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LANDING PATTERN AND VERTICAL LOADING RATES DURING SHOD AND BAREFOOT RUNNING IN HABITUAL SHOD RUNNERS

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There is evidence to support that habitual barefoot runners are able to disperse impact loading rates by landing pattern modification. However, case studies have been reported that barefoot running may cause stress fractures. It may be due to the immediate biomechanical response difference between habitual and novice barefoot runners. Therefore, purpose of this study was to examine the immediate effects of barefoot running in habitual shod runners. Thirty habitual shod runners were asked to run on an instrumented treadmill at 10km/hr in shod and barefoot. Vertical average (VALR) and instantaneous loading rates (VILR) were obtained by previously established methods. The landing pattern was presented as a ratio between number of footfall with heel-strike and the total step number. Twenty out of 30 participants demonstrated an automatic transition to a non-heel-strike landing. A mixed landing pattern was observed in 10 participants. Compared to shod running, both VALR and VILR significantly reduced during barefoot running ($p<0.021$). In the subgroup analysis, VALR for the shod condition was significantly higher than barefoot running, regardless of the state in the landing pattern transition. Furthermore, VALR for the non-heel-strike pattern during barefoot running was significantly lower than the condition of barefoot running with mixed landing pattern (mean difference=4.3; 95%CI 0.2-8.5). We observed the similar but marginal insignificant effect of footwear condition on VILR ($p=0.066$). Habitual shod runners presented lower loading rates during impact but their landing pattern transitions were not uniform. A kinetic evaluation after a transition program is thus recommended.

KEY WORDS: kinetics, transition, shoe, injury.

INTRODUCTION: Running is a globally popular sport. Although its health benefits are well documented, running related overuse injury is very common. It has been reported that 39-85% of runners will sustain an injury during a one-year period (van Ghent, 2007). Interestingly, sophisticated footwear design and professional shoe prescription according to foot type do not reduce running injury (Knapik et al., 2010).

It has been reported that habitual barefoot runners exhibited a significant lower vertical loading rates by modifying the landing from a heel-strike to a non-heel-strike pattern (Lieberman et al., 2010). High average (VALR) and instantaneous vertical loading rate (VILR) have been associated with stress fractures (Crowell and Davis, 2011), patellofemoral pain (Cheung and Davis, 2011), and plantar fasciitis in runners (Pohl et al., 2009). Therefore, barefoot running may impose a positive impact towards injury prevention and rehabilitation.

Despite there is biomechanical evidence to support that habitual barefoot runners are able to disperse impact loading rates, case studies have been reported that both barefoot running and barefoot-simulating footwear may cause stress fractures (Giuliani et al., 2011; Salzler et al., 2012). A possible explanation is the difference of the immediate biomechanical response between habitual and novice barefoot runners. Since most of the studies examining the effects of barefoot running recruited experienced barefoot runners, the mechanical behavior during the adaptation period in habitual shod runners remains unknown. Therefore, this study aimed to examine the immediate effects of barefoot running in habitual shod runners who never attempt barefoot running or running with barefoot-simulating shoes.

METHODS: Thirty runners (age range 19-35 years old, 18 males) were recruited from local running clubs. All participants did not experience barefoot running or running with barefoot-simulating footwear prior to the present investigation. They were all regular runners (reported weekly mileage 37.3 ±6.78 kg) and free from any active injury upon enrollment. Written informed consent was obtained prior to participation. All participants ran with their usual running shoes or perform barefoot running at 10 km/hr on an instrumented treadmill (Zebris FDM, Zebris Medical GmbH, Allgäu, Germany). The testing sequence of footwear condition was randomized. Data was sampled at 240 Hz for 10 seconds after a 4-minute adaptation period (Divert et al., 2005). In addition, a force sensor (FSR-400, Digi-Key Corporation, MN, USA) located at the right heel was be used to register a heel-strike landing stride, according to the method used by a previous study (Cheung and Davis, 2011). A 15-minute rest was given between two testing conditions to minimize the effects of fatigue.

All loading variables were averaged across all footfalls in the 10-second period from the right leg. Ground reaction force data was body mass normalized and filtered using a 50 Hz low-pass Butterworth filter. VALR and VILR were obtained by the methods described by Crowell and Davis (2011). The landing pattern during shod and barefoot running was presented as a heel-strike ratio, which was a ratio between number of footfall with heel-strike and the total number of contacts in the 10-second period.

Unpaired t tests were used to compare VALR, VILR, and the heel-strike ratio in barefoot running and shod running. An univariate one-way ANOVA was used to compare the loading variables in participants during shod running, participants who had modified their landing pattern in barefoot running, and participants who did not. Tukey's HSD was used for pairwise comparison if applicable.

RESULTS: Most of the footfalls (99.5% ± 1.8) were identified as a heel-strike landing during shod running. The heel-strike ratio significantly lowered when the participants ran barefoot (20.5% ± 29.8, p<0.001) (Table 1). Out of 30 participants, we observed that 20 participants demonstrated an automatic transition from a heel-strike pattern to a complete non-heel-strike landing i.e. heel-strike ratio = 0%. However, we still observed a mixed landing pattern (heel-strike ratio ranges 50-71%; mean 61.4% ± 7.7) in 10 participants.

Table 1
Landing pattern and vertical loading rates between shod and barefoot running

	Shod running	Barefoot running	*p*
Percentage of heel-strike landing (%)	99.5 ± 1.8	20.5 ± 29.8	<0.001*
VALR (body mass/ sec)	83.9 ± 4.54	69.9 ± 4.77	<0.001*
VILR (body mass/ sec)	107.8 ± 5.80	102.9 ± 9.34	0.021*

* indicates *p*<0.05

Compared to shod running, both VALR and VILR significantly reduced during barefoot running (p<0.021) (Table 1). In the subgroup analysis, VALR differed significantly across different shoe conditions i.e. shod, participants with complete transition of landing pattern, and participants demonstrating a mixed landing pattern (F(2, 58)=76.97, p<0.001). Post-hoc comparisons indicated that VALR for the shod condition was significantly higher than barefoot running, regardless of the state in the landing pattern transition (mean difference with barefoot non-heel-strike pattern=15.4; 95%CI 12.3-18.5; mean difference with barefoot mixed landing pattern=11.1; 95%CI 7.2-15.0) (Figure 1a). Furthermore, VALR for the non-heel-strike pattern during barefoot running was significantly lower than the condition of barefoot running with mixed landing pattern (mean difference=4.3; 95%CI 0.2-8.5). We observed the similar trend of VILR. However, there was a marginal insignificant effect of footwear condition on VILR (p=0.066) (Figure 2b).

If we considered the cutoff values of VALR (>72 body mass/ sec) and VILR (>100 body mass/ sec) suggested by previous studies (Davis et al., 2010; Pohl et al., 2009; Zadpoor and Nikooyan, 2011; Zifchock et al., 2006), we observed two subjects who automatically and completely altered their landing pattern during barefoot running, presented an exceeded loading rates.

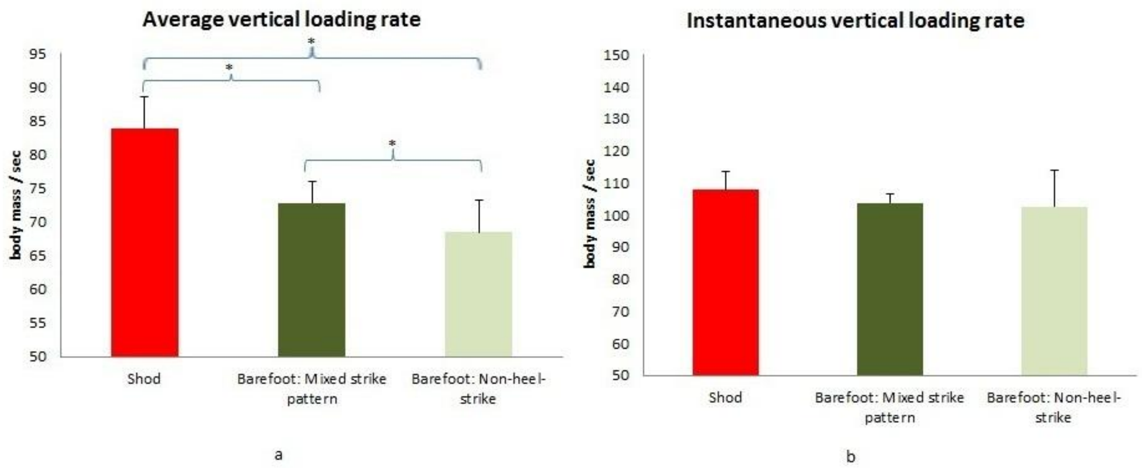

Figure 1: VALR and VILR in participants during shod running, participants with complete transition of landing pattern, and participants demonstrating a mixed landing pattern. *indicates $p<0.05$

DISCUSSION: In contrast with studies which reported the biomechanical advantages in experienced barefoot runners, habitual shod runners manifested a different landing pattern modification and changes in the vertical loading rates during early experience of barefoot running.

Barefoot running did not guarantee an instant and complete modification of landing pattern in habitual shod runners. There were 10 out of 30 participants (33.3%) presented a mixed landing pattern during early barefoot running. This is an interesting finding which could explain the potential cause of calcaneal stress fracture in novice barefoot runners (Salzler et al., 2012). Twelve and 25% of habitual barefoot runners from Kenya and the USA had been reported to adopt a heel-strike landing respectively (Lieberman et al., 2010). Taken together with the proportion of heel-strikers among habitual shod runners (Hasegawa et al., 2007), barefoot running may induce a tendency of non-heel-strike landing, but not lead to an complete avoidance of heel-strike landing. In other words, it is highly possible to observe runners with a heel-strike landing pattern after the transition from shod to barefoot running.

VALR and VILR are another two measures of the load applied to the body and they have been associated with various running related injuries. We found that shod running exhibited a significant higher VALR and VILR than barefoot running. Lower loading rates have been related to higher lower extremity compliance during impact (Bishop et al., 2006; Lieberman et al., 2010). Because human tissue is viscoelastic, its loading response is time dependent and less prone to injury at lower rates of loading (Kulin et al., 2011; Schaffler et al., 1989). Runners who altered their landing pattern from a heel-strike to a non-heel-strike landing presented a significantly lower VALR than runners converted to a mixed landing pattern. Because most runners have spent a lifetime wearing traditional running shoes, the absence of a significant reduction of VILR may be due to inadequate adaptation for the new motor pattern. Since VALR and VILR have been associated with various running related injuries, runners who successfully converted to a non-heel-strike pattern may be less injury prone.

However, a non-heel-strike landing may also result a high VALR and VILR. Although we did not collect kinematics data in this experiment, the two participants we classified as outliers were landing with a stiff ankle joint during impact. Even with a forefoot or midfoot landing maneuver, the overall leg compliance can be affected by joint stiffness of the ankle, knee, and hip. As stated in the mass-spring model (McMahon and Cheng, 1990), low leg compliance leads to high loading rates. Metatarsal stress fractures incurred by novice barefoot runners can be explained by a landing pattern transition accompanied with high loading rates during impact (Giuliani et al., 2011).

As barefoot running or running with barefoot-simulating footwear is the modern trend in the running community, many transition programs are available in different clinical settings. These transition programs often comprise muscle conditioning and gait retraining. Gait retraining is a novel approach to modify running posture and gait pattern for injury prevention and rehabilitation (Heiderscheit, 2011). Previous gait retraining used kinematics (Cheung and Davis, 2011) and kinetics (Crowell and Davis, 2011) data as biofeedback variables for gait modification. In order to ensure a lower impact loading rates in runners after the program, real time kinetics evaluation may be a better feedback type compared with kinematics measurement.

One major limitation of the present study was lacking of kinematics data. Future study should examine the immediate effects of barefoot running on individual joint stiffness and overall leg compliance in habitual runners. This information may explain the relationship between landing pattern and loading variables.

CONCLUSION: In conclusion, based on the results of this study, habitual shod runners may not automatically alter their landing pattern from a heel-strike to a non-heel-strike pattern during early experience of barefoot running. During barefoot running, they should experience lower loading rates but the magnitude of reduction can be, but not always, influenced by the landing pattern. Therefore, a kinetic evaluation after a barefoot transition program is recommended.

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