PERFORMANCE, STRIDE CHARACTERISTICS, AND MUSCLE ACTIVITY WHILE RUNNING WITH A TRADITIONAL COMPARED TO A NEWLY DEVELOPED RUNNING SHOE

Eric Lichtenstein[1], Lars Donath[1,2], Aislinn Oeri[1], Ralf Roth[1], Roland Rössler[1,3], Lukas Zahner[1], and Oliver Faude[1]

[1]Department of Sport, Exercise and Health, University of Basel, Basel, Switzerland
[2]Institute of Exercise Training and Computer Science in Sport, German Sport University Cologne, Köln, Germany
[3]Amsterdam Collaboration on Health & Safety in Sports & Department of Public and Occupational Health, Amsterdam Movement Sciences, VU University Medical Center, Amsterdam, the Netherlands

Original scientific paper
UDC: 796.02:796.015.54

Abstract:

A new running shoe cushioning technology has been developed intending to dampen the landing impulse during running while allowing a powerful and direct push-off. We aimed to compare this newly developed technology to traditional running shoes in regard to endurance performance, spatiotemporal stride characteristics, ground reaction forces, and muscle activity. In a randomized crossover design, 13 recreational runners (age 24.9±1.2 years, height 1.68±0.07 m, body mass 62.8±6.0 kg, weekly running distance >30 km) were tested twice, once with their own traditional shoes and (with a 2-week run-in and a 6-week wash-out period) with shoes featuring the new technology. The two-day testing procedure consisted of a graded exercise running test to assess lactate threshold (LT) on day one. On the following day, muscle activity, ground reaction forces and spatiotemporal stride characteristics at two velocities (80% and 95% LT velocity) were recorded on an instrumented treadmill. Finally, 4 km time trial performance was assessed. Magnitude-based inferences were calculated to compare the two shoe conditions. Ground reaction force was likely higher at 95% LT (+5.7%) and possibly higher at 80% LT (+2.2%) with the newly designed shoes, while muscle activity was likely reduced in the tibialis anterior and biceps femoris muscles during push-off. Spatiotemporal stride parameters, physiological markers during the graded exercise test as well as time trial performance showed trivial or unclear differences between the conditions. The observed differences between the shoe conditions in ground reaction forces and muscle activity were insufficient to elicit improvements in selected performance parameters.

Key words: *time trial, endurance performance, running biomechanics, EMG, running shoes*

Introduction

Running is one of the most popular leisure time sporting activities. There is a huge number of competitions, with steadily rising numbers of participants even on an amateur level that attract people of all age and performance groups as well as ethnicities. When performance optimization starts to play a role, the choice of equipment, especially shoes, receives increasing attention (Moore, Jones, & Dixon, 2014). Thus, a dynamic market has grown where new technologies promise performance improvements, comfort and injury prevention, sometimes simultaneously.

A unique cushioning technology has been developed that pursues performance improvements by offering a barefoot-like, direct push-off, while at the same time providing enough cushioning to enable a maintenance of the preferred stride characteristics. This should be achieved by an interlocking of the cushioning elements upon ground contact. Barefoot or minimalistic running shoes have attempted to enable a direct push-off and improve running economy, but usually lead to altered stride characteristics or increased impact forces (Hall, et al., 2013). Traditional running shoes often feature similar cushioning in the heel and the forefoot, dampening not only the landing forces but, unfortunately, also the push-off forces. The new technology attempts to combine the benefits of either shoe design while omitting the limitations and, additionally, minimizing shoe weight. This provides an opportunity to use the shoe as an option for racing as shoe weight is inversely associated with running economy (Divert, et al., 2008) and a reduction in weight could potentially improve performance. Comparing different shoes in regard to time trial performance is lacking in the literature as the focus has so far been on the surrogate measure of running economy (Fuller, et al., 2015).

The aim of this study was to investigate the effect of the new cushioning technology by comparing it to the traditional running shoes (TRS) in ambitious recreational runners. We investigated: (1) vertical ground reaction forces, (2) spatiotemporal stride characteristics, (3) muscle activity during submaximal running, and (4) performance parameters, including a 4 km time trial, to add insight into the technologies' effect on performance and possible biomechanical mechanisms, which have thus far been inadequately investigated. Following the noted features of the cushioning technology, we expected differences in vertical ground reaction forces, which we hypothesized would be increased during push-off for shoes featuring the new technology but not during the landing phase. These differences may potentially result in performance improvements, if muscle activity is not altered.

Materials and methods

Study design and employed procedures complied with ethical standards and the Declaration of Helsinki. The study was approved by the local ethics committee (Ethikkommission beider Basel, EKBB, Basel, Switzerland). All participants gave their written informed consent prior to the start of the study.

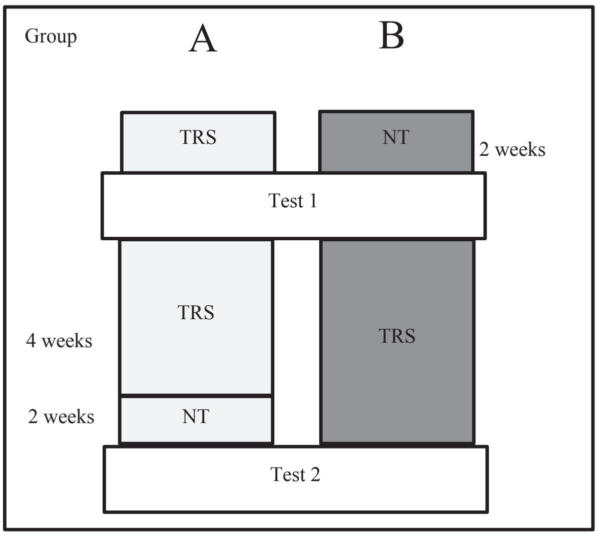

Figure 1. Study design.

Participants and general design

The present study was conducted as a randomized crossover study (Figure 1). Participants (age 24.9 ± 1.2 years, 10 women, body height 1.66 ± 0.04 m, body mass 60.6 ± 4.5 kg, three men, 1.76 ± 0.08 m, 69.7 ± 4.5 kg) were randomly assigned to either first being tested wearing the shoes with the new technology (NT) or their individual traditional running shoes (TRS). Measurements for both shoe conditions were conducted with a 6-week wash-out and a two-week run-in phase for the new shoe condition to achieve familiarization with and dishabituation from the shoe. ON AG (Kloten, Switzerland) provided the shoes with the new technology. Participants were instructed to maintain their training routine (36.5 ± 7.7 km/week). Shoe weight (TRS: 288 ± 32 g, NT: 269 ± 11 g) and anthropometrical data were gathered. Testing was conducted on two different days, with a day or two in between.

Procedures

On the first day physiological performance parameters were assessed during a graded exercise running test (GXT). Capillary blood samples were taken from the right earlobe prior to the start of the test, at the end of every stage and directly after the termination of the GXT for the determination of blood lactate concentration (bLa; Super GL ambulance, Dr. Müller Gerätebau, Freital, Germany). Participants started at 6 km/h with the speed incremented by 2 km/h every 3 minutes, and with 30 s rest between stages. Heart rate was taken from the ECG recordings (cardio 100, custo med GmbH, Ottobrun, Germany). Running velocity at lactate threshold (LT) was determined according to the method described by Röcker et al. (1998) at a blood lactate concentration of 1.5 mmol/l above the exercise baseline. Participants were instructed to run until volitional exhaustion and were verbally encouraged by the test staff. Maximal running velocity (v_{max}), heart rate (HR_{max}) were documented. Maximal blood lactate concentration (bLa_{max}) was taken from the blood sampled immediately after the termination of the GXT.

On the second day, participants were instructed to run under three conditions on an instrumented treadmill (Zebris FDM-T, zebris Medical GmbH, Isny, Germany). Participants started with 10 minutes of running at 70% of their LT velocity (warm-up), followed by 3-minute running at 80% and 3-minute running at 95% LT velocity, according to moderate and high-intensity continuous endurance running (Faude, Kindermann, & Meyer, 2009). All participants were familiar with running on a treadmill. During these 16 minutes of running, the following measurements were conducted.

Spatiotemporal stride parameters: stride length, stride time, cadence and ground contact time as well as flight time were measured. Additionally, vertical ground reaction forces were recorded at 100 Hz by the above-mentioned treadmill. During the last minute of the 80% and 95% LT runs, stride parameters and ground reaction forces were evaluated. Force data were normalized to the gait cycle and averaged. The peak force and the acceptance load, defined as the steepest rise in force during the landing phase, were calculated.

Participant's outdoor running performance was assessed one hour after the submaximal treadmill test on day two on an outdoor athletic track. They performed a 1600 m warm-up at 70% of their LT, paced by whistle signals every 50 m. Then they performed a 4000 m all-out run. Running time was assessed by a photoelectric light barrier (Witty, Microgate, Bolzano, Italy). During the test, participants did not receive any information on their current pace nor were they motivated by the testers. Blood lactate concentration was gathered prior to and directly after the termination of the run according to the above-mentioned procedure.

Muscle activity

Prior to the running trials, bipolar surface electromyography (EMG) electrodes (Blue Sensor, Ambu, Balerup, Denmark) were placed on the M. gastrocnemius medialis (GM), M. soleus (SOL), M. peroneus longus (PER), M. tibialis anterior (TA), M. rectus femoris (RF), and M. biceps femoris (BF) of the right leg in accordance with the SENIAM guidelines in a distance of 2.5 cm on the required spot marks (Stegeman & Hermens, 2007). A ground electrode was placed on the shin, directly above the tibia bone. The inter-electrode resistance was kept below 5 kΩ by shaving the hair and abrading the skin with fine sandpaper. An alcohol solution was used to further reduce impedance. Inter-electrode resistance was checked for each muscle.

Muscle activity was recorded with a sampling rate of 500 Hz and synchronized with the spatiotemporal running analysis. In order to receive a trigger for foot contact, the Optogait (Microgate, Bolzano, Italy) photoelectric system was mounted on the treadmill and connected to the A/D card.

Raw data were processed using the proEMG data recording and analysis software (Prophysics AG, Kloten, Switzerland). This included the application of the following filters in the given order: Offset correction, 50 Hz notch, Butterworth low-pass (200 Hz, 2nd order), Butterworth high-pass (10Hz, 2nd order). The zero line was visually inspected to detect artefacts and noise. EMG data were time-normalized to the stride cycle followed by the calculation of the average root mean square of muscle activity of all recorded strides during the following phases of the gait cycle: (1) pre-activation phase (50 ms before foot contact), (2) during the initial-contact phase (50 ms after foot contact), and (3) during 50 ms before the toe-off. Muscle activity was normalized to the average activation over the first 10 seconds of the respective 80% LT running trial.

Statistical analysis

The magnitude-based inference approach was used for statistical analyses (Batterham & Hopkins, 2006). The smallest meaningful change was defined at a standardized change of 0.20 of the inter-individual standard deviation with 90% confidence limits. The likelihood for meaningful changes was calculated using the following scale: 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; >99.5%, almost certainly. Data were computed using an open-access Microsoft® Excel spreadsheet for crossover trials (Hopkins, et al., 2009). The probabilities for a meaningful beneficial effect, no effect and harmful effect and the magnitude of this effect are reported as standardized mean changes and as percentage change of the mean.

Results

Performance

Likely trivial differences were found for the performance in the 4000 m time trial between the conditions. On average, participants ran 3 s or 0.36 % faster with NT. Despite huge confidence intervals [-16.97; 10.97] for this differences, subjects were very unlikely slower (Table 1).

Physiological variables during GXT

We observed likely trivial differences for most parameters measured during the incremental running test (Table 1). Only maximal blood lactate concentration was very likely higher in the NT condition. As the LT did not differ between shoe conditions, the subsequent treadmill tests were conducted at identical velocities.

Spatiotemporal stride parameters and ground reaction forces

Likely trivial differences were observed for stride length, stride time, stride frequency as well as contact and flight time at both speeds (Table 1). We found likely higher peak vertical forces during the 95% LT run in the NT condition. The difference in acceptance load was likely trivial, albeit very unlikely decreased in the NT condition.

Muscle activity

During the pre-activation phase muscle activity in the six observed muscles did unlikely deviate between the shoe conditions (data not shown). EMG showed likely increased muscle activity during the initial contact phase at 80% LT in RF and SOL as well as a likely reduced activity in TA wearing NT (Table 2). During the push-off phase, muscle activity of the BF and TA was likely reduced at both

Table 1. Performance parameters, spatiotemporal parameters and ground reaction forces during running

	NT	TRS	Absolute difference	Relative difference (%)	d	Decrease/ Increase probabilities
	Mean (SD)	Mean (SD)	Δ [90%-CI]	Δ [90%-CI]		
v_{max} (km/h)	16.25 (1.21)	16.09 (1.12)	0.18 [-0.01; 0.38]	1.11 [-0.11;2.36]	0.15	0/65/35
HR_{max} (bpm)	175 (4)	176 (5)	-0.4 [-3.0; -2.2]	-0.2 [-1.68; 1.26]	0.10	24/35/40
LT pace (km/h)	12.5 (0.6)	12.5 (0.7)	0.0 [-0.3; 0.3]	0.1 [-2.1; 2.2]	0.01	18/62/20
bLa_{max} (mmol/l)	11.2 (1.7)	9.5 (1.7)	1.7 [0.7; 2.8]	18.9 [5.9; 33.6]	0.91	**0/3/97
4 k time trial (min:s)	16:52 (1:20)	16:55 (1:11)	-3.0 [-16.97; 10.97]	-0.36 [-1.70;1.00]	0.04	10/88/2
4 k time trial bLa_{Δ}	7.6 (1.8)	8.0 (2.1)	- 0.4 [-1.2; 0.5]	-4.1 [-13.1; 5.8]	0.17	41/53/5
			80 % LT pace			
Stride length (cm)	196 (14)	196 (14)	0.07 [-4.24; 4.38]	0.05 [-2.1; 2.2]	0.00	12/75/13
Stride frequency (/min)	85 (4)	85 (4)	-0.02 [-0.97; 1.01]	0.02 [-1.1; 1.2]	0.01	12/75/13
Contact time (s)	0.27 (0.02)	0.27 (0.03)	0.00 [-0.01; 0.01]	0.22 [-2.5; 3.0]	0.00	7/81/12
Peak force (N)	1091 (180)	1064 (136)	27.9 [-37.3; 93.1]	2.23 [-3.5; 8.3]	0.19	8/48/44
Acceptance load (N/s)	511 (149)	503 (174)	6.9 [-30.4; 44.2]	3.06 [-5.3; 12.17]	0.04	3/77/20
			95 % LT pace			
Stride length (cm)	226 (17)	224 (16)	0.07 [-4.24;4.38]	0.76 [-1.44;3.00]	0.10	5/67/28
Stride frequency (/min)	87 (4)	88 (4)	-0.54 [-1.64;0.57]	-0.64 [-1.87;0.61]	0.13	36/62/2
Contact time (s)	0.25 (0.02)	0.25 (0.02)	0.00 [-0.01;0.00]	-0.56 [-2.47;1.38]	0.08	16/81/3
Peak force (N)	1085 (181)	1022 (136)	63.13 [12.73;113.54]	5.76 [1.30;10.41]	0.43	*1/7/92
Acceptance load (N/s)	577 (178)	556 (194)	20.43 [-8.32;49.18]	4.96 [-1.02;11.32]	0.10	0/76/24

Note. Differences are NT – TRS with 90%-CI. NT – new technology shoe, TRS – traditional shoe, v_{max} – maximal velotICy during IRT, HR_{max} – maximal heart rate during IRT, LT – lactate threshold, bla_{max} – maximum blood lactate concentration during the graded exercise test, bLA_{Δ} – blood lactate increase during 4k time trial, d – Cohen's d. ** – indicates very likely differences, * – indicates likely differences.

speeds in the NT condition (Table 2). PER and GM activity was likely increased for NT at 80% LT but not at 95 % LT (Table 2). Likely trivial differences were observed for the RF and SOL during either velocity.

Discussion and conclusions

The present study aimed to identify differences between the newly developed and the traditional running shoe regarding vertical ground reaction forces, spatiotemporal stride parameters, muscle activity, physiological parameters during an incremental running test and endurance performance during a 4000 m time trial. Likely meaningful increases were identified for peak vertical ground reaction forces while running at 95% LT as well as maximum blood lactate concentration during the graded exercise test with higher values observed in NT. A likely decrease of surface EMG activity for the selected muscles during the push-off phase in the NT condition was found. No relevant differences were observed for spatiotemporal stride characteristics, the activity of most muscles during the pre-activation and initial contact phase and measures of performance.

This study is among the first investigating the influence of a newly developed running shoe with a promising cushioning technology on running performance in a time-trial event, on performance in a standard incremental test and on biomechanical characteristics during submaximal steady-state running. We observed no relevant changes in 4 km running performance with NT. The unique cushioning technology did alter the selected biomechanical parameters during push-off, which, however, did not translate to performance improvements in the time trial event. Correspondingly, during the incremental running test no relevant differences were found for lactate threshold and maximum running velocity. The observed differences for maximum lactate concentrations might appear meaningful. However, Faude et al. (2017) recently showed that this difference is within the intra-individual variability of blood lactate concentrations during high-intensity endurance exercise. Large differences between different shoes in time-trial events have been found when comparing lightweight racing shoes to heavier running shoes (Fuller, et al., 2016). Therefore, it seems the weight of the shoe is most important for performance and the role of different cushioning technologies appears to be of minor importance. Fuller et al. (2015) concluded, that the optimal shoe weight is around 220g. The shoes investigated here were heavier (269 ± 11g).

Table 2. Muscle activity measured via surface EMG, standardized to the average activation during the first 10 s of 80% LT pace and probability of differences

		TRS	NT	Relative difference (%)	d	Decrease/ Increase probabilities
			Push-off phase			
	Velocity	Mean (SD)	Mean (SD)	Mean [90%-CI]		
Tibialis anterior	80% LT	89.6 (45.1)	56.1 (36.5)	-45.7 [-62.5; -21.37]	0.69	**98/2/0
	95% LT	88.1 (42.9)	70.5 (46.5)	-31.1 [-53.6; 2.4]	0.39	*87/10/3
Biceps femoris	80% LT	23.0 (18.8)	11.5 (7.0)	-43.3 [-62.2; -15.0]	0.59	**95/5/0
	95% LT	27.0 (28.6)	11.5 (6.3)	-50.2 [-69.0; -19.8]	0.49	**96/3/1
Gastrocnemius medialis	80% LT	13.4 (21.2)	5.5 (2.1)	-35.3 [-63.2; 13.62]	0.34	*78/18/4
	95% LT	7.3 (3.5)	8.1 (6.0)	4.8 [-28.0; 52.7]	0.22	20/44/35
Peroneus longus	80% LT	24.7 (19.4)	16.8 (8.8)	-28.4 [-47.8; -1.77]	0.37	*87/12/1
	95% LT	27.5 (20.6)	23.6 (18.4)	-19.2 [-45.2; 19.2]	0.18	64/29/7
Soleus	80% LT	11.9 (5.9)	10.0 (4.2)	-14.2 [-36.3; 15.7]	0.28	58/36/6
	95% LT	11.0 (5.9)	14.0 (13.0)	13.7 [-35.7; 100.8]	0.46	22/27/51
Rectus femoris	80% LT	49.4 (24.0)	44.0 (27.7)	-15.5 [-40.6; 20.2]	0.21	65/25/10
	95% LT	53.9 (18.7)	68.0 (58.3)	-6.5 [-46.8; 64.1]	0.70	49/17/34
			Initial contact phase			
Tibialis anterior	80% LT	103.0 (36.8)	84.5 (31.0)	-16.1 [-40.1; 17.6]	0.46	67/24/9
	95% LT	95.4 (40.2)	85.8 (48.2)	-19.3 [-57.7; 54.1]	0.22	60/21/19
Biceps femoris	80% LT	66.5 (50.7)	51.1 (25.9)	-14.5 [-46.9; 37.9]	0.27	51/36/13
	95% LT	71.3 (50.9)	58.9 (52.1)	-22.0 [-57.9; 44.2]	0.22	57/31/12
Gastrocnemius medialis	80% LT	123.2 (77.9)	100.7 (52.5)	-5.2 [-44.2; 61.1]	0.27	32/47/21
	95% LT	120.9 (68.2)	112.6 (43.2)	3.6 [-42.3; 85.9]	0.11	28/37/35
Peroneus longus	80% LT	121.7 (76.8)	109.0 (38.9)	3.5 [-28.8; 50.4]	0.15	21/48/31
	95% LT	122.3 (77.5)	134.8 (61.3)	20.6 [-26.18; 97.1]	0.15	13/29/58
Soleus	80% LT	111.1 (59.6)	143.5 (61.2)	45.2 [3.6; 103.4]	0.49	*1/14/85
	95% LT	111.0 (62.8)	124.7 (68.6)	9.0 [-38.0; 91.4]	0.20	26/28/46
Rectus femoris	80% LT	85.6 (64.1)	132.7 (64.9)	76.4 [5.2; 196.0]	0.66	*2/8/90
	95% LT	115.3 (72.6)	119.7 (82.8)	-18.9 [-69.2; 114.0]	0.06	53/23/24

Note. Differences are NT – TRS with 90%-CI. NT – new technology shoe, TRS – traditional shoe, d – Cohen's d. ** – indicates very likely differences, * – indicates likely differences.

In contrast to numerous studies (Hall, et al., 2013; Lussiana, et al., 2013; Willy & Davis, 2013) investigating the effect of footwear on running biomechanics, no differences were found for spatiotemporal parameters. Usually, stride frequency is increased in shoes with less cushioning and its associated measures are reduced (e.g., stride time, contact time) as well as step length. Most shoes used for comparison feature reduced cushioning, or in case of barefoot studies no cushioning at all. This leads to most participants altering their stride, possibly due to increased pain sensation or discomfort. The NT's cushioning seems to be similar to the TRS as loading rates during landing showed no differences and thus, participants had none of the mentioned reasons to alter their stride.

We found no differences for loading rates during the landing phase. Several studies have reported increased loading rates in barefoot and minimalist shoe conditions (Willy & Davis, 2013), but only when participants did not alter their stride. Generally, loading rates seem to be more correlated to foot strike pattern than the footwear used (Liebermann, et al., 2010). Our participants appeared to be predominantly heel-strikers and remained so in the NT condition due to the NT design being similar to the TRS. Thus, the lack of differences for GRF during the landing phase is comprehensible.

A different observation was made for peak vertical ground reaction forces during push-off, which were likely increased in the NT condition. The literature focuses on the comparison between shod and unshod running in this regard and unshod running has been shown to feature reduced peak vertical ground reaction forces (Hall, et al., 2013), but not when controlled for stride type and thus spatiotemporal stride parameters. Our findings may indicate a more direct transmission of the forces to the ground and possibly leading to an improved impulse for push-off. Unfortunately, we were not able to record horizontal ground reaction forces, as they seem more relevant to a forward motion than vertical forces considering that the vertical forces were reduced with increasing speed in the present observation. So far, no study has investigated this matter with a focus on different shoe conditions. It seems possible that a certain shoe design might redirect vertical forces to horizontal forces. This could enhance forward motion and reduce peak vertical ground reaction forces. Our data also suggest that peak vertical forces are attenuated at higher speeds and might therefore not be a good marker of forces for propulsion in endurance running.

In running at 80% LT, we observed a likely increased muscle activity during the initial contact phase in the RF and SOL and a possibly reduced muscle activity in the TA wearing NT. During the push-off phase, likely reduced muscle activity was observed in the BF, PER, GL and TA. At 95% LT, we found likely reduced muscle activity in the BF and TA during push-off. So far, there is a paucity in the literature investigating muscle activity while running in different shoes and therefore this study is the first to compare different shoe conditions. Studies investigating differences between barefoot and shod muscle activity found more activity in the plantar flexors when running barefoot (Divert, et al., 2005; Fleming, et al., 2015). As Shih et al. (2013) concluded that this observation could be explained by an altered running style, therefore running technique seemed to play a more important role in muscle activity patterns between these two conditions. This also serves as the primary explanation for the lack of differences observed in this study during the pre-activation and initial contact phase, because running technique was unlikely altered due to the similarities in the construction of the shoes. Likely changes observed during push-off align well with our findings of increased peak vertical ground reaction forces, as this suggests a more efficient push-off and therefore an improvement during the later phases of the stance phase. It has to be noted, however, that muscle activity during the toe-off phase is the lowest over all muscles while running as reported by Novacheck (1998). This in return could explain why this advertised a more efficient push-off does not likely influence performance to a degree sufficient to enhance it.

Combining the presented results of increased push-off forces and simultaneously reduced muscle activity could hint to an improved muscular efficiency. It could be speculated that this in turn could be relevant for longer endurance events, where accumulation of fatigue could be influenced by very small differences between shoes.

The normalization of the EMG activity to the first ten seconds of the 80% LT trial of each condition could lead to erroneous data as the average activity of this bout could already be influenced by the shoe condition. In our opinion, these errors are alleviated by the fact that velocities between these trials did not differ. Performing maximum voluntary contraction trials is often used for standardization, but could have introduced more measurement error. Additionally, this method permitted us to include unavoidable EMG artefacts caused by the strenuous dynamic movement.

Further, the investigation of fixed timeframes before and after the initial contact as well as push-off instead of using percentages of the gait cycle (Baur, et al., 2011) or force triggers (Fleming, et al., 2015; Kyröläinen, et al., 2007) can be questioned, but it likely did not affect the results, as ground contact time did not relevantly differ between the conditions and therefore the conferred timeframes were probably very similar.

Additionally, we recorded EMG data with a frequency of 500 Hz, which is low compared to studies conducted in this field, but it was the limit of our recording device. We feel that the recording of one-minute bouts and therefore approximately 80 to 90 steps per subject attenuates this problem as a lot of data were gathered and averaged to allow for valid interpretation. Overall, the EMG results have to be interpreted with caution.

Lastly, it is debatable if the run-in phase and the wash-out periods were adequate. In their review, Fuller et al. (2015) stated that there was only one study investigating into this matter, but they implied that a too short period might mask actual adaptations to the footwear as a 4-week familiarization leads to significant differences. We think that our 6-week washout and 2-week run-in is a substantial improvement over studies comparing acute effects that disregard possible long-term effects.

The present study is the first to show that altering footwear seems to have an effect on muscle activity during submaximal running. In addition, we are among the first to compare different shoes concerning time-trial performance after a substantial familiarization period. Additionally, the randomized cross-over design rules out effects due to learning, training or adapting to the conducted tests and the comprehensive set of measurements conducted permits holistic insight into the difference, or lack thereof, of the shoes tested.

This study found no differences between the shoes featuring a new cushioning technology and the traditional running shoes regarding endurance performance and stride characteristics. We found some differences for muscle activity and vertical ground reaction forces but these did not affect performance. It seems that different cushioning technologies might only have a miniscule influence on individual running biomechanics when comparing shoes of similar weight.

References

Batterham, A.M., & Hopkins, W.G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance, 1*(1), 50-57.

Baur, H., Hirschmüller, A., Müller, S., Cassel, M., & Mayer, F. (2012). Is EMG of the lower leg dependent on weekly running mileage? *International Journal of Sports Medicine, 33*, 53-57. doi: 10.1055/s-0031-1286250

Divert, C., Mornieux, G., Baur, H., Mayer, F., & Belli, A. (2005). Mechanical comparison of barefoot and shod running. *International Journal of Sports Medicine, 26*(7), 593-598. doi: 10.1055/s-2004-821327

Faude, O., Hecksteden, A., Hammes, D., Schumacher, F., Besenius, E., Sperlich, B., & Meyer, T. (2017). Reliability of time-to-exhaustion and selected psycho-physiological variables during constant-load cycling at the maximal lactate steady state. *Applied Physiology, Nutrition and Metabolism, 42*(2), 142-147. doi: 10.1139/apnm-2016-0375

Faude, O., Kindermann, W., & Meyer, T. (2009). Lactate threshold concepts. *Sports Medicine, 39*(6), 469-490. doi: 10.2165/00007256-200939060-00003

Fleming, N., Walters, J., Grounds, J., Fife, L., & Finch, A. (2015). Acute response to barefoot running in habitually shod males. *Human Movement Science, 42*, 27-37. doi:10.1016/j.humov.2015.04.008

Fuller, J.T., Bellenger, C.R., Thewlis, D., Tsiros, M.D., & Buckley, J.D. (2015). The effect of footwear on running performance and running economy in distance runners. *Sports Medicine, 45*(3), 411-422. doi: 10.1007/s40279-014-0283-6

Fuller, J.T., Thewlis, D., Tsiros, M.D., Brown, N., & Buckley, J.D. (2016). Effects of a minimalist shoe on running economy and 5-km running performance. *Journal of Sports Sciences, 34*(18), 1740-1745. doi: 10.1080/02640414.2015.1136071

Hall, J.P.L., Barton, C., Jones, P.R., & Morrissey, D. (2013). The biomechanical differences between barefoot and shod distance running: A systematic review and preliminary meta-analysis. *Sports Medicine*, *43*(12), 1335-1353. doi: 10.1007/s40279-013-0084-3

Hopkins, W.G., Marshall, S.W., Batterham, A.M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise, 41*(1), 3-13. doi: 10.1249/MSS.0b013e31818cb278

Kyröläinen, H., Avela, J., & Komi, P.V. (2005). Changes in muscle activity with increasing running speed. *Journal of Sports Sciences, 23*(10), 1101-1109. doi: 10.1080/02640410400021575

Lieberman, D.E., Venkadesan, M., Werbel, W.A, Daoud, A.I., D'Andrea, S., Davis, I.S., & Pitsiladis, Y. (2010). Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature, 463*(7280), 531-535. doi: /10.1038/nature08723

Lussiana, T., Fabre, N., Hébert-Losier, K., & Mourot, L. (2013). Effect of slope and footwear on running economy and kinematics. *Scandinavian Journal of Medicine and Science in Sports, 23*(4), e246-e253. doi: 10.1111/sms.12057

Moore, I.S., Jones, A., & Dixon, S. (2014). The pursuit of improved running performance: Can changes in cushioning and somatosensory feedback influence running economy and injury risk? *Footwear Science, 6*(1), 1-11. doi: 10.1080/19424280.2013.873487

Novacheck, T.F. (1998). The biomechanics of running. *Gait and Posture, 7*(1), 77-95. doi: 10.1016/S0966-6362(97)00038-6

Shih, Y., Lin, K.-L., & Shiang, T.-Y. (2013). Is the foot striking pattern more important than barefoot or shod conditions in running? *Gait and Posture, 38*(3), 490-494. doi: 10.1016/j.gaitpost.2013.01.030

Willy, R.W., & Davis, I.S. (2013). Kinematic and kinetic comparison of running in standard and minimalist shoes. *Medicine and Science in Sports and Exercise, 46*(2), 318-323. doi: 10.1249/MSS.0b013e3182a595d2

Correspondence to:
Eric Lichtenstein, M.Sc.
Department of Sport, Exercise and Health,
University of Basel
Birsstr. 320B, 4052 Basel, Switzerland
Phone: +41 – 79 – 641 5225
Fax: +41 – 61 – 207 47 39
E-mail: e.lichtenstein@unibas.ch

Acknowledgements

We would like to thank the ON AG (Kloten, Switzerland) for supplying us with the tested shoes. The company had no influence on the planning, execution or interpretation of this study. The authors gratefully acknowledge the support of Joanna Peter for her help in the acquisition of the data. In addition, we thank all participants for their effort and their compliance.