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The influence of minimalist, maximalist and conventional footwear on impact shock attenuation during running

Jonathan Sinclair

Centre for Applied Sport & Exercise Sciences, School of Sport & Wellbeing, College of Health & Wellbeing, University of Central Lancashire, Lancashire, UK

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Abstract. The current investigation examined the effects of minimalist, maximalist and conventional footwear on skeletal accelerations and shock attenuation during running. Ten male runners ran at 4.0 m.s^{-1} in minimalist, maximalist and conventional footwear. Axial accelerations were measured using accelerometers positioned at the tibia and sacrum. Peak tibial and sacral accelerations were obtained and used to calculate the extent of shock attenuation. The results showed that peak tibial acceleration and shock attenuation were significantly lower in the minimalist in comparison to the conventional and maximalist footwear. Running in conventional and maximalist footwear may place increased demands on the musculoskeletal structures in order to attenuate impact transients, which may be detrimental to passive tissues.

Key words: Footwear, injury, shock attenuation

Résumé. Influence du port de chaussures minimalistes, maximalistes et conventionnelles sur l'atténuation des chocs durant la course à pied.

Cette étude a examiné les effets du port de chaussures minimalistes, maximalistes et conventionnelles sur les accélérations et l'atténuation des chocs lors de la course à pied. Dix coureurs de sexe masculin ont couru à 4,0 m.s^{-1} avec trois types de chaussures différentes : minimalistes, maximalistes et conventionnelles. Les accélérations axiales ont été mesurées en utilisant des accéléromètres positionnés au niveau du tibia et du sacrum. Les pics d'accélération ont été utilisés pour calculer l'importance de l'atténuation des chocs. Les résultats ont montré que l'accélération maximale au niveau tibial et l'atténuation des chocs étaient significativement plus faibles avec les chaussures minimalistes par rapport aux chaussures maximalistes et conventionnelles. Courir dans des chaussures maximalistes ou conventionnelles implique une sollicitation accrue des structures musculo-squelettiques pour atténuer les forces d'impact transitoires qui peuvent être préjudiciables aux tissus passifs.

Mots clés : Chaussures, blessure, amortissement de chocs

1 Introduction

Runners are known to be highly susceptible to chronic pathologies (Taunton, Ryan, Clement, McKenzie, Lloyd-Smith, & Zumbo, 2002), with 19.4–79.3% becoming injured over the course of one year (Van GentGent, Siem, van Middelkoop, van Os, Bierma-Zeinstra, & Koes, 2007). Although the aetiology of running injuries is often poorly understood, it is commonly believed that running injuries are related to repetitive loading of the lower extremities (Robbins, & Hanna, 1987; Whittle, 1999; Murphy, Connolly, & Beynnon, 2003; Burne, *et al.*, 2004; Warden, Burr, & Brukner, 2006).

During running each footstrike leads to the generation of a transient shock wave which is transmitted through the musculoskeletal system (Whittle, 1999). The impact shock wave generated by each footstrike has to be attenuated in order to minimize accelerations of the skull, which can lead to disturbances of the vestibular and visual systems (Derrick, Hamill, & Caldwell, 1998; Hamill, Derrick, & Holt, 1995; Lafortune, Lake, & Hennig, 1996). Shock attenuation is a key parameter in biomechanical analyses that is useful when investigating how the body dissipates the impact shock wave as it propagates through the musculoskeletal system (Mercer, Devita, Derrick, & Bates, 2002; Shorten, & Winslow, 1992). Shock attenuation is achieved *via* energy absorption from active muscle contraction, alterations in lower limb alignment, and through deformation of passive tissues (Paul, *et al.*, 1978; Chu, Yazdani-Ardakani, Gradisar, & Askew, 1986; Valiant, 1990; Mercer, *et al.*, 2010). Previous analyses have shown that shock attenuation is influenced by a number of biomechanical and physiological parameters (Mercer, *et al.*, 2010). However, there is a paucity of research which has examined the influence of different footwear on shock attenuation during running.

Footwear has been proposed as a mechanism by which chronic running injuries can be controlled (Shorten, 2000). Minimalist footwear has been subjected to considerable research attention in the field of biomechanics. Running in minimalist footwear is characterized by the lack of a discernible impact transient in the vertical ground reaction force (Lieberman, *et al.*, 2010). Given the proposed association between impact forces and the aetiology of running injuries, this has led many researchers to speculate that minimalist footwear may be able to reduce the incidence of chronic running injuries (Lieberman, *et al.*, 2010; Warburton, 2001). The findings of research into the effects of minimalist footwear are somewhat conflicting however. Squadrone and Gallozzi (2009) showed that running in minimalist footwear produced a more plantarflexed foot position and also reduced the impact peak of the vertical ground reaction force in comparison to conventional footwear. Sinclair, Greenhalgh, Edmundson, Brooks, & Hobbs (2013a); Sinclair, Hobbs, Currigan, & Taylor (2013c) showed that whilst minimalist footwear also mediated a more plantarflexed ankle they were associated with significant increases in average and instantaneous loading rate in comparison to conventional running shoes. Sinclair (2014) demonstrated that barefoot and minimalist footwear mediated a midfoot strike patters. In addition, minimalist footwear also served to reduce the loads experienced by the patellofemoral joint but they also correspondingly increased the forces experienced by the Achilles tendon during the stance phase.

In addition to the interest in minimalist footwear, there has also been attention on so called maximalist footwear which have been recently released and advocated by shoe manufacturers (Sinclair, Richards, Selfe, Fau-Goodwin, & Shore, 2016). Maximalist footwear has a much thicker midsole than conventional footwear and is intended to provide additional cushioning and shock attenuation. Currently very little published information exists regarding the biomechanics of maximalist footwear (Sinclair *et al.*, 2016). Although the biomechanical influence of minimalist and maximalist footwear have been examined in previous literature, their effects on shock attenuation have yet to be investigated. Therefore the aim of the current investigation was to examine the effects of minimalist, maximalist and conventional footwear on skeletal accelerations and shock attenuation during running. This investigation tests the hypothesis that skeletal accelerations will be reduced when wearing conventional and maximalist.

2 Methods

2.1 Participants

Ten male runners volunteered to take part in this study. All runners were free from musculoskeletal pathology at the time of data collection and provided written informed consent. All were recreational runners who trained a minimum of 3 times / week completing a minimum of 35 km. Each of the participants habitually wore conventional running footwear and through pilot analyses we showed that all were rearfoot strikers as they exhibited an impact peak in their vertical ground reaction force curve. The mean characteristics of the participants were; age 24.25 ± 3.54 years, height 1.77 ± 0.11 cm and body mass 75.24 ± 6.85 kg. The procedure utilized for this investigation was approved by the University of Central Lancashire, Science, Technology, Engineering and Mathematics, ethical committee (Ref 361).

2.2 Procedure

Participants ran at a velocity of 4.0 $m.s^{-1}$ ± 5%, striking a force platform (Kistler, Kistler Instruments Ltd., Alton, Hampshire; length, width, height = 0.6×0.4×0 m) with their right foot (Sinclair, Hobbs, Taylor, Currigan, & Greenhalgh, 2014). The force plate was embedded into the floor (Altrosports 6mm, Altro Ltd.) in the centre of a 22 m biomechanics laboratory. Running velocity was quantified using Newtest 300 infrared timing gates (Newtest, Oy Koulukatu, Finland). The stance phase of running was delineated as the duration over which >20 N of vertical force was applied to the force platform Sinclair, Edmundson, Brooks, & Hobbs, 2011). Runners completed five successful trials in each footwear condition and order in which participants ran in each footwear condition was randomized. As the maximalist and minimalist footwear were novel to the runners, they were familiarized to these footwear prior to data collection. This involved 10 mins of treadmill running in both shoes at the experimental velocity for 5 consecutive days.

To measure skeletal accelerations two accelerometers (Biometrics ACL 300, Gwent United Kingdom) sampling at 1000 Hz were used. One of which was placed onto the right tibia (participants were all right side dominant) and the other one on the sacrum. The accelerometers were attached onto a piece of lightweight carbon-fibre material using the protocol outlined by Sinclair, *et al.* (2013a). The tibial accelerometer was strapped securely to the distal anterio-medial aspect of the tibia in alignment with its longitudinal axis 0.08 m above the medial malleolus (Sinclair, Bottoms, Taylor, & Greenhalgh, 2010). Strong non-stretch adhesive tape was placed over the device and leg to avoid overestimating the acceleration due to tissue artefact. The sacrum accelerometer was pressed onto the skin at the bony prominence of the sacrum and secured using an elastic belt around the waist (Mizrahi, Verbitsky, Isakov, & Daily, 2000). The accelerometer on the sacrum was oriented along the longitudinal axis of the spine.

As minimalist footwear has been shown to influence the footstrike pattern during running (Sinclair, *et al.*, 2013a; Sinclair, 2014), ankle angles were also quantified. This involved placing retroreflective markers unilaterally onto the right 1st metatarsal, 5th metatarsal, calcaneus, medial and lateral malleoli and medial and lateral epicondyles allowing the segment co-ordinate axes of the foot and shank to be defined. The center of the ankle was delineated as the mid-point between the malleoli and femoral epicondyle markers (Graydon, *et al.*, 2015). Static calibration trials were obtained in each footwear allowing for the anatomical markers to be referenced in relation to the tracking markers/ clusters. The Z (transverse) axis was oriented vertically from the distal segment end to the proximal segment end. The Y (coronal) axis was oriented in the segment from posterior to anterior. Finally, the X (sagittal) axis orientation was determined using the right hand rule and was oriented from medial to lateral. From this information the sagittal plane position of the ankle at the instance of footstrike was calculated. Kinematics, ground reaction force and acceleration data were collected synchronously using an analogue to digital interface board.

2.3 Processing

Running trials were processed in Qualisys Track Manager and then exported as C3D files. Kinematic and acceleration parameters were quantified using Visual 3-D (C-Motion Inc., Gaithersburg, USA). Marker data were smoothed using a low-pass Butterworth 4th order zero-lag filter at a cut off frequency of 12 Hz. Ankle kinematics were quantified using an XYZ cardan sequence of rotations (where X is flexion-extension; Y is ab-adduction and Z is internal-external rotation).

The acceleration signals were filtered with a 60 Hz low-pass Butterworth 4th order zero-lag filter. Peak tibial acceleration (PTA) was defined as the highest positive acceleration peak measured during the first 20% of the stance phase. The peak sacrum acceleration (PPA) curve was associated with two peaks at around 40% (PPA 1) and 60% (PPA 2) stance respectively. PTA slope was quantified by dividing the magnitude of PTA by the time taken from footstrike to PTA. PPA 1 and PPA 2 by dividing the magnitude of each by the time taken from footstrike to PTA 1 and PTA 2. With the data obtained above, shock attenuation was also calculated using the formula outlined below:

$$\text{Shock attenuation} = (1 - (\text{PPA1} - -\text{PTA}) \times 100)$$

Using the above formula, if accelerations were similar at the sacrum and tibia this indicates a low amount of shock attenuation whereas if tibial accelerations are high in relation to those experienced by the sacrum then this is indicative of a large amount of shock attenuation. All data were normalized to 100% of the stance phase then processed trials were averaged within subjects.

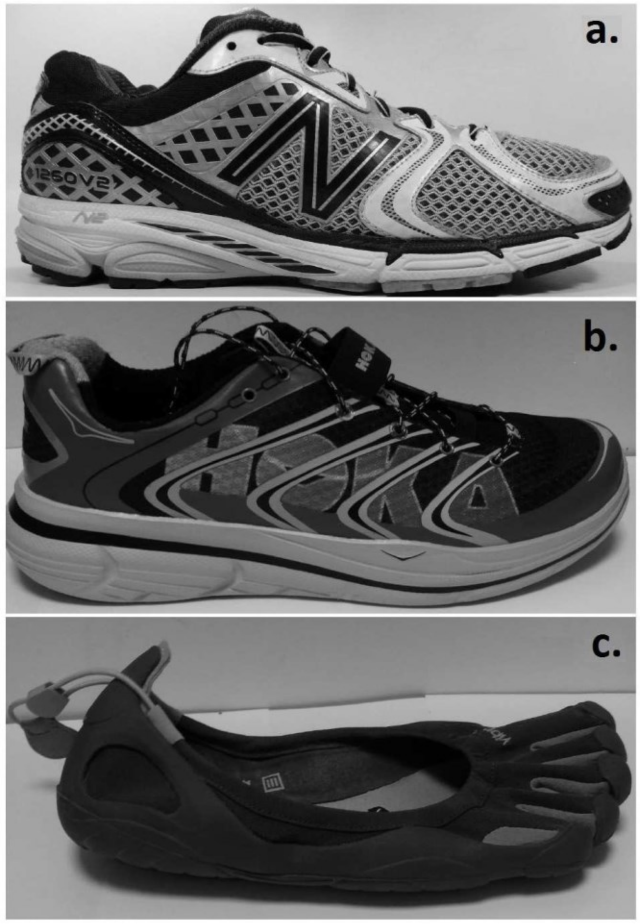

Fig. 1. Experimental footwear: a) conventional, b) maximalist, c) minimalist.

2.4 Experimental footwear

The footwear used during this study consisted of conventional footwear (New Balance 1260 v2), minimalist (Vibram five-fingers) and maximalist (Hoka One-One) footwear in sizes 8–10 UK. The conventional footwear had an average mass of 285 g and a heel drop of 14 mm (Fig. 1a). The maximalist footwear had an average mass of 318 g and a heel drop of 6 mm (Fig. 1b). Finally, the minimalist footwear had an average mass of 167 g and a heel drop of 0 mm (Fig. 1c).

2.5 Analysis

Differences in kinematics, acceleration and attenuation parameters between footwear were examined using one-way repeated measures ANOVAs, with significance accepted at the $P \leq 0.05$ level (Sinclair, Taylor, & Hobbs, 2013b). Effect sizes were calculated using partial eta quared ($p\eta^2$). *Post-hoc* pairwise comparisons were conducted on all significant main effects. All statistical actions were conducted using SPSS v22.0 (SPSS Inc., Chicago, USA).

Table 1. Mean ± SD acceleration parameters as a function of footwear.

	Minimalist		Maximalist		Conventional		
	Mean	SD	Mean	SD	Mean	SD	
PTA (g)	4.55	0.84	6.09 *A*	1.23	5.29	1.02	*
PPA 1 (g)	3.15	0.82	3.29	0.87	2.98	0.71	
PPA 2 (g)	1.68	0.39	1.62	0.40	1.70	0.45	
Time to PTA (s)	0.03	0.02	0.03	0.03	0.04	0.03	
Time to PPA 1 (s)	0.08	0.02	0.08	0.01	0.08	0.01	
Time to PPA 2 (s)	0.21	0.02	0.22	0.02	0.22	0.02	
PTA slope (g/s)	167.48	91.32	201.39 *A*	84.51	145.28 *B*	86.32	*
PPA 1 slope (g/s)	39.68	14.24	41.29	19.52	38.27	10.50	
PPA 2 slope (g/s)	8.19	2.50	7.35	6.39	7.74	3.12	
Shock attenuation (%)	31.04	13.44	45.07 *A*	19.22	44.40 *A*	16.21	*

* = significant difference between footwear $p \leq 0.05$.
A = significantly different from minimalist.
B = significantly different from maximalist.

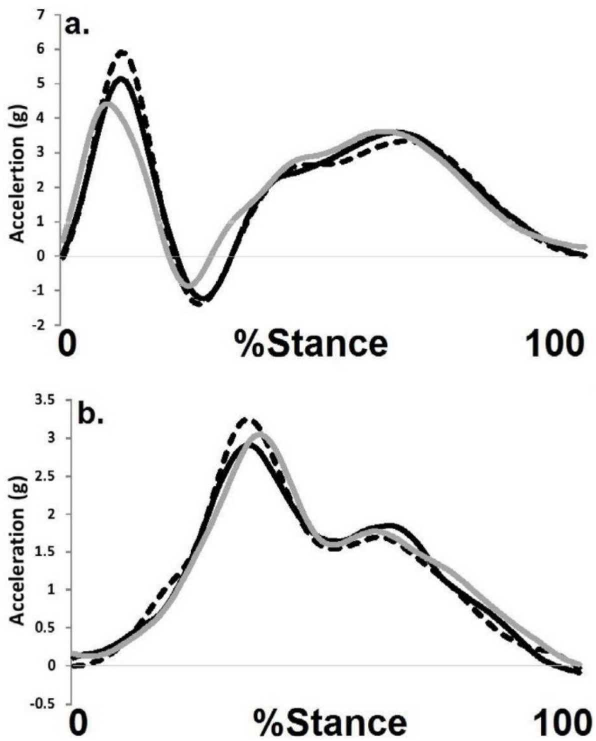

Fig. 2. a) Tibial and b) sacrum acceleration time curves as a function of footwear: (black = conventional, grey = minimalist, dash = maximalist).

3 Results

3.1 Acceleration and attenuation

A significant difference ($P \leq 0.05$, $p\eta_2 = 0.43$) between footwear was observed for PTA. *Post-hoc* analyses showed that PTA was significantly larger in the maximalist footwear in comparison to the minimalist condition (Tab. 1; Fig. 2). A significant difference ($P \leq 0.05$, $p\eta_2 = 0.40$) was also found for PTA slope. *Post-hoc* analysis showed that PTA slope was significantly larger in the maximalist in comparison to the conventional and minimalist footwear (Tab. 1; Fig. 2). Finally, a significant difference ($P \leq 0.05$, $p\eta_2 = 0.48$) was shown for shock attenuation. *Post-hoc* analyses showed that shock attenuation was greater in the maximalist and conventional footwear in comparison to minimalist (Tab. 1).

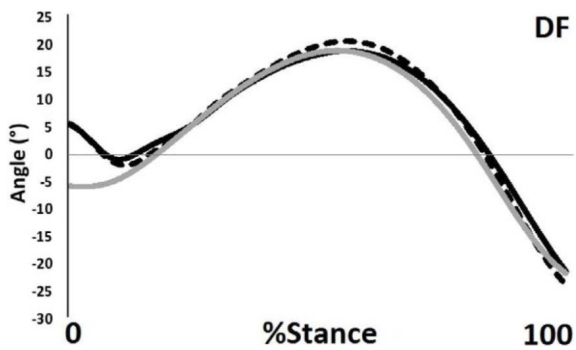

Fig. 3. Ankle kinematics as a function of footwear (DF = dorsiflexion), (black = conventional, grey = minimalist, dash = maximalist).

3.2 Ankle kinematics

A significant difference ($P \leq 0.05$, $p\eta_2 = 0.39$) between footwear was observed for ankle position at footstrike. *Post-hoc* analyses showed that the ankle was significantly more plantarflexed in the minimalist footwear (−6.25 ± 7.33) in comparison to the maximalist (7.02 ± 4.91) and conventional (6.58 ± 3.98) conditions (Fig. 3).

4 Discussion

The aim of the current study was to explore the effects of minimalist, maximalist and conventional footwear on skeletal accelerations and shock attenuation during running. To the authors knowledge, this represents the first comparative investigation of shock attenuation parameters when wearing different running footwear.

The first key finding from the current study is that PTA was found to be significantly larger in the maximalist footwear in comparison to the minimalist condition. This finding is in agreement with those Lieberman, *et al.* (2010) but disagrees with those of Sinclair, *et al.* (2013a, c). It is hypothesized that this relates to the level of habituation that runners had to minimalist footwear. The current investigation and the work of Lieberman, *et al.* (2010) used participants who had previous experience of minimalist footwear whereas Sinclair, *et al.* (2013a, c) examined runners who had no previous experience. This finding may have clinical relevance taking into account the relationship between excessive tibial accelerations and the aetiology of chronic running pathologies (Milner, Ferber, Pollard, Hamill, & Davis, 2006; Whittle, 1999). As such the current investigation indicates that minimalist footwear may place runners at reduced risk from running pathology in relation to conventional and maximalist conditions.

The kinematic analysis showed that the ankle was in a significantly more plantarflexed position at footstrike when running in minimalist footwear. This indicates that participants modified their footstrike pattern towards a midfoot strike when using the minimalist footwear. This finding is in agreement with those of Sinclair, *et al.* (2013a, c) who demonstrated that the ankle was more plantarflexed ankle at footstrike when wearing minimalist footwear. It is proposed that this finding is due to the lack of cushioning in the minimalist footwear, whereby participants adopted a flatter foot position in order to compensate for the lack of cushioning (Sinclair, *et al.*, 2013a).

It is proposed that this finding is caused by the change in footstrike pattern associated with running in minimalist footwear (Lieberman, *et al.*, 2010; Sinclair, *et al.*, 2013a, c). Running with minimalist footwear causes runners who habitually strike the ground with the posterior aspect of their foot to adopt a mid/forefoot strike pattern (Lieberman, *et al.*, 2010; Sinclair, *et al.*, 2013a, c), which decreases the vertical velocity of the centre of mass and thus effectively attenuates the magnitude of impact transient generated by the footstrike itself. This observation may have clinical significance, given the association between impact accelerations and the aetiology of chronic injuries (Robbins, & Hanna, 1987; Whittle, 1999; Murphy, *et al.*, 2003; Burne, *et al.*, 2004; Warden, *et al.*, 2006). The current investigation indicates that minimalist footwear may reduce runners risk from impact related injuries compared to maximalist running shoes.

A further important finding from the current study was the sacrum accelerations did not change as a function of footwear. As PTA was significantly reduced in the minimalist footwear this meant that shock attenuation was also significantly reduced in these footwear in comparison to the conventional and maximalist conditions. Shock attenuation is achieved *via* energy absorption from active muscle contraction, alterations in lower limb alignment, and energy absorbing capabilities of anatomical structures such as bone and the calcaneal fat pad (Paul, *et al.*, 1978; Chu, *et al.*, 1986; Valiant, 1990; Mercer, *et al.*, 2010). Shock attenuation, the process by which impact energy is absorbed, is achieved *via* eccentric muscle actions and passive energy absorbing capabilities of anatomical structures such as bone and the calcaneal fat pad (Valiant, 1990). It can therefore be speculated that the increased shock transmission from the tibial tuberosity to the sacrum level observed in the maximalist and conventional footwear is associated with an augmented propensity for damage as passive anatomical structures are placed under greater stress.

A limitation of the present study is that runners who habitually use conventional footwear were recruited for this investigation. The results of research concerning the effects of minimalist footwear have been conflicting, often as a function of the experience of the experimental sample with minimalist footwear (Sinclair, *et al.*, 2013a, c; Squadrone, & Gallozzi, 2009). Although a short period of habituation was provided, it has been shown that full familiarization can take considerably longer (Moore, Pitt, Nunns, & Dixon, 2015). Therefore, it remains unknown as to whether the observations from the current work would have been inverted had participants been habitual minimalist footwear users. A further limitation to the current investigation is that an all-male sample was utilized. Sinclair, *et al.* (2016) showed that females runners were associated with significantly different tibial acceleration and shock attenuation parameters in relation to age matched males, thus it is unlikely that the findings from the current investigation can be generalized to females. It is thus recommended that the current investigation to be repeated using a female sample in order to determine the effects of different footwear on tibial accelerations and shock attenuation.

5 Conclusion

In conclusion, whilst previous investigations have extensively examined the biomechanics of running in minimalist and also maximalist footwear there has yet to be any published work which has examined shock attenuation in different footwear. The current study addresses this by providing a comparative investigation of skeletal accelerations and shock attenuation when running in minimalist, maximalist and conventional footwear. The current investigation showed that tibial accelerations and shock attenuation were significantly lower in the minimalist footwear. This indicates that running in conventional and maximalist footwear may place increased demands on the musculoskeletal structures to attenuate impact transients which may be detrimental to passive tissues.

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