Small Step Frequency Changes Due to Footwear Condition Have No Effect on Running Economy

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ABSTRACT

The aim of this study is to examine if small increases to step frequency associated with minimal footwear can influence Running Economy (RE). Twelve club-level runners with eight weeks of minimal footwear experience were recruited (age, 41 ± 9 years; stature, 177.2 ± 10.4 cm; body mass, 72.6 ± 10.2 kg; $\dot{V}O_{2max}$, 52.1 ± 7.5 mL · min⁻¹ · kg⁻¹). Two 6-min RE tests, one in minimal footwear and one in conventional running shoes were performed at 11 km · h⁻¹. Two more 6-min tests were completed during which step frequency was controlled using a metronome at the cadence of the opposite footwear condition (RE_{revSF}). Comparisons were completed between the same footwear using repeated measures ANCOVA. The increase in step frequency for minimal footwear vs. conventional running shoes was 7.3 ± 2.3 steps per minute (3.9 % difference; 95 % CI of difference [5.87 to 8.80 steps/min]; $p \leq 0.001$; Cohen's d = 0.70). No significant differences were identified between RE and RE_{revSF} for minimal footwear (40.72 ± 4.08 vs. 41.09 ± 4.19 mL · min⁻¹ · kg⁻¹; 95 % CI of difference [−1.71 to 0.97]; p = 0.55; Cohen's d = 0.09), or conventional running shoes (42.04 ± 4.68 vs. 41.74 ± 5.09 mL · min⁻¹ · kg⁻¹; 95 % CI of difference [−0.78 to 1.37]; p = 0.55; Cohen's d = 0.06). Small changes in step frequency (~4 %) did not have any significant impact on RE.

Introduction

Over the last ten years, renewed interest in more natural running footwear has seen the development of the minimalist footwear (MFW) sector. Minimalist footwear can be described as "providing minimal interference with the natural movement of the foot due to its high flexibility, low heel to toe drop, weight and stack height, and the absence of motion control and stability devices" [14]. Self-report surveys have reported that 76 % of runners in 2012 and 53 % in 2014 have been interested in this novel footwear condition at some point [21, 33], due to suggestions of improved performance and reduced injury risk, despite the fact that this has not yet been supported by consistent high-level evidence in the literature.

Whilst there are numerous purported benefits of running in minimalist shoes, perhaps the only consistent observation in the literature is an improvement in running economy (RE) [3, 13, 24, 31, 32, 36, 42, 43], which is supported by a recent systematic review [7]. RE can be described as the energy cost of running at a given submaximal, steady-state velocity [35], and is often reported as the oxygen cost of running

[34]. RE has been shown to be the most reliable indicator of endurance performance in a similarly trained group of runners [22, 23], explaining up to 65 % of race performance over 10 km [10]. In addition, recent research has suggested RE above the lactate threshold may be a reasonable predictor of 1500 m performance [39].

The improvements in RE reported in MFW have largely been associated with a reduced shoe mass when compared to conventional running shoes (CRS) [7, 13, 14]. However, the magnitude of improvement in RE cannot be explained by shoe mass alone [7] and may be attributed to a number of other variables. In this regard, it has been suggested that running biomechanics, which are consistently observed to change when switching to MFW [4, 24, 37], may also influence RE [11, 16, 31, 44]. One biomechanical variable that has received attention in this regard is step frequency. There is limited evidence that suggests increasing step (or stride) frequency can improve RE [11, 40]. However, although somewhat dated research, increasing step frequency can also negatively influence RE [6, 20] or have no effect [26]. An increased step frequency has been well documented when running in minimalist footwear (MFW) when compared to CRS [24, 41–43], and it is possible that this difference could influence RE. However, the natural changes to step frequency in relation to footwear type are typically small (~2–4 %) [24, 41–43]. In addition, previous studies that have deliberately manipulated step frequency have done so at a greater magnitude (e. g. 8–10 %) [17, 20], which may therefore not be applicable to this small "footwear-related' change in step frequency reported above. The small spontaneous changes in step frequency associated with different footwear remain to be examined with respect to its impact on RE.

Therefore, the aim of this study was to examine if small enforced changes in step frequency, of a magnitude typically experienced by changing from CRS to MFW footwear types, will influence RE in trained males. A secondary aim was to provide practical advice for those using different footwear in an attempt to increase step frequency in the belief that it might enhance running performance.

Methods

Participants

Twelve male club-level runners with eight weeks prior minimal footwear experience (up to approx. 30 km/week) were recruited for the study (age, 41 ± 9 years; stature, 177.2 ± 10.4 cm; body mass, 72.6 ± 10.2 kg; $\dot{V}O_{2max}$, 52.1 ± 7.5 mL · min^{-1} · kg^{-1}). Participants typically ran 4–6 days per week with a mean weekly running distance of 52 (± 11) km at the time of the study. Participants were excluded if they had reported any running-related injuries in the last three months or had previous barefoot or minimalist running experience before the eight-week MFW transition. This transition has been previously reported [42]. All participants had previous experience with treadmill running. The participants gave informed consent at the beginning of testing. Ethical approval for this study was granted by the Dublin City University Research Ethics Committee. The present study meets the ethical standards required of this journal [18].

Experimental design

In a single testing session, subjects underwent two 6-min RE tests: one in MFW and one in CRS (balanced randomisation), during which the subject's naturally selected step frequency was recorded. For testing, foot size was measured and participants were provided with one pair of MFW (Vibram® Five Finger "KSO"; ~150 g), and a neutral CRS (Asics® "GEL-Cumulus" 2012; ~400 g). The same RE tests were then repeated in both types of footwear (again randomised) but with enforced changes in step frequency. This was controlled by a metronome ("Mobile Metronome" Android software) set at the corresponding tempo of the opposite condition being tested (when participants ran in MFW, their recorded step frequency in CRS was enforced and vice versa), denoted "revSF" [reversed step frequency].

Testing procedure

Resting blood lactate (Lactate Plus, Nova Biomedical, Waltham, MA, USA) was sampled from the earlobe prior to the testing sessions. Respiratory data were measured using a Viasys Vmax Encore 299 online gas analysis system (Viasys Healthcare, Yorba Linda, CA, USA). The system was calibrated according to the manufacturer guidelines, including atmospheric pressure and temperature, before each new test. For this system, accuracy has been reported at 0.02 % for oxygen measures, following a 15-min warm-up period and calibrated within 5 % of absolute operating range. A treadmill (Cosmed T170, Sport Med, Weil am Rhein, Germany) RE test was then conducted in the assigned footwear, either MFW or CRS in random order. Treadmill incline was set at 1 % to account for air resistance [25]. Participants ran four trials lasting 6 min at 11 km · h^{-1}, which has previously been considered an appropriate steady-state "endurance running" velocity [19]. At the end of each 6-min stage, participants were asked to stand to the side of the treadmill and a blood lactate sample was collected within 30 s. At minute 5 in each stage, step frequency was collected by counting the left foot contact with the treadmill belt for 60 s duration. This procedure was repeated by the same investigator in each subject and also filmed for a second assessment and accuracy (R^2 = 0.95; Sony HDR-CX210, 60FPS; Sony, San Diego, CA, USA). Rudimentary foot strike pattern (FSP) analysis was undertaken using this low-cost video camera, in which participants were filmed in the sagittal plane at foot level over a 15 s period during minute 4 of testing. The video footage was then used to assign 1, 2, or 3 (1 = forefoot strike, 2 = midfoot strike, 3 = rearfoot strike) to the participants' foot strike pattern by the principal investigator using Dartfish video analysis software (Dartfish 5.5, Fribourg, Switzerland). A midfoot strike was assigned when there was no clear initial forefoot or heel contact. The validity of this method has been previously examined and highly correlated to the strike index (R^2 = .85) [1]. The next test in the opposite footwear was started after 3 min of passive rest to allow the shoe type to be swapped over. After each shoe test was completed once, both tests were repeated after three minutes of passive recovery, but this time with the step frequency dictated by a metronome as reported above.

A $\dot{V}O_{2max}$ test was completed at the end of the day for subject characterisation. This involved a ramped treadmill protocol at 12 km · h^{-1} for a 5-min warm-up before increasing to 14 km · h^{-1} at

1 % incline. The incline was then increased every minute until volitional exhaustion and correlated with participants achieving a respiratory quotient (RQ) of 1.1 or above. Participants conducted this test in their own shoe choice. $\dot{V}O_{2max}$ was recorded as the highest breath-by-breath value averaged over 60 s.

Data processing

The RE values were determined from the mean data over the last 2 min of each stage when participants had reached a true steady-state $\dot{V}O_2$. This was verified by less than a 1 mmol increase in blood lactate (post-trial minus resting lactate) because this is considered well below maximal lactate steady state [38], and an RQ of less than 1.0 [5].

Data analysis

Direct comparisons between RE and RE_{revSF}, were completed in the same footwear (MFW vs. MFW_{revSF} and CRS vs. CRS_{revSF}) using repeated measures ANCOVA following establishment of parametric assumptions. Because it is possible that the foot strike pattern can influence $\dot{V}O_2$ values [16, 31], the foot strike pattern was included as a covariate in the analysis. Difference in step frequency between MFW and CRS was also examined with a paired t-test. Statistical significance was accepted at $\alpha \leq 0.05$ (Statistical Package for the Social Sciences data analysis software V22.0, SPSS Inc., Chicago, IL, USA).

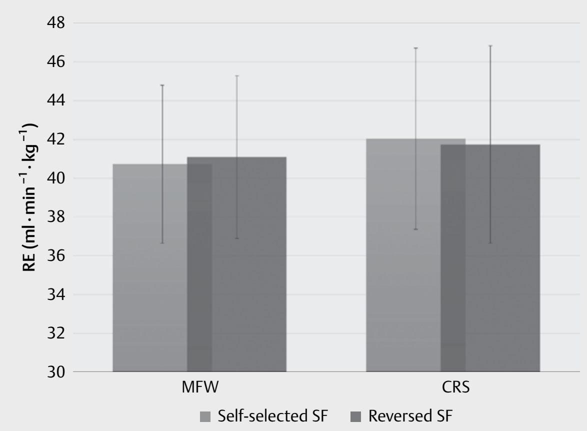
Effect sizes are reported as Cohen's d [8]. The smallest standardised change that is considered meaningful was assumed to be an effect size of 0.20 for Cohen's d [8].

Results

No participants were excluded based on any visual slow component for submaximal $\dot{V}O_2$ consumption, an increase in blood lactate of > 1 mmol (mean change from resting = 0.44 mmol), or an RQ greater than 1.0. Because this was an acute study, no dropouts occurred due to injury or other reasons.

There was no difference whatsoever in the foot strike classification between the normal and reversed stride frequency for either shoe condition. For the MFW footwear, the distribution of foot strike patterns was 4 rearfoot strikes, 3 mid-foot strikes, and 5 forefoot strikes. For the CRS footwear, the distribution of foot strikes was 6 rearfoot strikes, 3 mid-foot strikes, and 3 forefoot strikes. The mean increase in step frequency for minimal footwear vs. conventional running shoes was 7.3 ± 2.3 steps per minute (3.9 % change; $p \leq 0.001$; 95 % CI of difference [5.86 to 8.80]; MFW 184.2 ± 10.6 vs. CRS 176.8 ± 10.5 steps per minute).

No differences were identified between RE and RE_{revSF} for minimal footwear when foot strike pattern was taken into account as a covariate ($p = 0.55$; 95 % CI of difference [–1.71 to 0.97]; Cohen's d = 0.09; RE 40.72 ± 4.08 vs. RE_{revSF} 41.09 ± 4.19 $mL \cdot min^{-1} \cdot kg^{-1}$), or conventional running shoes ($p = 0.55$; 95 % CI of difference [–0.78 to 1.37]; Cohen's d = 0.06; RE 42.04 ± 4.68 vs. RE_{revSF} 41.74 ± 5.09 $mL \cdot min^{-1} \cdot kg^{-1}$). Differences are displayed in ▶ **Fig. 1**. Removing the foot strike pattern as a covariate factor did not influence the outcome in any way.



▶ **Fig. 1** Differences in running economy (RE) when comparing the minimalist footwear (MFW) self-selected step frequency to reversed step frequency (SF), and the same comparison in conventional running shoes (CRS). No significant differences were observed. Error bars represent SD.

Discussion

The main finding of the present study is that changes in step frequency as a result of footwear condition (~4 %) are not large enough to have any significant impact on RE, even when the foot striking pattern is controlled for in the analysis. Therefore, we reject the alternate hypothesis for this study. If RE changes are indeed associated with switching to MFW, this is most likely not due to the changes in step frequency that are typical of changing into this footwear.

The results of this study support previous work suggesting that step frequency is not an influencing factor for RE [2, 9, 22, 44]. Naturally selected step frequency has been found to be close to that which optimises running economy, with small deviations resulting in little or no change [6, 30]. To support this observation, more recent studies have deliberately reduced stride length by 3 % (which will increase stride frequency) and have shown no change in RE [12, 28]. A possible reason for this absence of any difference in RE is most likely due to the magnitude of the changes to step frequency observed, which were found to be well below the changes imposed in experimentally imposed studies [17, 20]. In one study, Franz, Wierzbinski and Kram [15] estimate that the ~3 % greater step length observed during traditionally shod running when compared to barefoot would account for less than a 0.4 % metabolic saving. As changes to step frequency in MFW were also in the region of ~3 % reported by Franz, Wierzbinski and Kram [15] in the barefoot condition, it could be suggested that the same conclusion applies. In the study by Hamill, Derrick and Holt [17], the authors noted that the preferred step frequency was the optimal for oxygen consumption. The authors also noted significantly greater oxygen consumption at –10 %, –20 %, and + 20 % step frequency, but there was no significant difference at + 10 %. Therefore, the mean + 3.9 % increase in step frequency in MFW in the present study is very small, and as such unlikely to cause any changes in RE, as observed here.

In contrast to these findings, a significant negative correlation between RE and stride frequency (r = −0.61) has been previously observed in 16 male long-distance runners [40]. In addition, Connick and Li (2014) have suggested that RE was optimised at a stride which was 2.9 % (± 2.4 %) shorter than preferred [11]. In an earlier training study, 9 runners who presented with uneconomical freely chosen step lengths underwent a 3-week biofeedback programme to reduce step length by 10 %; a marked reduction in freely chosen step length as well as an improvement in RE was observed [29]. It is therefore possible that benefits to RE with changes in step frequency may only be apparent for those runners with low step frequency and/or uneconomical step length/frequency, and this should be examined further. Regardless, there appears to be contradictory research in the association between step mechanics and RE, with the current study confirming that no changes in RE are observed with small changes to step frequency.

One limitation of the current study is that the changes in step frequency were experimentally imposed in an acute study, and it is possible that acute, forced, unnatural changes to running mechanics may limit any potential benefits to RE [27, 42]. However, this theory needs to be investigated further, as well as long-term training studies on self-optimisation of RE with changes in running mechanics. Finally, it would have been beneficial to work with a larger sample size, so that groups could be divided according to foot strike patterns in order to establish if there is any interaction between foot strike and step frequency changes in RE. This question could be examined in future research with a large cohort of runners with varied running mechanics.

Conclusion

Changes in step frequency as a result of footwear condition (~4 %) do not have any significant effect on RE. Therefore, changes in RE associated with MFW are most likely due to other factors not examined in this study.

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None

Conflicts of Interest

The authors have received a donation of footwear for the present study from Vibram® (Milan, Italy). No honoraria or conditions were attached to this donation, and the company has no direction or involvement in the research. All authors report no other conflicts of interest.

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