

BIOMECHANICAL ANALYSIS OF VERTICAL JUMP WITH DIFFERENT FOREFOOT MORPHOLOGY

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This study examined biomechanical differences between habitually barefoot male and habitually shod male during vertical jump. Foot morphology was measured with Easy-Foot-Scan. Foot kinetics and ankle kinematics were obtained from EMED pressure platform and Vicon motion analysis system as completing vertical jumps under barefoot condition. The results showed that habitually barefoot subjects had a significantly larger minimal distance between hallux and other toes. habitually unshod subjects showed larger loading under hallux and medial forefoot, while habitually shod subjects presented larger loading under medial and central forefoot. in addition, habitually barefoot male had smaller ankle plantarflexion, eversion and external rotation during vertical jump. Differences of kinematics and kinetics during vertical jump might attribute to the morphological differences in the toes region, which possibly explain the foot injury risks between habitually barefoot and habitually shod individuals.

KEY WORDS: foot morphology, toes, plantar pressure

INTRODUCTION: Forefoot width and toes separation increased significantly when walking barefoot. Robbins et al. (1987) indicated that the habitually barefoot feet likely to be injured than the habitually shod feet. Metatarsal pathologies were more serious in the habitually shod populations than that in the habitually barefoot populations (Zipfel et al., 2007). This could illustrate that acquired behavior such as footwear wearing would affect the pathological fluctuation of metatarsus.

Ankle sprain is one of the most significant injuries for participants of sports such as volleyball, basketball and soccer (Doherty et al., 2014), secondary to the rapid impulse loads imparted bilaterally on each lower extremity during landing maneuvers. this is primarily due to the fast shock load of lower limbs during landing. During the vertical jump, both the habitually barefoot populations and habitually shod populations took off with forefoot and toes, and landed with forefoot and toes during the vertical jump. This makes it easy and feasible for comparative analysis of vertical jump between habitually barefoot male (HBM) and habitually shod male (HSM).

Therefore, the objective of this study was to investigate the biomechanics of lower limb during vertical jump, particularly motion of ankle and plantar pressure to the forefoot and toes. Based on the foot morphological difference between HBM and HSM, it aimed to verify the HBM have unique functions in the take-off phase and landing phase of vertical jump compared with HSM.

METHODS: Participants: Eighteen habitually barefoot males, with age: 24±1.2, height:

165.3 ± 1.2 cm, mass: 65.4 ± 6.9 kg, BMI: 23.88 ± 0.93 kg/m², and twenty habitually shod males, with age: 24 ± 2.1 years, height: 172.1 ± 1.6 cm, mass: 66.2 ± 6.5 kg, BMI: 22.31 ± 1.97 kg/m² volunteered to join the test. They had no pain, injury or surgery to their lower limbs or lower back in the past six months.

Experiment procedure: Easy-Foot-Scan (EFS), OrthoBaltic (Kaunas, Lithuania) was used to measure foot morphological differences including minimal distance between the hallux and remaining toes. The minimal distance of habitually shod feet was smaller than the distance of habitually barefoot feet (Figure 1-a, b, HSM: 6.28±1.42mm, HBM: 23.75±2.09mm, P< 0.001). An 8-camera Vicon motion analysis system (Oxford Metrics Ltd., Oxford, UK) was used to capture the three-dimensional kinematics at the frequency of 200 Hz. A standard reflective marker set was used to define joint centers and axes of rotation. Participants were required to wear tight shorts, 16 reflective points (diameter 14 mm) were attached on right and left lower limbs respectively on different key locations including: anterior-superior iliac spine, posterior-superior iliac spine, lateral mid-thigh, lateral knee, lateral mid-shank, lateral malleolus, second metatarsal head and calcaneus. Kinetics was record at 50Hz using an EMED force plate (Novel, Germany). Both the HBM and HSM touched the ground with forefoot and toes in take-off and landing phases with right foot on the force plate for data collection. The forefoot and toes were divided into five anatomical parts: medial forefoot (MF), central forefoot (CF), lateral forefoot (LF), hallux (H), other toes (OT) (Figure 1-c). Peak pressure, contact area and pressure-time integral were used to analyze the difference of participants during take-off and landing phase. Participants performed countermovement jump motions under barefoot condition. Each participant performed five trials, with resting 30 seconds to avoid fatigue.

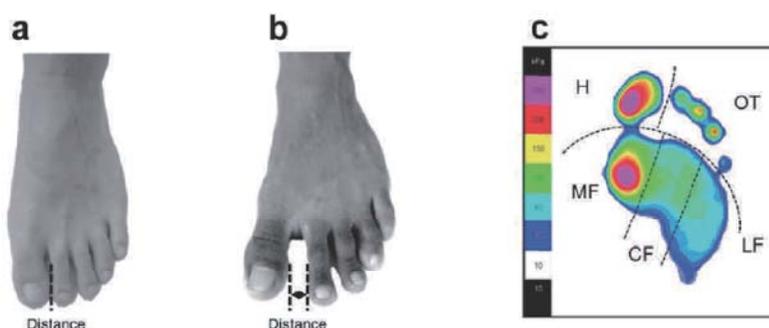


Figure 1: Habitual shod foot (a), habitual barefoot foot (b) and anatomical parts of plantar pressure (c)

Statistical analysis: All statistical analysis was performed using Stata 12.0 software. The t test was taken to analyze the differences between the main variables of interest. In the result of t test, defining P<0.05 is significant difference statistically.

RESULT: During take-off, the ankle of HSM showed significantly larger peak dorsiflexion, eversion and external rotation than those of HBM. In the moment of take-off, the ankle joints of HBM showed significant larger plantarflexion than that of HSM (P<.001). The ankle joints of

HBM showed inversion and that of HSM showed eversion ($P < .001$). The ankle joints of HBM showed significant smaller external rotation than that of HSM ($P < .001$).

For pressure time integral, the HBM showed higher pressure time integral than HSM in H ($P < .001$). However, the HSM showed higher pressure time integral than HBM in MF and CF (MF: $P = 0.0347$; CF: $P < .001$). For peak pressure, the HBM showed higher peak pressure than HSM in H ($P < .001$). But the HSM showed higher peak pressure than HBM in MF and CF (MF: $P < .001$; CF: $P < .001$). For contact area, the HBM showed larger contact area than HSM in MF ($P = 0.0082$).

During landing, the ankle of HSM showed significantly larger peak dorsiflexion, eversion and external rotation than those of HBM. In the moment of landing, the ankle joints of HBM showed significant smaller eversion and external rotation than that of HSM (eversion: $P < .001$, external rotation: $P < .001$).

For pressure time integral, the HBM showed higher pressure time integral than HSM in H ($P = 0.0132$). But the HSM showed higher pressure time integral than HBM in MF, CF and LF (MF: $P = 0.0083$; CF: $P = 0.0335$; LF: $P = 0.0447$). For peak pressure, significant differences were found in H, CF and LF. The HBM showed higher peak pressure than HSM in H ($P = 0.0075$). But the HSM showed higher peak pressure than HBM in CF and LF (CF: $P < .001$; LF: $P = 0.0256$). For contact area, significant differences were found in OT and CF. The HBM showed larger contact area than HSM in OT ($P = 0.0011$). But the HSM showed larger contact area than HBM in CF (CF: $P < .001$).

DISCUSSION: In this study, participants of HBM showed separate toes compared with HSM. During take-off and landing, HBM showed significantly larger peak pressure and pressure time integral than HSM in hallux. It corresponded with the hallux of habitually barefoot feet was significant separate from other four toes (Shu et al., 2015).

The main pressure area of HBM was H and MF, but the main pressure area of HSM was MF and CF. While heel rose and foot was stabilized by flexor muscles, forefoot touching surface supported large ground reaction force. Highly stresses were produced in the touching area in particular the metatarsal heads (Chen et al., 2010). It could explain that in take-off phase, the plantarflexion of HBM was significantly larger than that of HSM. Similarly, the plantar pressure of HBM was larger under MF and MF and CF for HSM. This could explain that the instant angle in eversion and external rotation of HSM were significantly larger than HBM. Previous researches of HSM and HBM running suggest that the difference of hallux between HBM and HSM was that of HBM indicated distinctive functions in the pushing-off phase (Wolf et al., 2008). The hallux gripping action in the push-off phase would expand and firm the supporting base, which was focused on the metatarsals head leading to running foot injuries. With the ankle joint angle range of motion, Papaiakovou (2013) found that the flexible group jumped higher. There were significant differences in sagittal plane but no significant differences in jump height in this study. It could infer that no significant differences of flexibility between HSM and HBM. In addition, the dorsiflexion of HSM was significant larger than HBM. Although dorsiflexion produced alteration in muscle activation, this did not intend that there was an improvement of performance in the distinction.

During landing, the ankle of HBM showed smaller plantarflexion than HSM during landing phase. Treating foot as a lever, fulcrum of HSM was the forefoot but hallux and forefoot for

HBM, which could reduce the loading of fulcrum. The functions of the remaining toes were to balance control under static and dynamic conditions. The ankle of HSM showed larger eversion and external rotation than HBM during the landing phase, it could infer from the different larger pressure area of HSM and HBM.

Compared with internal eversion moment of ankle (provide by structures, such as: foot eventers, ligaments), external inversion moment of ankle had a stronger possibility to occur ankle sprain (Stacoff et al. 1996). The external foot rotation would be the principal mechanism of ankle sprain in the clinical literature. Williams et al. (2007) indicated the mechanism of external rotation during the dorsiflexion and eversion would damage ankle from the athletes with high ankle sprain. The injury mechanism of combined dorsiflexion, eversion and external rotation . This could consider that HBM had a low risk of ankle injury compare with HSM.

CONCLUSION: Based on the foot morphological difference between HBM and HSM in the distance from hallux to second toe, the loading under hallux and medial forefoot of HBM was larger, while the loading to medial and central forefoot of HSM was larger. Additionally, The HBM had smaller ankle plantarflexion and HSM had larger eversion and external rotation during take-off and landing of jump. Differences of kinematics and kinetics during vertical jump might attribute to the morphological differences in the toes region, which possibly explain the foot injury risks between habitually barefoot and habitually shod individuals. These suggested that enhancing toes' function would benefit for ankle injury prevention.

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