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Mechanisms for changes in running economy during barefoot, minimalist shod and shod running

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SUMMARY
Biomechanical and muscular activity mechanisms behind changes in running economy (RE) when running two different stride lengths during barefoot, minimalist shod and shod were investigated. Stride length had no effect upon RE, but (lack of) footwear significantly affected RE, specifically the best RE (i.e. lowest oxygen consumption (VO_2)) was found during barefoot running and the worst (i.e. highest) during shod running. Biomechanical results show, generally, a flatter foot, less dorsiflexion during stance and slower angular velocities could contribute to a lower RE. However less consistent patterns were observed in muscular activity, such as high coactivation in barefoot running but low coactivation in minimalist shod running. Therefore it appears that biomechanical gait alterations dominate when considering improved RE in barefoot and minimalist shod running. These may counteract any changes in muscular activity, which on their own could increase the metabolic cost of cushioning.

INTRODUCTION
The debate regarding the performance implications of running barefoot or in minimalist footwear has received much attention. Scientific rigor has meant researchers have controlled for the extra mass of shoes by adding mass to barefoot conditions [e.g. 1]. This limits the applicability to actual barefoot running. Furthermore research has shown runners naturally adopt an economically optimal stride length (SL) [2], yet during barefoot running they shorten their stride length. The effect that this has on their RE has not been investigated.

The aim of this study was to assess whether RE differed between barefoot stride length (BSL) or shod stride length (SSL), when running barefoot, in minimalist shoes and trainers. Additionally, the potential mechanisms behind any differences in RE were investigated; specifically lower limb kinematics and muscular activity.

METHOD
15 female, habitually shod, recreational runners volunteered and provided informed consent prior to testing. Each participant visited the laboratory twice. During the first visit participants were given treadmill familiarisation to both barefoot and shod running. Duration of treadmill familiarisation for barefoot was based on results from our laboratory and for shod based upon previous literature [3]. Their SL during each run was determined. During visit two the participants performed each SL whilst running barefoot, in minimalist shoes (Vibram FiveFinger) and shod. They ran for 6 minutes during each condition, with 10 minute rest periods in between each bout.

Three-dimensional lower limb kinematics (Peak Motus, 120 Hz), electromyography (EMG) (Delsys Inc., 2000 Hz) and oxygen consumption (Cortex Metalyzer II) were simultaneously recorded during the final two minutes of each run. The muscles of interest for the EMG data collection were: rectus femoris (RF), vastus lateralis (VL), biceps femoris (BF), tibialis anterior (TA) and the medial (GM) and lateral gastrocnemius (GL) muscles. Integrated (iEMG) preactivation of the TA and BF were recorded. Additionally muscular coactivation during stance of the following pairs was determined: RFBF, VLBF, GLTA and GMTA. iEMG during stance was also calculated for each muscle. RE was calculated as the average oxygen consumption over the final two minutes.

Absolute RE values (L/min) were adjusted to body mass and the difference in mass between the barefoot/footwear conditions. This allowed comparisons to be made without adding extra mass to the minimalist or barefoot conditions.

Descriptives (mean±SD) were calculated for each variable. Two-way (SL x barefoot/footwear condition) repeated measures ANOVAs were performed on the RE data. Post-hoc one-way ANOVAs were then used to determine significant differences. Paired T-tests were performed on the kinematic and EMG data if there was a significant difference in RE.

RESULTS AND DISCUSSION
SL was significantly shorter (2.5%) during barefoot running than shod running, in addition to shorter ground contact times (256 vs. 267 ms, BSL and SSL respectively). The two-way ANOVA revealed only the barefoot/footwear condition to have an effect upon RE. Post-hoc analysis showed that RE during barefoot running was significantly better (i.e. lower VO_2) than running in minimalist footwear (2.1 and 2.5%, BSL and SSL respectively) or trainers (5.8 and 4.6%, BSL and SSL respectively). Additionally, RE was better (i.e. lower VO_2) during running in minimalist footwear than in trainers for both BSL (3.1%) and SSL (1.4%) (Figure1).

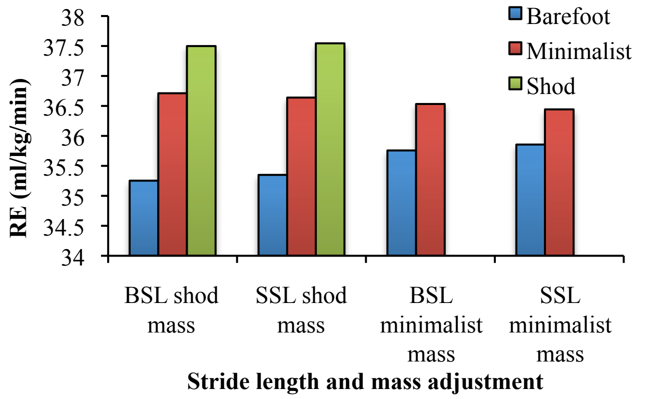

Figure 1: Running economy during each running condition.
BSL = barefoot stride length. SSL = shod stride length. Shod mass = RE adjusted for the mass of the shoe. Minimalist mass = RE adjusted for the mass of the minimalist shoe.

Even though the BSL was shorter than the SSL, there was no significant change in RE which suggests that the degree to which individuals shorten their SL is not a performance related response, specifically it is not detrimental to RE. It is possible that this may be a mechanical adjustment based upon a heightened proprioception and injury prevention strategies.

Several kinematic differences were observed between barefoot-minimalist, barefoot-shod and minimalist-shod (Table 1), however only a few muscular activity changes were found. The iEMG preactivity of the BF during SSL was lowest during barefoot running compared to minimalist and shod running (0.78 ± 0.34, 1.08 ± 0.57 and 1.00 ± 0.00 arbitrary units, respectively). However, iEMG preactivity of the TA remained unchanged across each condition, even though iEMG of the TA differed during stance (Table 1). Coactivation of the GLTA and GMTA muscular pairs were lowest during minimalist running (Table 1).

The lower angular velocities evident during the running conditions exhibiting lower oxygen consumption (Table 1) supports previous research whereby reduced lower limb velocities were found when beginner runners improved their RE [4].

The greater TA activity during barefoot running may suggest active cushioning of the lower limb, whilst the higher coactivation levels may also provide stability to the lower limb. It could be argued, therefore, that with these results there may be an expected rise in the metabolic cost of running. However there was no detrimental effect upon RE, suggesting that the kinematic adaptations, such as a flatter foot at touchdown, less peak dorsiflexion during stance and lower angular velocities, counteracted these cushioning mechanisms, thus challenging the 'cost of cushioning' hypothesis [6].

CONCLUSIONS

In conclusion running barefoot improves RE when compared to both shod and minimalist footwear. The shorter SL adopted during barefoot running appears to have no effect upon RE. Furthermore, it appears that kinematic rather than muscular activity adaptations provide the gait adjustments which may contribute to an improved RE. This suggests that there is no additional metabolic cost of cushioning when running barefoot.

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REFERENCES

1. Perl DP, et al., *Medicine and Science in Sports and Exercise.***44**:1335-1343, 2012.
2. Cavanagh PR, Williams KR, *Medicine and Science in Sports and Exercise.* **14**:30-35, 1982.
3. Lavcanska V, et al., *Human Movement Science.* **24**:544-557, 2005.
4. Moore IS, et al., *Medicine and Science in Sports and Exercise.* **44**:1756-1763, 2012.
5. Frederick EC, *Applied Ergonomics.* **15**:281-287, 1984.

Table 1: Selected biomechanical and EMG variables (means ± SDs) that were significantly different between conditions.

Variable	**Condition**					
	BSL			**SSL**		
	Barefoot	Minimalist	Shod	Barefoot	Minimalist	Shod
TD foot angle (°)	7.51 ± 4.72^{A}	9.24 ± 4.72	10.69 ± 5.34	9.21 ±5.22^{A}	11.34 ± 6.31	11.27 ± 5.27
Peak dorsiflexion (°)	-9.61 ± 4.14^{AC}	-16.68 ± 5.51^{B}	-22.24 ± 3.50	-11.28 ± 4.57^{AC}	-16.94 ± 6.00^{B}	-19.78 ± 5.23
TO plantarflexion (°)	11.31 ±7.17^{A}	17.21 ±6.46	16.50 ± 7.34	13.00 ± 7.79^{A}	17.21 ±6.46	18.66 ± 8.39
TD ankle velocity (°/s)	-34.60 ± 94.53^{AC}	79.06 ± 158.52	79.68 ± 87.95	6.38 ± 64.63^{A}	40.22 ± 89.63	87.90 ± 122.64
Peak dorsiflexion velocity (°/s)	-172.60 ± 73.03^{AC}	-276.13 ± 81.40$^{\mathbf{B}}$	-341.26 ± 71.46	-233.98 ± 96.56^{A}	-312. 35 ± 106.15	-341.91 ± 68.25
GLTA coactivation (%)	61.63 ± 13.89^{C}	46.64 ± 18.84$^{\mathbf{B}}$	57.16 ±14.43	53.44 ±18.67	55.40 ± 18.14	55.96 ± 13.15
GMTA coactivation (%)	63.02 ± 13.83^{C}	54.89 ± 17.55	59.72 ±12.79	60.36 ± 12.88	60.01 ± 15.47	60.56 ± 13.70
TA iEMG stance (normalised arbitrary units)	1.32 ± 0.50^{AC}	1.03 ± 0.58	0.95 ± 0.28	1.23 ± 0.71	1.26 ± 0.40^{B}	1.00 ± 0.00

^{A} denotes barefoot significantly different to shod. ^{B} denotes minimalist significantly different to shod. ^{C} denotes barefoot significantly different to minimalist.