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). $\text{VO}_2\text{t}$ 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.
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].

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

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

(\(n_i\) = 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)

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

\(\text{VO2}\) and RER were measured continuously during the entire test using a portable breath-by-breath spirograph (K4b², Cosmed, Rome, Italy). The gas analyser was calibrated prior to each test with a high precision gas mixture (15.8 % O₂, 5 % O₂ in N; Praxair, Düsseldorf, Germany) and a 1L syringe (nSpire, Oberthulba, Germany). The mean value during the last five minutes of each trial for VO2 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 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)

<table>
<thead>
<tr>
<th></th>
<th>LEAF</th>
<th>FOAM</th>
<th>diff(LEAF-FOAM)</th>
<th>p-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>stride rate [Hz]</td>
<td>1.34 ± 0.02</td>
<td>1.35 ± 0.03</td>
<td>-0.01 ± 0.00</td>
<td>0.029 (*)</td>
<td>0.82</td>
</tr>
<tr>
<td>stride length [mm]</td>
<td>2193 ± 97</td>
<td>2184 ± 96</td>
<td>9 ± 4</td>
<td>0.040 (*)</td>
<td>0.76</td>
</tr>
<tr>
<td>VO$_2$ [ml/min/kg]</td>
<td>39.88 ± 1.61</td>
<td>40.26 ± 1.67</td>
<td>-0.38 ± 0.19</td>
<td>0.082</td>
<td>0.62</td>
</tr>
<tr>
<td>RER</td>
<td>0.87 ± 0.02</td>
<td>0.87 ± 0.02</td>
<td>0.00 ± 0.00</td>
<td>0.808</td>
<td>0.08</td>
</tr>
</tbody>
</table>

**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.

**REFERENCES:**


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