF (mean ± SE)	FOAM (mean ± SE)	diff(LEAF-FOAM) (mean ± SE)	p-value	Cohen's d
stride rate [Hz]	1.34 ± 0.02	1.35 ± 0.03	-0.01 ± 0.00	0.029 (*)	0.82
stride length [mm]	2193 ± 97	2184 ± 96	9 ± 4	0.040 (*)	0.76
VO_2 [ml/min/kg]	39.88 ± 1.61	40.26 ± 1.67	-0.38 ± 0.19	0.082	0.62
RER	0.87 ± 0.02	0.87 ± 0.02	0.00 ± 0.00	0.808	0.08

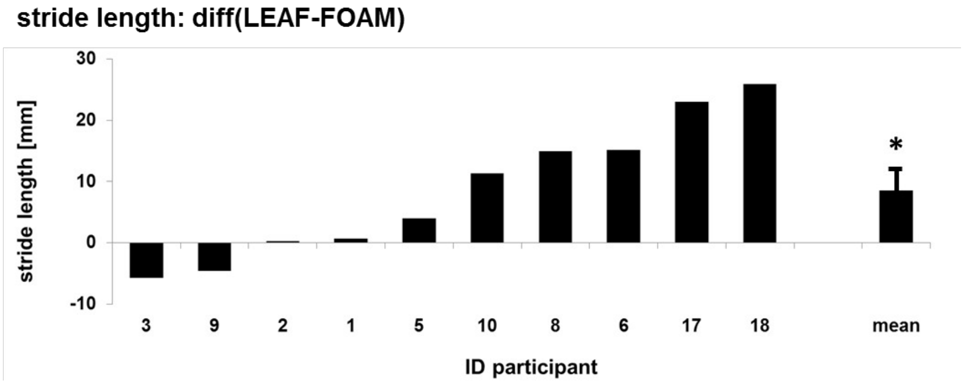

Figure 2: Individual differences between a leaf spring structured midsole shoe (LEAF) and a standard foam midsole shoe (FOAM) concerning stride length

DISCUSSION: The study examined spatio-temporal variables and running economy in overground running comparatively with LEAF and FOAM at an individual constant running speed referring to an intensity of about 2 mmol/l lactate. The spatio-temporal variables show the theoretically assumed differences between LEAF and FOAM in overground heel-toe running. The increased stride length (9 ± 4 mm) and decreased stride rate (-0.01 ± 0.00 Hz) when running with LEAF compared to FOAM led to a decrease of 0.7 strides per 400 m-lap. According to a previous study conducted in treadmill running (Wunsch et al., under review) similar effects, but reduced absolute differences between both shoe conditions were found. An individual analysis of the participants (Fig. 2) demonstrated that the absolute differences in stride length ranged from -5 to 26 mm. The pronounced individual differences are in line with results from Nigg et al. (1995) showing that the foot to ground interaction as well as the response on a certain shoe concept is highly individual.
Concerning running economy, VO_2 revealed a trend towards a reduction of 1 % (d_z=0.62, $p<0.08$) when running with the LEAF compared to the FOAM. Two aspect may be considered to explain the differences between these results and those from treadmill running (Wunsch et al., under review). Firstly, the participants demonstrated less pronounced effects in the economy determining variables stride rate and stride length (Tartaruga et al., 2012). Secondly, the environmental conditions during outdoor overground running might have influenced the VO_2 measurements (Saunders et al., 2004). Air and wind resistance make up to 4-8% of the total energy expenditure in outdoor running (Davies, 1980; Pugh, 1970). That explains the higher absolute VO_2 values in overground running compared to treadmill running (LEAF 36.24 ± 1.06 ml/min/kg, FOAM 37.17 ± 0.99 ml/min/kg; Wunsch et al. (under review)).

Furthermore, the variability in these external conditions might have increased the variance within the trials.

CONCLUSION: Running with the LEAF increases running economy in terms of determining spatio-temporal variables compared to running with the FOAM. These findings are in line with previous results found in treadmill running even though the effects are less pronounced. Considering the results from treadmill and overground running the LEAF is a suitable running shoe for performance orientated heel-strikers focusing on an improved running economy.

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