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Author(s): J. Sinclair, R. Mcgrath, O. Brook, P. J. Taylor and S. Dillon

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Influence of footwear designed to boost energy return on running economy in comparison to a conventional running shoe

J. Sinclair[a], R. Mcgrath[a], O. Brook[a], P. J. Taylor[b] and S. Dillon[c]

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[a]Division of Sport Exercise and Nutritional Sciences, School of Sport Tourism and Outdoors, University of Central Lancashire, Lancashire, UK; [b]School of Psychology, University of Central Lancashire, Lancashire, UK; [c]International Institute of Nutritional Science and Food Safety Studies, School of Sport Tourism and Outdoors, University of Central Lancashire, Lancashire, UK

ABSTRACT

Running economy is a reflection of the amount of inspired oxygen required to maintain a given velocity and is considered a determining factor for running performance. Athletic footwear has been advocated as a mechanism by which running economy can be enhanced. New commercially available footwear has been developed in order to increase energy return, although their efficacy has not been investigated. This study aimed to examine the effects of energy return footwear on running economy in relation to conventional running shoes. Twelve male runners completed 6-min steady-state runs in conventional and energy return footwear. Overall, VO_2, heart rate, respiratory exchange ratio, shoe comfort and rating of perceived exertion were assessed. Moreover, participants subjectively indicated which shoe condition they preferred for running. Differences in shoe comfort and physiological parameters were examined using Wilcoxon signed-rank tests, whilst shoe preferences were tested using a chi-square analysis. The results showed that VO_2 and respiratory exchange ratio were significantly lower, and shoe comfort was significantly greater, in the energy return footwear. Given the relationship between running economy and running performance, these observations indicate that the energy return footwear may be associated with enhanced running performance in comparison to conventional shoes.

Introduction

Running economy is defined as the steady-state oxygen consumption (VO_2) required to maintain a given running velocity (Morgan, Martin, & Krahenbuhl, 1989). The economy of running is considered to be a principal determining factor of running performance (Cavanagh & Williams, 1982). It has been demonstrated that running economy is a better predictor of distance running performance than VO_2 max (Hanson, Berg, Deka, Meendering, & Ryan, 2011). Therefore, improvements in running economy are of significant interest to runners, and this area has received considerable research attention.

Athletic footwear has been advocated as a mechanism by which running economy can be improved (Frederick, Howley, & Powers, 1986). The current consensus in footwear biomechanics literature is that running economy can be enhanced by footwear with appropriate mechanical characteristics (Sinclair, Taylor, Edmundson, Brooks, & Hobbs, 2014b). A variety of different shoe parameters including midsole cushioning, comfort, rearfoot control, midsole longitudinal stiffness, mass and midsole viscoelasticity have been proposed to modify running economy (Fuller, Bellenger, Thewlis, Tsiros, & Buckley, 2014).

Recent research into the effects of footwear on running economy has focussed heavily on the effects of running barefoot in relation to conventional running shoes. Hanson et al. (2011) and Squadrone and Gallozzi (2009) demonstrated that running barefoot was associated with significant reductions in the oxygen cost of running in comparison to a shod condition. Moore, Jones, and Dixon (2014) examined the effects of barefoot, minimalist and conventional footwear on running economy. Their findings confirmed that running barefoot significantly improved running economy compared to both minimalist and conventional footwear. However, because shoe mass has been shown to increase the oxygen cost of running for a given workload (Franz, Wierzbinski, & Kram, 2012), studies of this nature have been criticised. Franz et al. (2012) placed additional mass equal to the weight of the running shoe onto the foot and examined the effects of barefoot and shod conditions on the oxygen cost of running. Their findings showed that when the effects of shoe mass were controlled, the oxygen cost of running was significantly greater when running barefoot.

Some investigations have shown that the midsole characteristics of the running shoe can influence the economy of running. Bosco and Rusko (1983) examined the effects of a shock-attenuating viscoelastic insert. Their results served to increase running economy during treadmill running in comparison to running in the same footwear without the viscoelastic insert. Frederick et al. (1986) reported that running in a

shoe with a gas-inflated cushioning system significantly increased running economy during treadmill running by 2.4% when compared with a conventional running shoe. Worobets, Wannop, Tomaras, and Stefanyshyn (2014) investigated the effects of a soft shoe and control shoe on running economy during both overground and treadmill running. Their findings confirmed that soft shoes produced significant improvements in running economy during both conditions. Luo, Stergiou, Worobets, Nigg, and Stefanyshyn (2009) examined the effects of footwear with different levels of subjectively rated comfort of steady-state VO_2. They showed that the most comfortable footwear conditions significantly reduced steady-state VO_2.

Conversely, Nigg, Stefanyshyn, Cole, Stergiou, and Miller (2003) examined the influence of footwear with distinct midsole material characteristics on muscle activation and running economy, and their findings confirmed that wearing viscoelastic, as opposed to hard, midsoles did not significantly influence steady-state VO_2. Sinclair et al. (2014b) investigated the effects of footwear with different midsole cushioning properties on running economy. Their observations similarly showed that distinct footwear cushioning properties did not significantly influence running economy.

New commercially available footwear has been recently released that utilises a thermoplastic polyurethane midsole, rather than more conventional ethylene vinyl acetate materials. This new midsole material is claimed by the manufacturer to be able to promote energy return in comparison to traditional ethylene-vinyl-acetate-based footwear midsoles. Only 1 study has investigated the efficacy of these new energy return footwear. Sinclair, Franks, Fau-Goodwin, Naemi, and Chockalingam (2014a) examined the kinetics and 3-dimensional (3-D) lower extremity kinematics of running in energy return and conventional running shoes. Their results indicated that tibial accelerations, peak eversion and tibial internal rotation parameters were significantly greater in the energy return footwear. Given that both tibial accelerations and ankle eversion are linked to the aetiology of chronic pathologies (Eslami, Begon, Farahpour, & Allard, 2007; Taunton, Clement, & McNicol, 1982; Whittle, 1999), this led to the conclusion that the energy return footwear may place runners at an increased risk of injury.

There is no published information regarding the influence of these new commercially available footwear designed to increase energy return on the economy of running. Therefore, the aim of the current study was to comparatively explore the effects of energy return footwear on the oxygen cost of steady-state running in relation to conventional running shoes. This study tests the hypothesis that energy return footwear serve to reduce the oxygen cost of running.

Methods

Participants

Twelve male runners volunteered to take part in this study. The mean characteristics of the participants were: age 22.4 ± 2.2 years, height 176.1 ± 5.3 cm and body mass 73.5 ± 6.2 kg. Participants were active runners engaging in training at least 3 times per week (≥35 km · week⁻¹) and with previous experience of treadmill running. Pilot work in our laboratory confirmed that all participants exhibited a rearfoot strike pattern as they demonstrated an impact peak in their vertical ground reaction force time-curve (Cavanagh & Lafortune, 1980). All were free from pathology at the time of data collection, and written informed consent for study participation was provided by the participants in accordance with the Declaration of Helsinki. The study procedure was approved by a university ethics committee.

Procedure

Participants ran at 12 km · h⁻¹ on an HP Cosmos treadmill (Quasar, HP Cosmos, Nussdorf-Traunstein) maintained with a 0% incline. Treadmill velocity was validated prior to the commencement of data collection in accordance with the protocol of Sinclair et al. (2014b) and found to be >99.9% accurate. In agreement with the procedure documented by Hanson et al. (2011), participants were required to undertake a 3-min habituation period in both footwear conditions during which they ran at the required velocity prior to the commencement of data collection.

Respiratory gases were collected throughout testing using the MetaLyser 3B system (Cortex Biophysic, Leipzig, Germany). Heart rate was monitored using a Polar heart rate monitor (Polar Electro Oy, Kempele, Finland). Prior to the commencement of each testing session, the Metalyser system was calibrated. This firstly involved inputting the atmospheric pressure, following which the pneumotach volume sensor was also calibrated using a 3.0 L syringe (Hans Rudolph Inc., Kansas City, USA). Lastly, the gas sensors were calibrated using ambient air and known gas concentrations of 5.09% O_2 and 14.46% CO_2. In order to eliminate the potential variation in VO_2 due to circadian rhythmicity, each data collection session was conducted at the same time of day. The data collection protocol consisted of 6 min steady-state runs in agreement with Nigg et al. (2003). Participants were required to attend the laboratory a minimum of 4 h postprandial, and the order of wearing each type of footwear was randomised to prevent any order effects (Frederick et al., 1986). Participants completed their runs in both shoe conditions within the same testing session, with rest in between; 1 trial was conducted in each type of footwear. The subsequent testing condition was not started until the participants' heart rate was less than 110 beats per minute and they felt ready to undertake further analysis (Hanson et al., 2011). The test–retest reliability of the metalyzer for this protocol observed has been investigated previously and was shown to be very good (R^2 = 0.95) (Sinclair et al., 2014b).

From the experimental data key measurements of mean VO_2 (ml · kg · min⁻¹), the respiratory exchange ratio (RER) and heart rate (BPM) were obtained. In addition, participants were asked to rate their perceived exertion (RPE) using the 6–20 point Borg scale at 2 min intervals. After each 6 min run, participants were asked to provide their rating of the comfort of each shoe. The comfort measurement procedure consisted of a 150 mm visual analogue scale, with the extreme left side being indicative of "not comfortable at all" and the extreme right of the scale labelled as "most comfortable condition

imaginable" (Mündermann, Nigg, Stefanyshyn, & Humble, 2002). Upon conclusion of the data collection, participants were also asked to subjectively indicate which shoe condition they preferred for running.

Experimental footwear

The running shoes used during the current investigation consisted of conventional footwear (Saucony pro grid guide II) and commercially available footwear which claims to boost energy footwear (Adidas Energy Boost), (shoe size 8–10 UK men's). As the energy return footwear were slightly lighter than the conventional running trainers, lead tape was applied in a pattern that maintained 3-D static balance until it reached the same mass (Sinclair et al., 2014b).

Statistical analyses

Differences between footwear were examined using Wilcoxon signed-rank tests. The alpha criterion for statistical significance was adjusted to $P \leq 0.008$ using a Bonferroni correction to control type I error. Effect sizes were calculated using eta^2 (η^2). Finally, a chi-squared (χ^2) test was utilised to test the assumption that an equal number of participants would subjectively favour each of the footwear conditions. All statistical actions were conducted using SPSS v22.0 (SPSS Inc, Chicago, USA), and the results are presented as mean ± standard deviations and 95% confidence intervals.

Results

VO$_2$ and RER

The results indicate that VO$_2$ was significantly lower ($Z = 2.67$, $P = 0.008$, $\eta^2 = 0.48$) in the energy return footwear in comparison to the conventional footwear (Table I). The individual differences are presented in Figure 1(a); 10 of the 12 participants exhibited reductions in VO$_2$ in the energy return footwear. In addition, it was shown that the RER was significantly lower ($Z = 2.69$, $P = 0.007$, $\eta^2 = 0.46$) in the energy return in comparison to the conventional footwear (Table I). Individual differences are presented in Figure 1(b), and 9 of the 12 participants exhibited reductions in the RER in the energy return footwear.

Heart rate and rating of perceived exertion

No significant differences ($P > 0.008$) were observed between footwear for either heart rate or rating of perceived exertion (Table I).

Shoe comfort and preference

The results indicate that participants rated the energy return as being significantly more comfortable ($Z = 2.75$, $P = 0.006$, $\eta^2 = 0.49$) than conventional footwear (Table I). In addition, the chi-squared analysis showed that there was no significant difference in footwear preference ($\chi^2 (1) = 3.80$, $P > 0.05$), with 5 participants indicating that they preferred the energy return footwear and 5 who preferred the conventional footwear.

Table I. Means, standard deviations and confidence intervals of the physiological and shoe comfort parameters for each footwear condition.

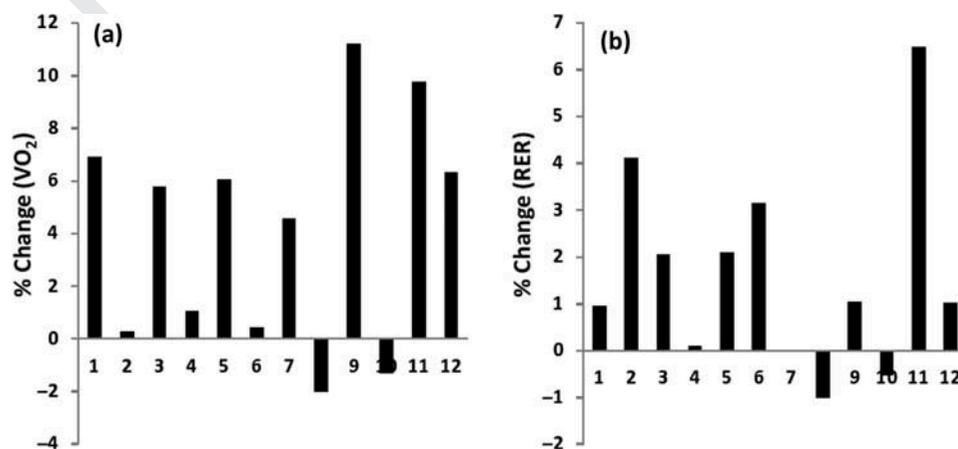|	Energy return			Conventional			
	Mean	SD	95% CI	Mean	SD	95% CI	% Change (95% CI)
VO$_2$ (ml · kg · min^{-1})	41.8	3.2	39.8–43.8	43.6	3.7	40.9–46.2	4.2 (1.4–6.8) *
RER	0.98	0.08	0.93–1.02	0.99	0.06	0.95–1.03	1.7 (0.3–3.0) *
Heart rate (BPM)	159.6	16.3	149.3–169.9	158.9	18	147.5–170.3	0.5 (−4.6–5.6)
RPE	10.5	1.3	9.7–11.3	11.0	1.9	9.8–12.2	5.4 (−1.5–11.6)
Comfort	12.0	1.9	10.8–13.2	10.1	2.9	8.1–11.9	15.8 (5.5–28.4) *

Note: * = significant difference.

Figure 1. Individual percentage differences in (a) VO$_2$ and (b) RER between the energy return and conventional footwear. Positive values indicate that VO$_2$ and RER were lower in the energy return footwear.

Discussion

The current investigation aimed to examine the influence of new commercially available footwear designed to increase energy return on the economy of steady-state treadmill running. This represents the first study to investigate the effects of these new footwear on the oxygen cost of running. A study of this nature may provide important information regarding the effects of different running footwear on running performance.

The first key observation from the current study was that the energy return footwear were associated with significant reductions in steady-state VO_2, with 10 of the 12 participants exhibiting reductions in these shoes. This observation provides support for the hypothesis and concurs with the results of Frederick et al. (1986), Bosco and Rusko (1983) and Worobets et al. (2014), who found that different footwear significantly influenced steady-state VO_2. Given the proposed inverse relationship between steady-state VO_2 and running performance, it appears, based on these observations, that the energy return footwear may be associated with increases in running performance in comparison to conventional shoes. The mechanisms behind this improvement in the energy return footwear cannot be exactly pinpointed. It can be speculated that the increase in returned energy mediated by the energy return footwear served to reduce the oxygen required to maintain experimental running velocity. The influence of the different footwear conditions on VO_2 can be contextualised by taking the observed differences and examining their influence on performance. Burkett, Kohrt, and Buchbinder (1985) demonstrated that every 1.0% increase in steady-state VO_2 mediated a subsequent $0.17 \text{ km} \cdot \text{h}^{-1}$ reduction in running velocity. Therefore, the application of the 4% reduction in VO_2 observed in the current study indicates that running in the energy return footwear would translate into a 3 min reduction in 10 km time.

A further key finding is that the RER was found to be significantly lower in the energy return shoes in comparison to conventional footwear, with 9 of the 12 participants exhibiting reductions in these shoes. Although the mean difference in RER was relatively small, this, nonetheless, suggests that running in the conventional footwear favours significantly greater carbohydrate utilisation in comparison to the energy return shoes (Holloszy, Kohrt, & Hansen, 1998). As such, this observation may also have important performance considerations as carbohydrate is the primary fuel source for endurance exercise such as running and places significant demands on the body's limited carbohydrate stores (Rapoport, 2010). Additionally, muscular contractions are mediated by a variety of metabolic substrates; but, in the context of long distance running, carbohydrate is crucial (Rapoport, 2010). This observation provides further support to the previous proposition regarding performance improvements when running in the energy return footwear. Firstly, the reduced reliance on carbohydrate may serve to delay the onset of fatigue during running or, alternatively, allow a greater running velocity to be maintained prior to the onset of fatigue (Joyner & Limberg, 2014).

A final key observation is that shoe comfort was shown to be significantly greater in the energy return footwear compared to conventional footwear. This observation concurs with those of Luo et al. (2009), who found significant reductions in oxygen consumption in footwear that was subjectively related as being the most comfortable. Footwear comfort has been proposed as being a mediator of the extent of muscular mechanical work output (Nigg, 2001). It is well established that muscle activity is positively related to global oxygen consumption (Nigg et al., 2003). Thus, the increased comfort noted in the energy return footwear may provide further insight into the differences in running economy observed between the 2 running shoes.

The observations of the current investigation present an interesting paradox in footwear biomechanics. The current investigation confirms that there may be significant performance benefits when running in the energy return footwear in relation to conventional shoes. However, Sinclair et al. (2014a) showed that energy return footwear were associated with greater kinetic and kinematic parameters that have been linked to the aetiology of injury. Therefore, it appears that whilst performance may be enhanced in these footwear, they place runners at an increased risk of musculoskeletal injury.

There are some limitations to the current investigation that should be acknowledged. Firstly, whilst the addition of supplementary mass to the energy return footwear was important as shoe mass is known to significantly influence steady-state VO_2 (Franz et al., 2012), this may have altered the mechanical properties of the shoe upper, which was not considered as part of the current work. In addition, whilst the mass of the experimental footwear was controlled, participants own preferences in terms of their lacing strategy were not standardised. Importantly, Hagen and Hennig (2009) demonstrated that different lacing configurations significantly influenced vertical loading rates and foot plantar pressures during running. Thus, it is recommended that the current study be repeated using a more consistent lacing pattern.

In conclusion, the current investigation provides new information describing the influence of commercially available footwear, claimed to increase energy return on the economy of running. On the basis that decreased VO_2 and RER were observed when running in the footwear which aims to increase energy return, the current investigation suggests that these new footwear may be associated with increases in running performance. This study indicates that runners interested in performance may wish to select the energy return footwear over more conventional shoe models. Future research should investigate the long-term effects of these new running shoes on the aetiology and prevalence of chronic running injuries.

Disclosure statement

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