EFFECT OF FOOT STRIKE PATTERN ON AXIAL AND TRANSVERSE SHOCK SEVERITY DURING DOWNHILL TRAIL RUNNING

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The purpose of the present study was to investigate the influence of foot strike pattern (FSP) on shock severity and attenuation during a downhill trail run. Twenty-three runners performed a 6.5-km downhill run (-1 264 m) equipped with four tri-axial accelerometers placed at tibia, sacrum, heel and metatarsals. FSP was identified using time difference between heel and metatarsals peak accelerations. Peak accelerations, median frequencies, and shock attenuation were calculated from tibial and sacral axial, antero-posterior and resultant accelerations over six sections during the run. Linear regressions analysis revealed that FSP affected differently the components of shock acceleration, i.e. although anterior FSPs enlarged shock severity along the tibial axial axis, they lowered shock severity along the tibial and sacral antero-posterior axis.

KEY WORDS: downhill running, axial acceleration, antero-posterior acceleration, foot landing, impact.

INTRODUCTION: Trail running races are generally characterized many uphill and downhill sections. Whereas uphill running requires the highest metabolic cost, downhill running is the most strenuous exercise for musculoskeletal structures Trail runners are exposed to high impact intensity during downhill sections. Repetitive and intense shocks have been shown to be a significant factor in degenerative changes at the articular structures, such as cartilage or menisci, exposing the underlying bone to high strain and increasing the risk of osteoarthritis (Fischenich et al., 2014; Brody, 2014). Likewise, bone stress injuries are very recurrent in long-distance runners (Warden et al., 2014). In downhill running compared to level running, higher vertical peak shock acceleration at tibia, sacrum and head were observed (Mizrahi et al. 2000; Chu et al., 2004). Eccentric work done by knee and ankle extensors is also elevated which induces severe muscle damages, leading worsened muscles capability to cushion impact (Eston et al.,1995). Several studies observed that high knee flexion and plantarflexed ankle at landing, which is characteristics of forefoot strike pattern (Shih et al., 2013), improved shock attenuation (Chu et al., 2004). Our purpose was to study over a downhill trail run the influence of the foot strike pattern (FSP) on shock severity.

METHODS: Twenty-three trail runners wearing the same shoe model were instructed to perform a 6.5-km downhill run (-1 264 m, Figure 1) with their natural FSP as fast as possible. They were equipped with four tri-axial accelerometers and an atmospheric pressure sensor. A single acquisition was launched from the start to the end of the run. Accelerations and air pressure were continuously recorded at 1344 and 12 Hz, respectively. Altitude was recalculated from atmospheric pressure. Accelerations were analyzed within six sections (Figure 1). Running surface was either soil trails (sections 1 to 4), asphalted road (section 5) or stony forest track (section 6). Two accelerometers were set at the left tibia and sacrum.

Tibial and sacral peaks of acceleration (PTA and PSA, respectively) and median frequencies (MDF_{tibia} and MDF_{sacrum}, respectively) were assessed in the axial (x), transverse (y) and resultant (r) directions. Note that transverse accelerations describe the component of acceleration acting along the tibial and sacral antero-posterior axis. Using transfer function, shock attenuation between tibia and sacrum was calculated in the axial, transverse and resultant directions (TFx, TFy and TFr, respectively) within the impact frequency range, i.e. 12-20 Hz (Shorten and Winslow, 1992). Two accelerometers were set on the left shoe at the heel and above metatarsals. Heel and metatarsals axial accelerations were 30 Hz high-pass filtered to easily detect peaks by removing the active (< 2 Hz) and impact (12-20 Hz) components of acceleration. They were used to identify FSP by measuring the time between heel and metatarsals peaks of acceleration (THM, Giandolini et al., 2014). Each step was classified as rearfoot strike (THM > 15.2 ms), midfoot strike (-5.49 ms < THM < 15.2 ms) or forefoot strike (THM < -5.49 ms), as proposed by Giandolini et al. (2014). Average speed was calculated for each section of interest.

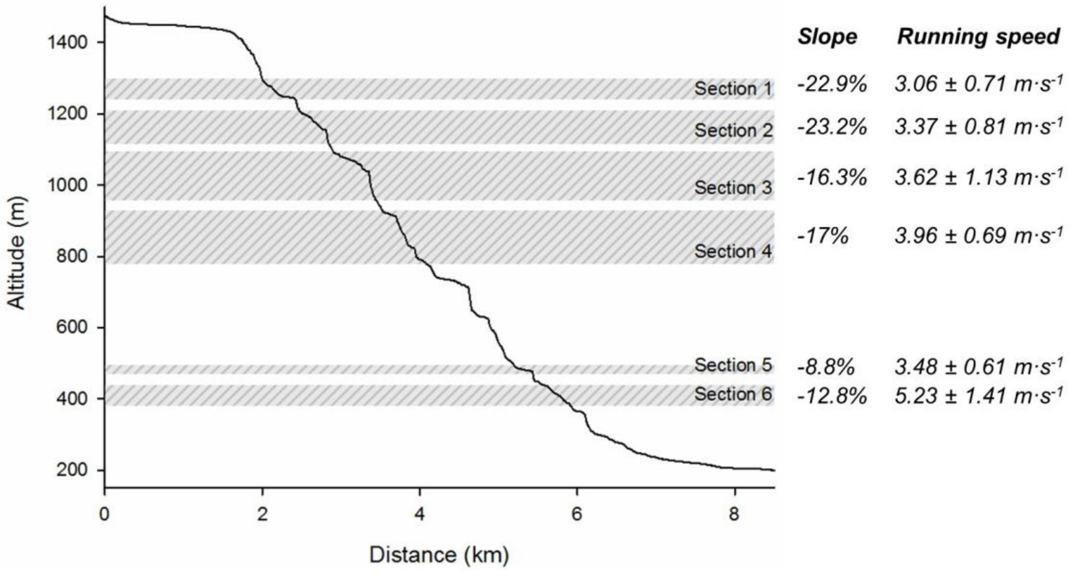

Figure 1: Description of the downhill run and the six sections used for data analysis.

For each section and each subject, mean ± SD of all variables were calculated among all steps analyzed. Parts of rearfoot (%RFS), midfoot (%MFS) and forefoot (%FFS) strikes were assessed within each section. The correlation between THM and running speed was tested using a Bravais-Pearson test (n = 138). To control the effect of running speed, multiple linear regressions were computed for each shock-related variable as dependent variable, and with THM and average running speeds as independent variables (n = 138).

RESULTS: The time for subjects to complete the run was 34 ± 6 min. Within the six sections, average running speed was 3.79 ± 0.77 $m \cdot s^{-1}$. A total of 439 ± 34 steps per subject were analyzed. There was no correlation between THM and running speed. %RFS, %MFS and %FFS within the analyzed sections were 40.2 ± 30.9, 23.8 ± 18.6 and 36.0 ± 27.9, respectively. PTAx, PTAy and PTAr were 10.7 ± 2.1, 9.4 ± 2.5 and 14.1 ± 2.8 g, respectively. $XMDF_{tibia}$, $yMDF_{tibia}$ and $rMDF_{tibia}$ were 15.3 ± 2.1, 19.8 ± 2.88 and 19.4 ± 1.88 Hz, respectively. PSAx, PSAy and PSAr were 6.3 ± 1.0, 3.3 ± 0.8 and 8.3 ± 1.5 g, respectively. $XMDF_{sacrum}$, $yMDF_{sacrum}$ and, $rMDF_{sacrum}$ were 16.5 ± 3.1, 19.3 ± 3.3 and 17.7 ± 2.5 Hz, respectively. Regarding shock attenuation, TFx, TFy and TFr were -5.9 ± 3.9, -10.5 ± 3.9 and -4.0 ± 3.0 dB, respectively. Linear regressions indicated negative correlations between THM and PTAx, $xMDF_{tibia}$ and $rMDF_{tibia}$ ($P < 0.01$, Table 1). TFx and TFr were found to be positively related with THM ($P < 0.001$). Also, positive correlations were reported between THM and $yMDF_{tibia}$, PSAy, PSAr, $yMDF_{sacrum}$ ($P < 0.02$).

Table 1
Multiplying factor and P-value for each interaction between dependent and independent variables

	Running speed		THM	
Tibia				
PTAx	**0.832**	***<0.001***	**-0.048**	***0.003***
PTAy	**0.871**	***0.002***	0.037	*0.122*
PTAr	**1.03**	***<0.001***	0.017	*0.483*
$xMDF_{tibia}$	-0.006	*0.974*	**-0.110**	***<0.001***
$yMDF_{tibia}$	0.348	*0.183*	**0.099**	***<0.001***
$rMDF_{tibia}$	0.127	*0.489*	**-0.074**	***<0.001***
Sacrum				
PSAx	**0.501**	***<0.001***	0.012	*0.137*
PSAy	**0.390**	***<0.001***	**0.018**	***0.002***
PSAr	**0.848**	***<0.001***	**0.029**	***0.014***
$xMDF_{sacrum}$	0.424	*0.176*	0.025	*0.353*
$yMDF_{sacrum}$	**0.597**	***0.048***	**0.062**	***0.019***
$rMDF_{sacrum}$	-0.016	*0.949*	-0.003	*0.891*
Shock attenuation				
TFx	**0.654**	***0.037***	**0.170**	***<0.001***
TFy	0.442	*0.246*	0.012	*0.717*
TFr	**0.527**	***0.044***	**0.120**	***<0.001***

DISCUSSION: Axial and transverse peaks of acceleration were observed to be of quasi-similar intensity during downhill running, and median frequencies were substantially greater in the transverse direction than in the axial one. The antero-posterior component was previously examined in level running by Lafortune (1991), and its relevance in downhill running has been underlined by Hardin & Hamill (2002) who suggested that *'transverse shock is probably greater during downhill than level running due to the shift in the orientation of the normal vector'*. The present results suggest that FSP affects differently the components of shock acceleration. Anterior FSPs were associated with greater peak acceleration and high frequencies content along the tibial axial axis (Figure 2). Otherwise, anterior FSPs were related to lower high frequencies content along the antero-posterior axis of the tibia and sacrum, as well as to lower peaks of acceleration at the sacral antero-posterior and resultant accelerations. Forefoot strike is characterized by a more flexed knee at contact inducing a more vertical position of tibia (Shih et al. 2013). This segment orientation may result in increasing the axial component of acceleration. Conversely, a tilted tibia at landing, as in rearfoot strike, may enlarge antero-posterior acceleration which could increase the transverse shock. Better axial shock attenuation were observed when adopting anterior FSPs, as previously reported by Chu et al. (2004). It is well known that the musculoskeletal system strives to attenuate shock to likely preserve visual and vestibular systems (e.g. Lafortune et al., 1996). Increasing impact intensity at the tibia therefore necessitates to improve shock attenuation (Lafortune et al., 1996). While observations in the axial and resultant directions follow this paradigm, observations done along the antero-posterior axis did not. Posterior FSPs seem to be inefficient in improving transverse shock attenuation in response to greater high frequency content at the tibia.

CONCLUSION: This study highlights (i) that the antero-posterior component of acceleration should be examined when investigating shock severity in running, and (ii) that FSP may affect differently the axial and transverse components of shock acceleration. Although anterior FSPs enlarged shock severity along the tibial axial axis, they lowered shock severity along the tibial and sacral antero-posterior axis. Also, high magnitudes of shock-related variables along the antero-posterior axis highlight the need to consider this component of acceleration when investigating shock severity in running. Further studies are needed to examine the role of transverse shock in the aetiology of overuse injuries.

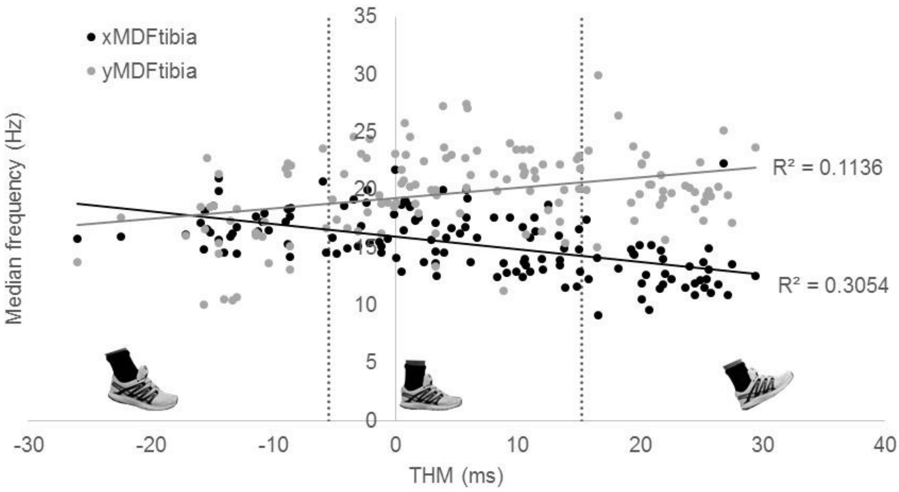

Figure 2: Correlations between THM and tibial axial and transverse median frequencies.

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