Taylor & Francis Group

Research Quarterly for Exercise and Sport

ISSN: 0270-1367 (Print) 2168-3824 (Online) Journal homepage: https://www.tandfonline.com/loi/urqe20

Impact Acceleration During Prolonged Running While Wearing Conventional Versus Minimalist Shoes

Marta Izquierdo-Renau, Ana Queralt, Alberto Encarnación-Martínez & Pedro Perez-Soriano

To cite this article: Marta Izquierdo-Renau, Ana Queralt, Alberto Encarnación-Martínez & Pedro Perez-Soriano (2020): Impact Acceleration During Prolonged Running While Wearing Conventional Versus Minimalist Shoes, Research Quarterly for Exercise and Sport, DOI: 10.1080/02701367.2020.1726271

To link to this article: https://doi.org/10.1080/02701367.2020.1726271

Published online: 25 Feb 2020.

RESEARCH QUARTERLY FOR EXERCISE AND SPORT
https://doi.org/10.1080/02701367.2020.1726271

Impact Acceleration During Prolonged Running While Wearing Conventional Versus Minimalist Shoes

Marta Izquierdo-Renau, Ana Queralt, Alberto Encarnación-Martínez, and Pedro Perez-Soriano

University of Valencia

ABSTRACT

Purpose: In recent years a sub-group of minimalist runners have emerged who aim to perform physical exercise more naturally in an attempt to reduce running-related injuries. Here we aimed to determine the effect that running with minimalist footwear in a prolonged run has on foot-impact accelerations. **Method**: Seventeen runners ran with minimalist and conventional shoes (MS and CS, respectively) in two separate sessions; the participants had experience with both footwear types. We measured the length and frequency of each stride, as well as the tibial and head impact acceleration every 5 minutes during a prolonged run (30 minutes at 80% of each individual's maximum aerobic speed). **Results**: There were significant differences in the acceleration rate in the tibia (CS: 516.1 ± 238.47 G/s and MS: 786.6 ± 238.45 G/s; p = .009) and head (CS: 73.3 ± 23.65 G/s and MS: 120.7 ± 44.13 G/s; p = .000). Our data indicate that the type of footwear increased the stride frequency and decreased length and that the impact acceleration is increased with MS compared to CS (p < .05 in both cases). However, the effect of prolonged run was not significantly different between CS and MS (p < .05). **Conclusions**: The peak tibia acceleration and headtibia acceleration rate indicate that the use of MS may be related to a higher risk of injury. These differences remained independently of the runners' fatigue state.

ARTICLE HISTORY
Received 9 June 2019
Accepted 2 February 2020

KEYWORDS
Barefoot; running technique; injuries; foot strike; running; biomechanics; sport

Running results in repeated foot-ground impacts (Lieberman et al., 2010) as a result of rapid leg deceleration after the initial contact with the ground. These impact accelerations are transferred through the body to the head via the different segments of the musculoskeletal system, and can affect the lower extremities or cause overload injuries (Abt et al., 2011; Milner, Ferber, Pollard, Hamill, & Davis, 2006). Several mechanisms can affect these impacts acceleration while running, including fatigue, the initial ground foot-strike pattern, and footwear type used (Lucas-Cuevas, Priego Quesada, et al., 2016).

The foot strike impact is higher among runners with rearfoot (RF) patterns which can result in increased soft-tissue vibration, and this effect is likely magnified when the person is fatigued (Friesenbichler, Stirling, Federolf, & Nigg, 2011). When the initial foot-strike contact with the ground is made via the midfoot (MF) or forefoot (FF), the knee and hips are in a more flexed position which results in a reduced impact peak with respect to RF strikers (Daoud et al., 2012; De Wit, De Clercq, & Aerts, 2000; Gruber, Boyer, Derrick, & Hamill, 2014; Lieberman et al., 2015), and this likely reduces the risk of suffering overload injuries (Chan et al., 2018). However, Chan et al (Chan et al., 2018) showed that after a program aimed to change gait pattern in runners, impact loading decreased as also did the frequency of running injuries.

Several authors have published data regarding the effects of fatigue on acceleration parameters, however, the results remain inconclusive. Some studies postulate that in order to maintain stable head acceleration while fatigued, the impacts acceleration and attenuation at the tibial level are increased (Derrick, Dereu, & McLean, 2002; García-Pérez, Pérez-Soriano, Llana Belloch, Lucas-Cuevas, & Sánchez-Zuriaga, 2014; Mizrahi, Verbitsky, Isakov, & Daily, 2000). In contrast, other authors have not observed any differences in acceleration variables in relation to fatigue (Abt et al., 2011; Clansey, Hanlon, Wallace, & Lake, 2012; Giandolini et al., 2016; Mercer, Vance, Hreljac, & Hamill, 2002). The type of footwear used while running also influences impact acceleration. A few years ago, some runners started running with minimalist shoes with the aim of reducing injuries. Unlike conventional footwear, minimalist shoes are a very flexible and lighter shoe without damping and motion control elements. This shoe facilitated a foot strike change, with more plantarflexed foot, and although certain studies postulate that running barefoot or wearing

CONTACT Marta Izquierdo-Renau marizre@uv.es Departament of Nursing, University School of Nursing and Chiropody, University of Valencia, C/ Jaume Roig s/n, Valencia 46010, Spain

minimalist shoes (MS) decreases impact forces (Hatala, Dingwall, Wunderlich, & Richmond, 2013; Lieberman et al., 2010; Squadrone & Gallozzi, 2009), very few have compared the impacts acceleration between runners wearing conventional shoes (CS) with respect to those running barefoot or with MS. Moreover, even fewer studies have considered the effect of fatigue on these acceleration variables while running. Another difference between MS and CS is their effect on stride spatiotemporal variables. A decreased stride length and an increased stride frequency when using MS is reported by several authors (Bonacci et al., 2013; De Wit et al., 2000; Divert, Mornieux, Baur, Mayer, & Belli, 2005; Divert et al., 2008; McCallion, Donne, Fleming, & Blanksby, 2014; Squadrone, Rodano, Hamill, & Preatoni, 2015)

The aim of this present study was to determine the effects that the use of MS or CS footwear have on spatiotemporal stride parameters and impact acceleration variables during sustained periods of running. Our main hypothesis was that, even when controlling for the FF, MF, or RF running initial foot-strike pattern, the mean foot strike magnitude would be lower among participants running in CS compared to those using MS. We also hypothesized that sustained running duration would increase the mean impacts acceleration, regardless of the footwear condition considered.

Materials and methods

Participants

Seventeen experienced male recreational runners (3 RF, 10 MF, and 4 FF-strikers, respectively) who also had experience in minimalist running, voluntarily participated in this study; their mean age was 37.94 ± 9.64 years, their average height was 1.77 ± 0.07 m, and mean weight 73.87 ± 8.97 kg. The following inclusion criteria for participation in the study were used: male and aged over 18 years; long-distance runner with a self-reported ability to sustain weekly training sessions of a minimum distance of 20 km; at least one years' experience in minimalist running; no injuries in the 6 months prior to the study. The nature of the study was explained to all the volunteers and they all signed their informed consent to their participation. The study met the conditions set out in the Declaration of Helsinki and was approved by the ethics committee at the University of Valencia (reference number: H1412433550236).

Experimental design

We used a within-subject repeated-measures design and carried out three sessions, each at least one week apart from each other, in which the participants warmed-up ad libitum (or for at least 10 minutes) prior to commencing. All measures were taken in a 400m track and field where a pressure platform (S-Plate, Medicapteurs©, Balma, France) was placed in order to check that foot-strike pattern remained unchanged. The first assessment of foot-strike pattern of each runner was performed during the warm-up phase according to the protocol described by Nunns et al. (Nunns, House, Fallowfield, Allsopp, & Dixon, 2013). All the data were collected with the runners using an outdoor tartan track surface. The volunteers were asked not to participate in any competitive activities or exhaustive physical activity in the 48 hours prior to each session, and the sessions were not performed in extreme temperature, wind, or rain conditions.

In the first session we performed a 5-minute test which was used to calculate the maximal aerobic velocity of each runner (Lucas-Cuevas et al., 2015). In the following two sessions the participants ran for 30 minutes at 80% of their individual maximal aerobic velocity (García-Pérez et al., 2014), once wearing MS and the other using CS (in a random order); participants used their own MS and CS The only inclusion-criteria characteristic for the footwear was that the MS had a 0 mm drop and a sole of less than 4 mm and the CS (the last conventional running shoe that the participant had used for training before transitioning to MS) were neutral and had a drop of at least 8 mm. The acceleration peak of each of these two sessions was measured for 10 seconds during minutes 5, 10, 15, 20, 25, and 30 (T5–30, respectively).

Instruments and instrumental methodology

In every session, the instrumental protocol was supervised by the same person and the equipment used was always the same. To register the acceleration peaks, two triaxial accelerometers (MEMS MPU-60X0, BlauTic©, Valencia, Spain), which weighed 2.5 g and measured 40 mm × 22 mm × 12 mm, were used; their sampling rate and power were 420 Hz and 500 μA, respectively. One of the accelerometers was placed on the proximal anteromedial zone of the tibia of the dominant leg (25% of the distance between the medial malleolus and the tibial plateau) along the longitudinal axis of the bone (Lucas-Cuevas, Encarnación-Martínez, Camacho-García, Llana-Belloch, & Pérez-Soriano, 2016). The other accelerometer was placed on the central area of the forehead. Once fixed, the accelerometers were connected by a cable to a transmitter (UL 94 HB, BlauTic©, Valencia, Spain), measuring 65 mm × 105 mm × 19 mm, which was placed on the participant's waist with an elastic belt. The transmitter was connected by Bluetooth 4.0 to a tablet device on which the Accel System© (BlauTic©, Valencia, Spain) application had been installed in order to record the data.

Data processing and statistical analysis

Data obtained from the accelerometers were analyzed using Matlab software, version 7.4 (The Math Works Inc., Natick, MA, USA). These acceleration data were filtered using 8-order low-pass digital Chebyshev type-II filter, applying a stop-band edge frequency of 120 Hz and a stop-band ripple of 40 dB; we considered the vertical signal components only, and the stride duration (signal period) was calculated by locating the moment of maximum autocorrelation. The stride parameters (stride frequency and length) and foot-strike acceleration parameters (head and tibia peak-acceleration [maximum amplitude] and magnitude [the difference between the positive and the negative peak-acceleration], acceleration rate [slope from ground contact to peak acceleration], and attenuation [reduction in foot-strike acceleration from the tibia to the head]) were analyzed based on the acceleration signal data (Lucas-Cuevas et al., 2015).

Statistical analysis was performed using IBM® SPSS® Statistics (SPSS®-IBM® Corporation, New York, USA) software, version 22.0. The data were checked for normality (Kolmogorov–Smirnov test), homoscedasticity (Levene test), and sphericity (Mauchly test) and then a repeated-measures ANOVA was performed using within-subject factors, shoe type (MS or CS), and the six exercise time-points (minutes 5, 10, 15, 20, 25, and 30) to analyze fatigue. Finally, Bonferroni post-hoc analysis was used to assess any significant changes between the groups. The data presented here are the mean, standard deviation, and 95% confidence intervals (95% CIs); data were considered statistically significant when $p < .05$ and the effect size exceeded 0.4 for ANOVA (ES_F) or, for pair-wise comparison (ES_D), was greater than 0.8.

Results

The ground foot-strike pattern did not change in any of the participants when they switched between CS or MS, however, there were significant differences in the spatio-temporal variables (stride length and stride frequency; Figure 1). Considering the effect size, when wearing MS, the stride frequency was higher ($p = .009$, $ES_F = 0.95$) but stride length was significantly shorter ($p = .007$, $ES_F = 1$). Regarding the shoe-time interaction, there were significant differences between MS and CS in terms of stride frequency (T5: $p = .040$; T15: $p = .046$; T20: $p = .015$; T25: $p = .009$; T30: $p = .003$), and the effect size was moderate at minutes 5, 15, and 20 and high at minutes 25 and 30. There were also statistically significant differences in the stride length at 5, 15, 20, 25, and 30 minutes (T5: $p = .037$; T15: $p = .042$; T20: $p = .11$; T25: $p = .008$; T30: $p = .002$), although the effect size was small.

Regarding the effect these footwear types had on the different impact variables, the peak tibial acceleration tended to be higher with MS ($p = .025$, $ES_F = 0.77$), but was also significant at several time points for CS (T5: $p = .013$; T10: $p = .033$; T20: $p = .013$; T25: $p = .046$; Figure 2a), although in the latter, the effect size was only satisfied at minute 5. The tibia acceleration magnitude was also higher with MS ($p = .013$, Figure 2b) and, although the shoe-time interaction was significant at all the timepoints, the established effect size was only met at minute 5.

A similar pattern was observed for the tibia and head rate (Figure 2c), which was significantly higher with MS compared to CS ($p = .012$, $ES_F = 0.904$ versus $p = .001$, $ES_F = 1.38$, respectively). The shoe-time interaction for the tibia to head rate was significant at all the timepoints,

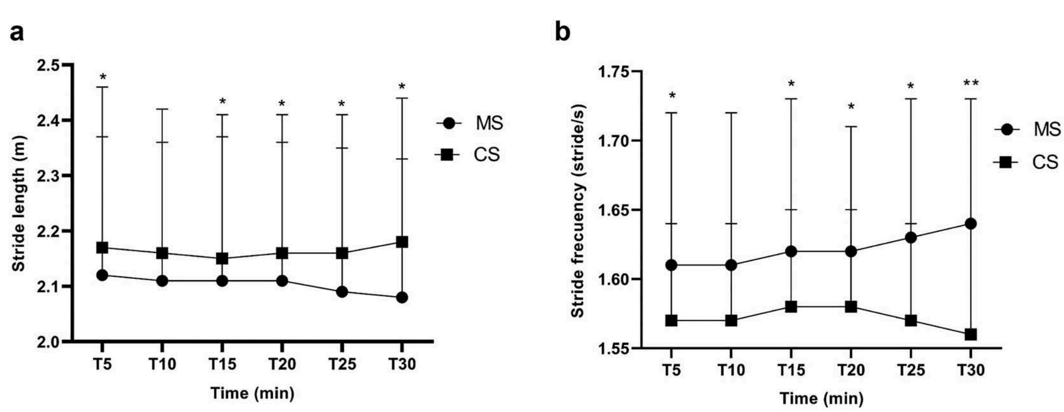

Figure 1. Spatio-temporal variables (stride length and frequency) based on shoe type. MS, minimalist shoes; CS, conventional shoes.

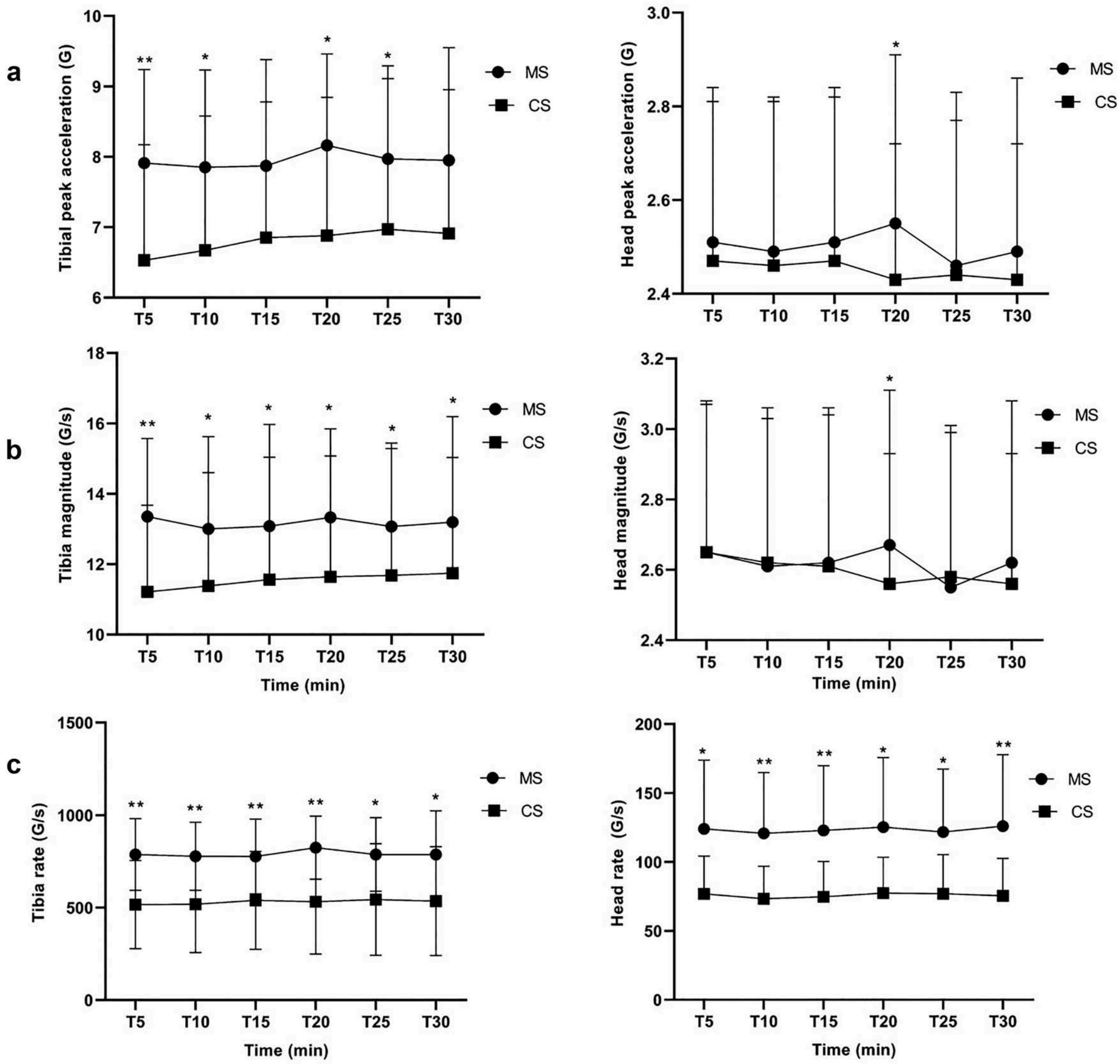

Figure 2. Acceleration variables: tibia and head peak-acceleration (a), Tibia and head foot-strike magnitude (b) Tibia and head ratio (c) Based on shoe type.* p < .05**Significant effect size (ESF).

but the effect size was only satisfied at minutes 5, 10, 15, and 20; the head acceleration showed a significant (p < .001) and strong effect size at minutes 10, 15, and 30.

Discussion

The main objective of this study was to analyze the effect of MS and CS on spatiotemporal stride and acceleration parameters in runners experienced in the use of MS. To date, very few studies have analyzed accelerometry in combination with the use MS or CS (Chambon, Delattre, Guéguen, Berton, & Rao, 2014; Lucas-Cuevas, Priego Quesada, et al., 2016). A large prospective survey study suggested that barefoot runners report fewer running injuries compared to shod runners (Altman & Davis, 2016), however clinical trials suggest that changing from CS to MS is associated with increased running injury risk (Fuller et al., 2017; Ryan, Elashi, Newsham-West, & Taunton, 2014). Moreover, most previous studies have not analyzed whether the initial foot-ground contact type is altered by the type of footwear worn (Altman & Davis, 2012; Daoud et al., 2012; Lieberman et al., 2010). Despite this, running with MS should not be associated only with an FF pattern, nor should the use of CS be related only to the RF pattern (Nigg & Enders, 2013). In addition, another important factor may be the extent to which runners are familiar with the shoe type in use, which could affect their running technique and thereby modify their foot-strike pattern (Franklin, Grey, Heneghan, Bowen, & Li, 2015).

In the present study we controlled runners' foot-strike so that it was the same in both the CS and MS conditions (Nunns et al., 2013). We also assessed the influence of sustained running duration on these parameters and assured that the runners were familiar with these shoe types by recruiting only runners experienced in the use of both MS and CS (Franklin et al., 2015; Nigg & Enders, 2013). Unlike some other studies that performed tests in laboratories (García-Pérez et al., 2014) we recorded our data in the open air and used an extended long-diatnce running protocol (Bigelow, Elvin, Elvin, & Arnoczky, 2013; Derrick et al., 2002) to try to replicate runners' 'real-world' experiences, as far as possible.

Our results showed that, compared to MS, the magnitude and maximum peak tibia acceleration and tibia to head acceleration rate were lower when CS were used, even when the initial foot-ground strike pattern was the same between runners. Therefore our results provide evidence that, compared to MS, CS reduce the impacts acceleration produced while running. However, we found no evidence that running for sustained periods, using either footwear condition, resulted in higher impacts acceleration in any of the study variables. Running for extended periods appeared to affect either of the spatiotemporal variables, in line with other studies in which reduced stride length and increased stride frequency were observed in fatigued runners (Girard, Millet, Slawinski, Racinais, & Micallef, 2013; Kasmer, Ketchum, & Liu, 2014), more significant differences between these two shoe types did emerge by minutes 25 and 30.

In agreement with other studies which showed that runners reduce their step length (our study 2.12 m MS vs 2.17 m CS/Bonacci 3.00 m MS vs 3.04 m CS/Squadrone 2015 2.29 m MS vs 2.34 m CS) and increase their stride frequency to maintain their running speed when using MS or running barefoot (our study 96.6 stride/m MS vs 94,2 stride/m CS/Bonacci 183.9 stride/m MS vs 181.9 stride/m CS/Squadrone 2015 85.4 stride/m MS vs 83.4 stride/m CS) (Bonacci et al., 2013; De Wit et al., 2000; Divert et al., 2005, 2008; Lucas-Cuevas, Priego Quesada, et al., 2016; McCallion et al., 2014; Squadrone & Gallozzi, 2009; Squadrone et al., 2015), our results show that the type of footwear used directly affected the spatiotemporal variables (stride frequency and length of our participants). Thus, stride length is decreased to reduce the impact forces experienced with MS; leading to a better impact attenuation which is absorbed, to a large extent, by the musculoskeletal system. (Derrick et al., 2002; Squadrone & Gallozzi, 2009; Squadrone et al., 2015).

The mass of the shoe used can also influence stride frequency while running because this variable decreases with increasing foot mass (Divert et al., 2008), thus it is logical that this variable would increase with the use of MS. In relation to the impact severity, Derrick et al. (Derrick et al., 2002) found that greater knee flexion at the moment of initial foot-strike contact with the ground effectively decreases limb mass and thus, decreases the impact forces and increases the peak tibial acceleration. Thus, we hypothesize that the decrease in the effective mass among runners using MS with respect to those using CS (MS < effective mass < CS) may result in an increase the tibial acceleration peaks (Derrick et al., 2002), which would concur with our finding that these values were higher among runners who wore MS during our study. In this sense, Lucas-Cuevas, Priego Quesada, et al. (2016) also found that the maximum tibial acceleration peak was higher while RF strikers ran barefoot, even when the participants had no previous experience with barefoot or MS running.

To the best of our knowledge, only one published study considered effective mass and used the same footwear conditions (MS versus CS) as in our study (Chambon et al., 2014), although it did not consider the participants' level of experience with minimalist footwear or sustained running durations. This might explain why, in contrast to our study, they did not find any difference in the peak acceleration or tibial acceleration rate between these footwear types. In line with other studies, we did not observe any alterations in the maximum peak acceleration between the standard and extended running-period conditions; thus, the magnitude of the impact acceleration was higher with the use of MS. In this sense, Lucas-Cuevas, Priego Quesada, et al. (2016) showed that this peak was increased in unexperienced barefoot runners compared those wearing CS, resulting in an increased risk of some types of impact injury, including lower-extremity stress fractures.

No significant differences were observed in the head-acceleration magnitude, but attenuation was higher with the use of MS (Figure 3). This may be an important because the aforementioned impact transfer must be attenuated to prevent excessive head deceleration from affecting the vestibular and visual systems; this could be influenced by factors such as plantar fat deformation, sports shoe type, the use of plantar supports or compression stockings (Lucas-Cuevas et al., 2015; O'Leary, Vorpahl, & Heiderscheit, 2008), runner speed (Mercer et al., 2002), running surface (García-Pérez et al., 2014), stride length, and the behavior of the osteo-articular and muscle-ligamentous structures of the body (Flynn, Holmes, & Andrews, 2004; Gruber et al., 2014; Mercer et al., 2002).

Finally, some controversy remains regarding the attenuation variable in relation to the presence of fatigue. In contrast to the study by Derrick et al., Mercer et al. and Clansey et al. (Clansey et al., 2012; Derrick et al., 2002; Mercer et al., 2002) observed that fatigue decreased attenuation, although this condition did not affect the tibial acceleration peaks. This could be because increased fatigue decreased these participants' ability to absorb the impacts produced by running, thus increasing the risk of overload injuries including stress fractures or osteoarthritis.

Furthermore, our results showed an increase in the head to tibial acceleration rate with the use of MS. Lucas-Cuevas, Priego Quesada, et al. (2016) showed a decrease in these values among runners who wore footwear,

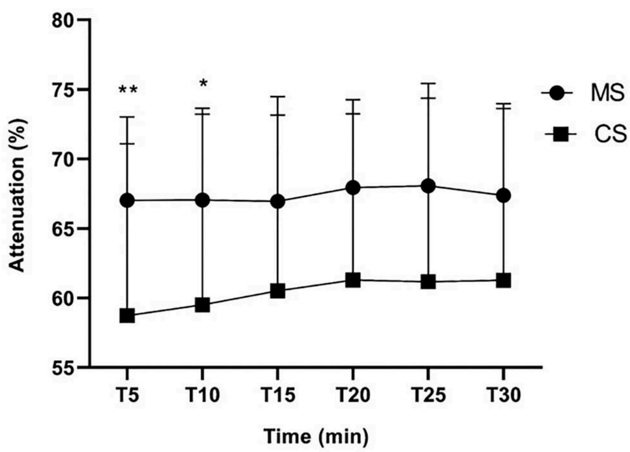

Figure 3. Acceleration variables: foot-strike attenuation based on the shoe type.

although this change was seen only at the tibial level. This suggests that the increased load-transmission speed observed with MS or barefoot running could result in a higher incidence of musculoskeletal system injury (Fuller et al., 2017; Ryan et al., 2014).

The main limitation of this study was the difficulty in finding a larger sample of active runners experienced in the use of MS. Moreover, although our experimental design required the participation of MS runners, these types of participants are also inherently limited because they are adapted to minimalist running. In conclusion, accounting for the same initial ground-contact foot-strike pattern among runners using both the CS and MS footwear, our results show that the impact acceleration magnitudes are higher among runners in the MS condition. In addition, this difference remained, regardless of runners' state of fatigue during the sustained extended-running protocol.

"*What does this article add?*": This work contributes to the body of scientific evidence related to the use of minimalist footwear and its effect on deceleration and impact transmission from the foot to the head. It also tries to avoid biases found in other similar studies by examining runners who were very experienced in running wearing minimalist footwear and by controlling the runners' initial ground foot-strike pattern when analyzing the results from both footwear types. It is also worth noting the environmental factor in this study because we collected all our data outside of the laboratory in order to simulate the real-world conditions in which amateur runners undertake their activities.

Acknowledgments

The authors wish to thank to Mr. Vicent Ribas for his assistance throughout the study.

ORCID

Alberto Encarnación-Martínez http://orcid.org/0000-0003-2149-134X
Pedro Perez-Soriano http://orcid.org/0000-0002-9825-3801

References

Abt, J. P., Sell, T. C., Chu, Y., Lovalekar, M., Burdett, R. G., & Lephart, S. M. (2011). Running kinematics and shock absorption do not change after brief exhaustive running. *Journal of Strength and Conditioning Research*, *25*(6), 1479–1485. doi:10.1519/JSC.0b013e3181ddfcf8

Altman, A. R., & Davis, I. S. (2012). Barefoot running: Biomechanics and implications for running injuries. *Current Sports Medicine Reports*, *11*(5), 244–250. doi:10.1249/JSR.0b013e31826c9bb9

Altman, A. R., & Davis, I. S. (2016). Prospective comparison of running injuries between shod and barefoot runners. *British Journal of Sports Medicine*, *50*(8), 476–480. doi:10.1136/bjsports-2014-094482

Bigelow, E. M. R., Elvin, N. G., Elvin, A. A., & Arnoczky, S. P. (2013). Peak impact accelerations during track and treadmill running. *Journal of Applied Biomechanics*, *29*(5), 639–644. doi:10.1123/jab.29.5.639

Bonacci, J., Saunders, P. U., Hicks, A., Rantalainen, T., Vicenzino, B. G. T., & Spratford, W. (2013). Running in a minimalist and lightweight shoe is not the same as running barefoot: A biomechanical study. *British Journal of Sports Medicine*, *47*(6), 387–392. doi:10.1136/bjsports-2012-091837

Chambon, N., Delattre, N., Guéguen, N., Berton, E., & Rao, G. (2014). Is midsole thickness a key parameter for the running pattern?. *Gait & Posture*, *40*(1), 58–63. doi:10.1016/j.gaitpost.2014.02.005

Chan, Z. Y. S., Zhang, J. H., Au, I. P. H., An, W. W., Shum, G. L. K., Ng, G. Y. F., & Cheung, R. T. H. (2018). Gait retraining for the reduction of injury occurrence in novice distance runners: 1-year follow-up of a randomized controlled trial. *The American Journal of Sports Medicine*, *46*(2), 388–395. doi:10.1177/0363546517736277

Clansey, A. C., Hanlon, M., Wallace, E. S., & Lake, M. J. (2012). Effects of fatigue on running mechanics associated with tibial stress fracture risk. *Medicine and Science in Sports and Exercise*, *44*(10), 1917–1923. doi:10.1249/MSS.0b013e318259480d

Daoud, A. I., Geissler, G. J., Wang, F., Saretsky, J., Daoud, Y. A., & Lieberman, D. E. (2012). Foot strike and injury rates in endurance runners: A retrospective study. *Medicine and Science in Sports and Exercise*, *44*(7), 1325–1334. doi:10.1249/MSS.0b013e3182465115

De Wit, B., De Clercq, D., & Aerts, P. (2000). Biomechanical analysis of the stance phase during barefoot and shod running. *Journal of Biomechanics*, *33*(3), 269–278. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10673110

Derrick, T. R., Dereu, D., & McLean, S. P. (2002). Impacts and kinematic adjustments during an exhaustive run. *Medicine & Science in Sports & Exercise*, *34*(6), 998–1002. doi:10.1097/00005768-200206000-00015

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

Divert, C., Mornieux, G., Freychat, P., Baly, L., Mayer, F., & Belli, A. (2008). Barefoot-shod running differences: Shoe or mass effect? *International Journal of Sports Medicine*, *29* (6), 512–518. doi:10.1055/s-2007-989233

Flynn, J. M., Holmes, J. D., & Andrews, D. M. (2004). The effect of localized leg muscle fatigue on tibial impact acceleration. *Clinical Biomechanics*, *19*(7), 726–732. doi:10.1016/j.clinbiomech.2004.04.015

Franklin, S., Grey, M. J., Heneghan, N., Bowen, L., & Li, F.-X. (2015). Barefoot vs common footwear: A systematic review of the kinematic, kinetic and muscle activity differences during walking. *Gait & Posture*, *42*(3), 230–239. doi:10.1016/j.gaitpost.2015.05.019

Friesenbichler, B., Stirling, L. M., Federolf, P., & Nigg, B. M. (2011). Tissue vibration in prolonged running. *Journal of Biomechanics*, *44*(1), 116–120. doi:10.1016/j.jbiomech.2010.08.034

Fuller, J. T., Thewils, D., Buckley, J. D., Brown, N. A. T., Hamill, J., & Tsiros, M. (2017). Body mass and weekly training distance influence the pain and injuries experienced by runners using minimalist shoes. *The American Journal of Sports Medicine*, *45*(5), 1162–1170. doi:10.1177/0363546516682497

García-Pérez, J. A., Pérez-Soriano, P., Llana Belloch, S., Lucas-Cuevas, Á. G., & Sánchez-Zuriaga, D. (2014). Effects of treadmill running and fatigue on impact acceleration in distance running. *Sports Biomechanics*, *13*(3), 259–266. doi:10.1080/14763141.2014.909527

Giandolini, M., Gimenez, P., Temesi, J., Arnal, P. J., Martin, V., Rupp, T., … Millet, G. Y. (2016). Effect of the fatigue induced by a 110-km ultramarathon on tibial impact acceleration and lower leg kinematics. *PloS One*, *11* (3), e0151687. doi:10.1371/journal.pone.0151687

Girard, O., Millet, G. P., Slawinski, J., Racinais, S., & Micallef, J. P. (2013). Changes in running mechanics and spring-mass behaviour during a 5-km time trial. *International Journal of Sports Medicine*, *34*(9), 832–840. doi:10.1055/s-0032-1329958

Gruber, A. H., Boyer, K. A., Derrick, T. R., & Hamill, J. (2014). Impact shock frequency components and attenuation in rearfoot and forefoot running. *Journal of Sport and Health Science*, *3*(2), 113–121. doi:10.1016/j.jshs.2014.03.004

Hatala, K. G., Dingwall, H. L., Wunderlich, R. E., & Richmond, B. G. (2013). Variation in foot strike patterns during running among habitually barefoot populations. *PloS One*, *8*(1). doi:10.1371/journal.pone.0052548

Kasmer, M. E., Ketchum, N. C., & Liu, X. C. (2014). The effect of shoe type on gait in forefoot strike runners during a 50-km run. *Journal of Sport and Health Science*, *3*(2), 122–130. doi:10.1016/j.jshs.2014.03.005

Lieberman, D. E., Castillo, E. R., Otarola-Castillo, E., Sang, M. K., Sigei, T. K., Ojiambo, R., … Pitsiladis, Y. (2015). Variation in foot strike patterns among habitually barefoot and shod runners in Kenya. *PloS One*, *10*(7), e0131354. doi:10.1371/journal.pone.0131354

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

Lucas-Cuevas, A. G., Encarnación-Martínez, A., Camacho-García, A., Llana-Belloch, S., & Pérez-Soriano, P. (2016). The location of the tibial accelerometer does influence impact acceleration parameters during running. *Journal of Sports Sciences*, *35*(17), 1–5. doi:10.1080/02640414.2016.1235792

Lucas-Cuevas, A. G., Priego Quesada, J. I., Giménez, J. V., Aparicio, I., Jimenez-Perez, I., & Pérez-Soriano, P. (2016). Initiating running barefoot: Effects on muscle activation and impact accelerations in habitually rearfoot shod runners. *European Journal of Sport Science*, *16*(8), 1145–1152. doi:10.1080/17461391.2016.1197317

Lucas-Cuevas, A. G., Priego-Quesada, J. I., Aparicio, I., Giménez, J. V., Llana-Belloch, S., & Pérez-Soriano, P. (2015). Effect of 3 weeks use of compression garments on stride and impact shock during a fatiguing run. *International Journal of Sports Medicine*, *36*(10), 826–831. doi:10.1055/s-0035-1548813

McCallion, C., Donne, B., Fleming, N., & Blanksby, B. (2014). Acute differences in foot strike and spatiotemporal variables for shod, barefoot or minimalist male runners. *Journal of Sports Science & Medicine*, *13*(2), 280–286.

Mercer, J. A., Vance, J., Hreljac, A., & Hamill, J. (2002). Relationship between shock attenuation and stride length during running at different velocities. *European Journal of Applied Physiology*, *87*(4–5), 403–408. doi:10.1007/s00421-002-0646-9

Milner, C. E., Ferber, R., Pollard, C. D., Hamill, J., & Davis, I. S. (2006). Biomechanical factors associated with tibial stress fracture in female runners. *Medicine and Science in Sports and Exercise*, *38*(2), 323–328. doi:10.1249/01.mss.0000183477.75808.92

Mizrahi, J., Verbitsky, O., Isakov, E., & Daily, D. (2000). Effect of fatigue on leg kinematics and impact acceleration in long distance running. *Human Movement Science*, *19*(3), 139–151. doi:10.1016/S0167-9457(00)00013-0

Nigg, B., & Enders, H. (2013). Barefoot running – Some critical considerations. *Footwear Science*, *5*(1), 1–7. doi:10.1080/19424280.2013.766649

Nunns, M., House, C., Fallowfield, J., Allsopp, A., & Dixon, S. (2013). Biomechanical characteristics of barefoot footstrike modalities. *Journal of Biomechanics*, *46*(15), 2603–2610. doi:10.1016/j.jbiomech.2013.08.009

O'Leary, K., Vorpahl, K. A., & Heiderscheit, B. (2008). Effect of cushioned insoles on impact forces during running. *Journal of the American Podiatric Medical Association*, *98* (1), 36–41. 98/1/36 [pii]. doi:10.7547/0980036

Ryan, M., Elashi, M., Newsham-West, R., & Taunton, J. (2014). Examining injury risk and pain perception in runners using minimalist footwear. *British Journal of Sports Medicine*, *48* (16), 1257–1262. doi:10.1136/bjsports-2012-092061

Squadrone, R., & Gallozzi, C. (2009). Biomechanical and physiological comparison of barefoot and two shod conditions in experienced barefoot runners. *The Journal of Sports Medicine and Physical Fitness*, *49*(1), 6–13.

Squadrone, R., Rodano, R., Hamill, J., & Preatoni, E. (2015). Acute effect of different minimalist shoes on foot strike pattern and kinematics in rearfoot strikers during running. *Journal of Sports Sciences*, *33*(11), 1196–1204. doi:10.1080/02640414.2014.989534