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IMPACT ATTENUATION DURING GAIT WEARING UNSTABLE VS TRADITIONAL SHOES

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ABSTRACT

Introduction: Impact force generates acceleration waves that travel through the body, and possible relationships may be exist between these acceleration waves and injuries. Several studies have analyzed the impact forces on the lower limb in healthy subjects wearing unstable shoes, but there is not accelerometric study analyzing the transmission of these impact forces along the locomotive system. The aim of the present study is to compare the acute effects of wearing unstable shoes (US) vs traditional shoes (TS), on maximum vertical acceleration, impact attenuation, cadence and stride length during gait. *Methods:* Fourty-three asymptomatic adults participated in the cross-sectional study. Subjects underwent gait analysis with simultaneously collecting heel and tibia peak acceleration, impact magnitude and acceleration rate, as well as shock attenuation and stride parameters (stride length, stride rate). *Results:* The results showed that wearing US increased cadence (10.99 steps/min; $p<0.01$), and decreased stride length (0.04 m; $p<0.01$). Additionally, an increase in maximum tibia peak acceleration, tibia impact magnitude and tibia acceleration rate were reported in the US condition compared to the TS condition, with a decrease of tibia attenuation in the US ($p<0.05$). *Conclusion:* Regarding shockwave transmission of ground reaction forces, a lower shock attenuation from the heel to the tibia was reported in the US vs TS condition. Bearing this in mind, it should be pointed that, while it is not yet clear if increased tibia acceleration is harmful to the musculoskeletal system, the US should be used with caution.

Keywords: accelerometry, biomechanics, footwear, ground reaction forces, injuries, walk

DISMINUCIÓN DEL IMPACTO DURANTE LA MARCHA CON CALZADO INESTABLE FRENTE AL TRADICIONAL

RESUMEN

Introducción: La fuerza de impacto genera ondas de aceleración que viajan a través del cuerpo, pudiendo existir una relación entre estas ondas y determinados tipos de lesión. Varios estudios han analizado las fuerzas de impacto en el miembro inferior, en sujetos sanos empleando calzado inestable, pero no existen estudios que analicen la transmisión de las aceleraciones a lo largo del aparato locomotor. El objetivo del presente estudio es comparar los efectos agudos del uso de calzado inestable (US) frente al calzado tradicional (TS), sobre la aceleración máxima vertical, la atenuación del impacto, la cadencia y la longitud de la zancada durante la marcha. Método: Cuarenta y tres adultos asintomáticos participaron en el estudio transversal. Los sujetos fueron analizados durante la marcha con la recogida simultánea de la aceleración máxima del talón y la tibia, la magnitud del impacto y la ratio de aceleración, así como la disminución del impacto y determinados parámetros durante la zancada (longitud, frecuencia). Resultados: Los resultados mostraron que el uso de US aumentó la cadencia (10,99 pasos/min; $p<0{,}01$) y disminuyó la longitud de la zancada (0,04 m; $p<0{,}01$). Adicionalmente, se muestra un aumento en la aceleración máxima, la magnitud del impacto y la ratio de aceleración en la tibia con el calzado US en comparación con la condición de TS, con una disminución en la tibia en los US ($p<0.05$). Conclusión: La disminución del impacto desde el talón hasta la tibia en la condición de US frente a TS fue menor. Teniendo esto en cuenta, debe señalarse que aunque no está claro si el aumento de la aceleración de la tibia es perjudicial para el sistema musculoesquelético, los US deberían ser empleados con precaución.

Palabras clave: acelerometría, biomecánica, calzado, fuerzas de reacción del suelo, lesiones, caminar

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INTRODUCTION

Gait is a well-studied area in biomechanics (Inman, Ralston, & Todd, 1981). There exist many studies that analyze the effects of different parameters, including footwear, on gait (Chambon et al., 2014; Frank, Callaghan, & Prentice, 2013). The unstable-shoe concept originated from exercising on unstable surfaces (Buchecker, Pfusterschmied, Moser, & Müller, 2012): an unstable shoe is designed with a modified outsole construction to mimic an uneven walking surface that would require additional postural control.

Footwear is purposely designed to dissipate kinetic energy, while being adaptable to the physical environment and specific task constraints for which it was built (Palmer, van Emmerik, & Hamill, 2012). In recent years, consumers have turned to purchasing rounded-outsole shoes due to manufacturers' advertising of the ability of such footwear to alleviate joint pain, increase muscle tone, and reduce joint maximum vertical acceleration. If such effects were real, the rounded-outsole shoe would have an effect on kinematics (Nigg, Hintzen, & Ferber, 2006; Nigg, Tecante, Federolf, & Landry, 2010) and maximum vertical acceleration (Sacco et al., 2012) during walking, compared to a traditional outsole shoe.

In normal walking, the body experiences an impact force (IF) during foot contact with the ground. This contact further generates a vertical ground-reaction force (GRF) approximately equal in magnitude to IF (Hamill & Knutzen, 2006). The IF can be modified by changing the running speed (Hamill, Bates, Knutzen, & Sawhill, 1983; Nigg, Bahlsen, Luethi, & Stokes, 1987), the running style (Christina, White, & Gilchrist, 2001; Derrick, Dereu, & Mclean, 2002) and/or the hardness of the shoe mid-sole (Clarke, Frederick, & Cooper, 1983). The IF generates acceleration waves that travel through the locomotor apparatus (García-Pérez, Pérez-Soriano, Llana Belloch, Lucas-Cuevas, & Sánchez-Zuriaga, 2014; Lucas-Cuevas et al., 2013). Several studies indicate possible relationships between these acceleration waves and injuries in some body structures such as articular cartilage (Wosk & Voloshin, 1981).

Some studies have analyzed the kinematic changes at the hip, knee, and ankle when walking with unstable shoes (Nigg et al., 2006). The results showed a decrease in the range of motion (ROM) of the hip and an increase in ROM of the ankle and knee. In the case of the knee, the increase in the mean knee flexion velocity might be attributed to a greater knee flexion ROM. Currently, it is accepted that increasing knee flexion at heel strike has different effects on the impact acceleration above and below the knee joint (Mizrahi, Verbitsky, Isakov, & Daily, 2000).

There are several studies (Boyer & Andriacchi, 2009; Myers et al., 2006; Sacco et al., 2012; Taniguchi, Tateuchi, Takeoka, & Ichihashi, 2012) that have analyzed the impact forces in the lower limb in healthy subjects wearing unstable shoes, but these studies were performed using force platforms. There is no accelerometric study analyzing the transmission of these impact forces along the locomotive system using triaxial accelerometers. The purpose of the present study was to determine the acute effects of wearing unstable vs traditional footwear on maximum vertical acceleration, impact attenuation, cadence and stride length in young healthy subjects. It was hypothesized that the use of unstable shoes would lead to lower impact acceleration compared to walking in traditional shoes.

METHOD

Forty- three healthy subjects, twenty-two male (age: 23.75 ± 5.07 years, BMI: 23.19 ± 2.58 kg/m^2 height: 1.79 ± 0.06 m and mass: 74.76 ± 8.54 kg) and twenty-one female (age: 25.13 ± 6.21 years, BMI: 22.18 ± 2.70 kg/m^2, height: 1.64 ± 0.06 m and mass: 60.20 ± 9.26 kg) participated in this study. Exclusion criteria were: obesity (BMI ≥ 30 kg/m^2), pathology or surgery in the lower limb or the trunk during the past year, evidence of arthritis, diabetes or a neuromuscular condition, and prior use of unstable footwear. On volunteering to take part in the study, each participant was provided with a pair of unstable and traditional shoes. All subjects were informed of the aims of the study, and they gave written informed consent before participating. All test protocols were approved by the University Ethics Committee.

Two shoe models were used in this study: unstable shoe (US) and traditional shoe (TS). The US were the Skechers Shape Ups© characterized by a rounded sole in the anterior–posterior direction and a flexible heel which provides an unstable base of support. The TS chosen were the Reebok Classic model©.

Two accelerometers (MMA7261QT model, Freescale Semiconductor©, Munich, Germany) with a total weight of 55g, dimensions 64×42×24 mm and a maximum range of + 20 g, were used (García-Pérez et al., 2014; Lucas-Cuevas et al., 2013), one on the proximal medial aspect of the tibia (Lucas-Cuevas, Encarnación-Martínez, Camacho-García, Llana-Belloch, & Pérez-Soriano, 2017), and the other at the heel of the shoe (Hübscher et al., 2011). Both accelerometers were synchronized using the Signal-Blt software package (Sportmetrics®, Valencia, Spain). The sampling rate was 500 Hz. The accelerometers were secured by elastic belts around the proximal anteromedial aspects of the tibia and around the rear shoe (heel). The vertical axes of the accelerometers were aligned parallel to the long axis of the shank (García-Pérez et al., 2014; Lucas-Cuevas et al., 2013).

The subjects underwent a 20 minute warm-up consisting of walking on a treadmill (Excite Run 700, TechnogymSpA, Gambettola, Italy) at the same speed as in the experimental procedure, to become familiar with the nature of the measurements (Wall & Charteris, 1980), since the inclination can alter the distribution of plantar loading, 0% slope was adjusted on the treadmill in order not to affect this parameter. After that, the two accelerometers were attached to the subjects as described. The participants then walked on a treadmill in each of the two types of shoes in a randomized order. The treadmill tests consisted of 2 x 3 minute walking trials at a walking speed of 1.44 m/s separated by a 15-minute pause in order to avoid possible fatigue. The accelerometry signals were recorded during the second (middle) minute of each 3-minute trial. Stride parameters were extracted from de accelerometry signal (Lucas-Cuevas et al., 2015; Pérez-Soriano et al., 2018).

Recorded data were analyzed with Matlab Software®: low-pass filtered with a 8-order lowpass digital Chebyshev Type II filter with stopband edge frequency 60Hz and stopband ripple 40dB (Parques & Burrus, 1987).

The main outcomes included: Stride parameters (stride length, stride rate), as well as impact acceleration parameters (heel and tibia peak acceleration [maximum amplitude], heel and tibia impact magnitude [the difference between the positive and the negative peak], heel and tibia acceleration rate [the slope from ground contact to peak acceleration], and shock attenuation [the reduction in impact acceleration from the heel to the tibia]). The outcome results were derived from the acceleration signals.

A data assessment for normal distribution using the Shapiro-Wilk test revealed that all the parameters were normally distributed. As a consequence, paired t-tests were used to compare the studied variables with both shoe-type conditions. Statistical analyses were performed using SPSS 20.0 for Windows (SPSS Inc., Chicago, IL, USA). Statistical significance was set at $p<0.05$ for all analyses.

An a priori analysis of effect size and sample size was made for the desired power of 95%. The effect size was estimated by means of Cohen's d (Cohen, 1988), calculated from the results of published work which studied similar dependent variables (kinematic data from the trunk) (Buchecker, Wagner, Pfusterschmied, Stöggl, & Müller, 2012), with the use of unstable footwear as an independent variable (Buchecker, Stöggl, & Müller, 2013). Sample size was calculated using the G*Power 3 software (Faul, Erdfelder, Lang, & Buchner, 2007). The result was an estimated minimum sample size of 39 subjects.

RESULTS

No statistically significant differences due to gender were observed for any of the studied variables, so data were pooled for subsequent analysis.

Cadence significantly increased in the US condition compared with the TS condition (TS: 116.54 ± 3.26 steps/min, US: 127.54 ± 3.26 steps/min; mean difference: 10.99 steps/min; 95% CI 10.02 to 11.98, $p < 0.01$). Stride length significantly decreased in the US condition (TS: 1.47 ± 0.07 m, US: 1.42 ± 0.06 m; mean difference: 0.04 m; 95% CI 0.03 to 0.63, $p < 0.01$).

The results (Table 1) showed significantly higher maximum (peak) tibia acceleration, tibia acceleration rate and tibia impact magnitude in the US condition compared to the TS condition (Fig. 1), and attenuation was less in the US condition compared to the TS condition. However, changes in the variables related with the heel were not found, showing similar values in both shoe conditions (Fig. 2).

TABLE 1
T-test results on different variables analysed in both conditions: Traditional Shoes vs Unestable shoes (statistical significance p < 0.05).

	TS	US	*p*	ES	% differences (95% CI)
Maximum heel acceleration (g)	8.34 ± 1.45	7.78 ± 1,68	NS	-	-
Maximum tibia acceleration (g)	2.32 ± 1.00	3.01 ± 1,26	<0.05	0.50	-0.69 (-1.08 to -0.31)
Attenuation (%)	71.12 ± 10.47	60.95 ± 15,92	≤0.05	0.57	10.17 (5.44 to 14.89)
Heel rate (g/s)	0.92 ± 0.30	0.89 ± 0,26	NS	-	-
Tibia rate (g/s)	0.07 ± 0.03	0.08 ± 0,03	<0.01	0.41	-0.01 (-0.01 to -0.002)
Heel magnitude (g)	6.26 ± 0.99	5.65 ± 1,53	NS	-	-
Tibia magnitude (g)	1.75 ± 0.76	2.54 ± 1,24	<0.05	0.58	-0.79 (-1.15 to -0.43)

TS: Traditional Shoes; US: Unestable Shoes; ES: Effect Size, Cohen's d values; CI: Confidence Interval

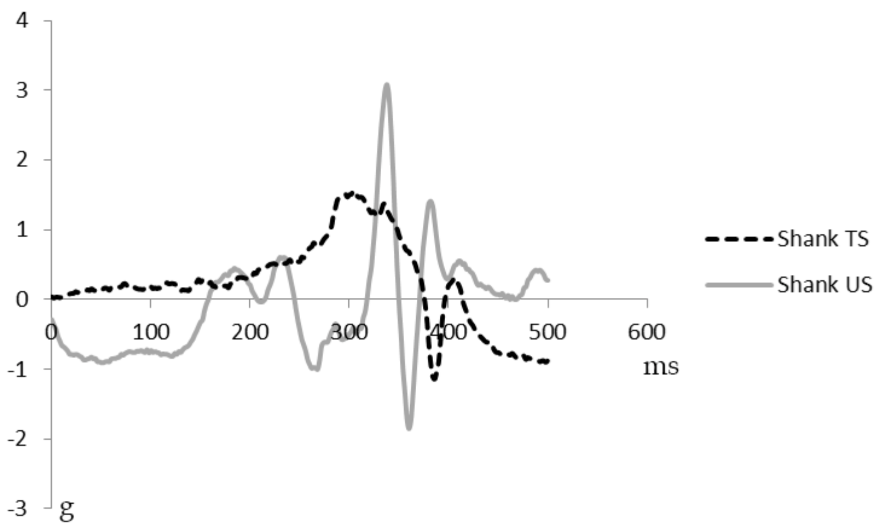

FIGURE 1: Mean of the shank acceleration: traditional shoe (TS) vs unstable shoe (US).

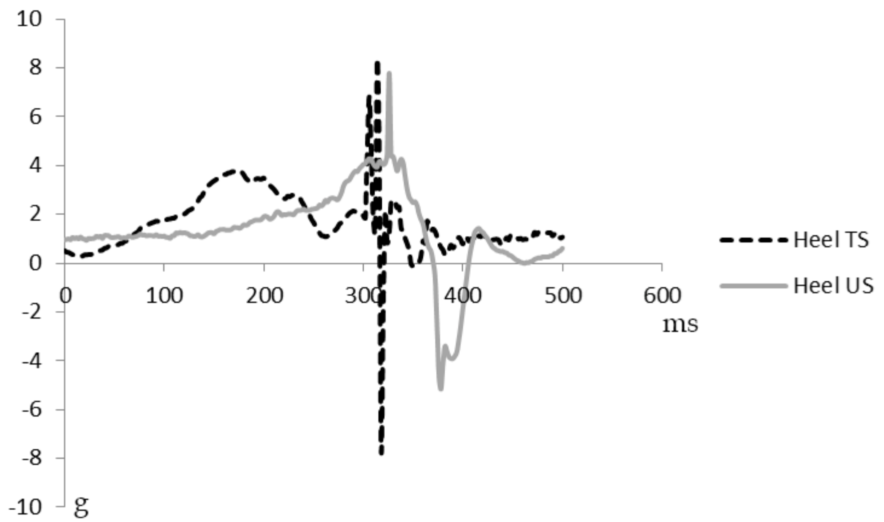

FIGURE 2: Mean of the heel acceleration: traditional shoe (TS) vs unstable shoe (US).

DISCUSSION

Despite the widespread use of US in clinical settings, there have been few investigations of how walking with this kind of shoes affects impact acceleration, because previous studies were performed using force plates (Boyer & Andriacchi, 2009; Myers et al., 2006; Sacco et al., 2012). Moreover, there are not studies of US that assess impact accelerations in the heel and tibia.

The temporal and spatial parameters monitored in this study were characterized by a step cadence increase (+8.6%), and a step length decrease (-3.4%). Walking speed is a factor that may influence on step cadence and length. However, in this study speed was controlled and consistent for all subjects (1.44 m/s). Therefore, changes in both step cadence and step length were not due to the walking speed, but to footwear. In fact, these results agree with those presented by Li and Hong (2007) and Yamamoto, Ohkuwa, Itoh, Yamazaki, and Sato (2000) at speeds from 1 m/s to 2 m/s.

Regarding GRF, previous studies have shown differences between shoe-model impacts expressed as the magnitude of GRF in the heel (Nigg et al., 2006; Ramstrand, Thuesen, Nielsen, & Rusaw, 2010). This is probably due to differences in shoe construction and in the way that the foot makes contact with the ground. The US has quite a different shape than a regular shoe – soft heel material and a round sole at the heel heavier than that in a TS – so it could be expected that GRF would be influenced by the characteristics of the shoe (Sacco et al., 2012). Using shock acceleration parameters, like in studies where analyze different surfaces (García-Pérez et al., 2014), foot orthoses (Lucas-Cuevas, Camacho-García, et al., 2017), or compression garment (Lucas-Cuevas et al., 2015), in the present study the maximum peak acceleration on the heel was similar for both shoe conditions (Fig. 2). Nevertheless, in the tibia the results are different: maximum peak acceleration, magnitude, and rate are higher for US, and consequently the attenuation is smaller (Fig. 1).

It could be hypothesized that US may increase the risk of some discomfort or even injuries related to an incorrect attenuation of shockwave in the tibia, such as degenerative joint disorders (Kerrigan, Todd, & Riley, 1998; Voloshin, Wosk, & Brull, 1981) or lower-back pain (Voloshin & Wosk, 1982; Voloshin & Loy, 1994). These results are consistent with those obtained by Sacco et al. (2012), who suggested that US might increase the momentum of the distal segment and consequently its acceleration. Moreover, it produced higher vertical forces than walking in standard shoes, which suggests an increase in the loads received by the musculoskeletal system.

There are several limitations to the present study that should be recognized. Firstly, the sample was one of convenience (i.e. all subjects were young and healthy), so the findings cannot be generalized over a wider or older population. However, the results of this study may be applicable to similar populations. Secondly, the fact of measuring just acute effects of wearing US on impact parameters instead of measuring long-term effects is other limitation that should be considered, because wearing US for a longer time could show different effects. Therefore, future research should investigate not only the acute effects of the GRF and their shockwaves, but also their chronic effects after a long period of adaptation to unstable shoes.

CONCLUSIONS

The findings of the current study suggest that gait is affected during walking in unstable shoes. A reduction in stride length and an increase in cadence are the most important changes observed in the spatiotemporal parameters. Regarding the shockwave transmission of GRF, a greater magnitude of acceleration (so a lower attenuation) was observed in the tibia, but not in the heel. Knowing that there are some studies that have indicated a possible relationship between these acceleration waves and injuries in some body structures (e.g. articular cartilage), and since it is not clear yet if increased tibia accelerations are harmful to the musculoskeletal system, the US should be used with caution, particularly in patients with lower-limb joint problems.

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