THE LOCAL BIOMECHANICAL ANALYSIS OF LOWER LIMB ON COUNTER-MOVEMENT JUMP BETWEEN BAREFOOT AND SHOD PEOPLE WITH DIFFERENT FOOT MORPHOLOGY

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The aim of this study was to explore the kinematic variations in knee and ankle joints and the ground reaction force between habitually barefoot (HBM) and shod males (HSM) during countermovement jump. Twenty-eight males (14 HBM,14 HSM) participated in this experiment. An 8-camera Vicon motion system was used to collect the kinematic data of knee and ankle joints from 3 dimensions and the force plate was used to collect the ground reaction force in take-off phase. Results in take-off phase showed that HSM produced two peak forces to take off and showed significantly greater knee ROM in sagittal plane, as well as greater ankle inversion and external rotation. In conclusion, the foot morphological differences can result in the different influence on jump performance. The relevant practioner should pay close attention to the effect of foot morphology on jump in training.

KEYWORDS: foot morphology; vertical jump performance; ground reaction force; kinematics.

INTRODUCTION: Habitually barefoot population (HBM) has some differences in morphology compared to habitually shod population (HSM) when running (Lieberman et al., 2010), which can lead to different performance and partly reduce sports injuries (Lieberman et al., 2010). Biomechanical studies reported that the separated large toe of HBM and the other toes of HSM had the specific prehensile function (Ashizawa et al., 1997); these characteristics lead to load and initiate larger push forces for take-off (Tam et al., 2016). Therefore, by gathering information on different foot types may provide more insight to understand human locomotion performance and help to prevent injuries (Mei et al., 2014). However, now days, the most highlighted area in relation to drawing comparisons between HBM and HSM appears to be running opposed to other regular movements such as jumping. In consideration of current evidences, this study was aimed to analyse the different foot morphology in biomechanical characteristics between HBM and HSM during counter-movement jump (CMJ). We hypothesized that the morphological differences between HBM and HSM can lead to different take-off patterns, which may further cause different performance in knee and ankle joints.

METHODS: Fourteen HBM (176±7.8cm, 68.8±12.6kg, 22.1±3.1 kg/m^2) from the south of India and fourteen HSM (177±6.3cm, 68±5.7kg, 21.9±3.4 kg/m^2) from China volunteered to participate in testing. Their different foot morphologies was showed in Figure 1. The study was obtained from the Research Academic of Grand Health Ethics Committee (RAGH20160318).

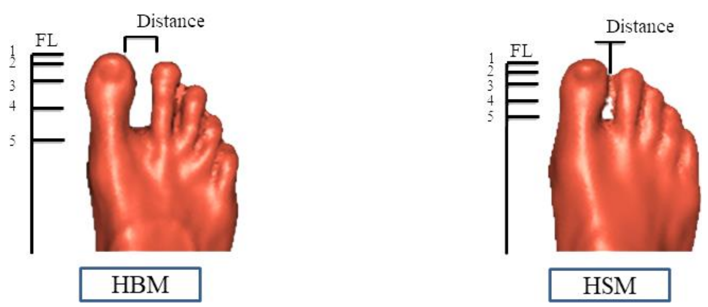

Figure 1 The foot morphology between habitually barefoot and shod male.
Note:
(1) FL indicates foot length; the number from 1 to 5 demonstrate toes from hallux to fifth toes.

(2) The measurement of toe length is based on 50% foot length; the width scale distance between the numbers demonstrates the bigger difference between adjacent toes.

In this study, participants were required to wear tight clothes during the experiment. 16 reflective markers (plug-in-gait model) were placed on different areas of the right and left lower extremity. Such as: anterior-superior iliac spine, posterior-superior iliac spine, lateral mid-thigh, lateral knee, lateral mid-shank, lateral malleolus, second metatarsal head and calcaneus. There was a five-minute warm-up period for the participants before testing. Afterwards, the subjects performed a barefoot counter-movement jump (CMJ) with their hands on their hips throughout the range of motion. Five trials were performed by each subject with thirty seconds rest, which helped to avoid the effects of fatigue.
Data was gathered and automatically calculated between the take-off and flight phase by the Vicon motion analysis system (Oxford Metrics Ltd., United Kingdom, 200 Hz) and Kistler (Switzerland, 1000 Hz). The take-off phase is defined from the initial knee flexion to the foot eventually leaving the ground; hence the vertical ground reaction force (GRF) returning to 0 N. The flight phase is from the GRF returning to 0 N to the moment of the foot touches the ground to complete knee extension that the ground reaction force will be greater than 0 N. And statistical analysis of all collected data was performed using Microsoft Excel 2010 and SPSS 17.0 software (Chicago, IL, USA). An independent t-test was used to determine the significance of kinematics variations in knee and ankle, GRF. P value <0.05 was defined as significant statistical difference.

RESULTS: During take-off phase, no significant difference of peak force in GRF was found; however, HSM showed two peaks in the vertical GRF compared HBM`s single during barefoot CMJ (Figure 2). HSM showed significantly higher knee flexion opposed to HBM, HBM showed significantly bigger in-eversion and in-external rotation in ankle (Figure 3, Table 1). No significant differences were found in eversion, inversion, internal rotation and external rotation of the knee and dorsi-flexion angles in ankle.

Table 1 The comparison of knee and ankle variation range between HBM and HSM.

	Take-off phase	
Subject	HBM (mean ± SD)	HSM (mean ± SD)
Knee		
Flex- Extension	49.88±2.57*	99.44±3*
In-Eversion	39.60±3.55	39.50±3.19
In-external rotation	33.69±2.52	33.69±2.51
Ankle		
Dosi-plantar flexion	56.4±9.3	64.4±1.9
In-Eversion	24.0±1.0*	5.4±1.4*
In-external rotation	29.5±0.6*	8.4±1.3*

Note:* indicates the significant difference between HBM and SBM, p<0.05

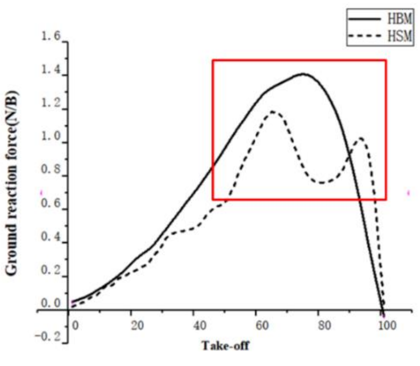

Figure 2 GRF of HBM and HSM in take-off phase during barefoot CMJ.

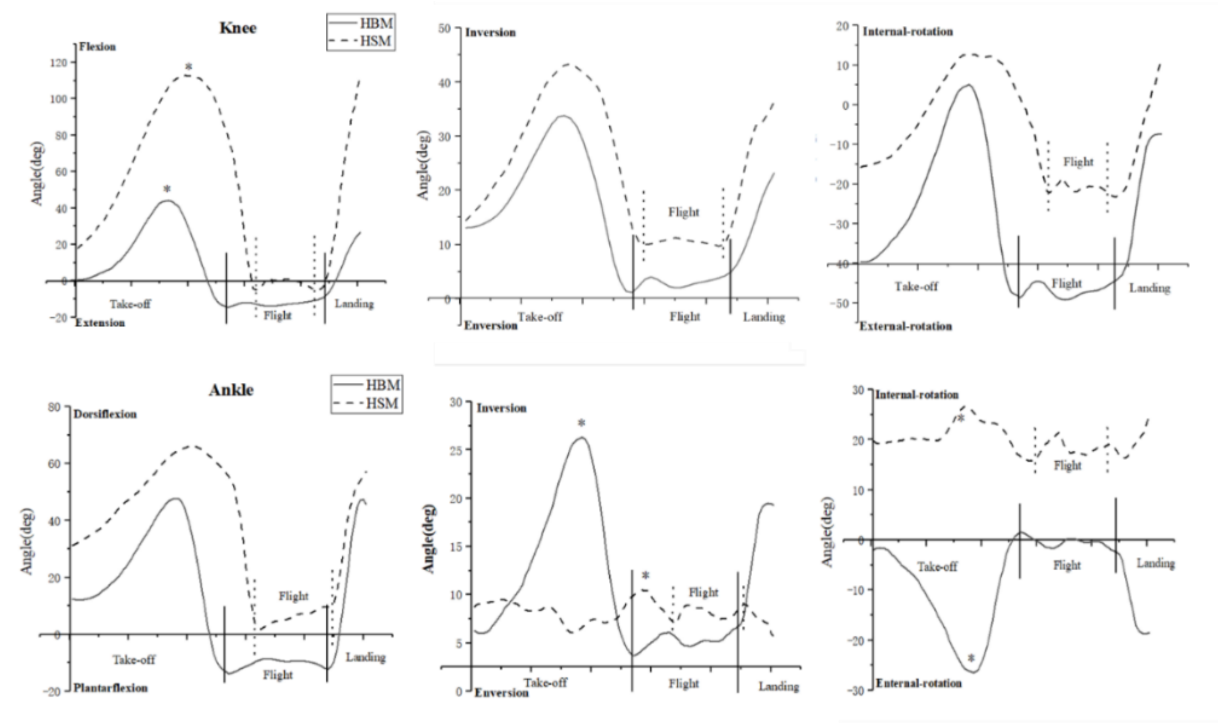

Figure3 The knee and ankle joint curve in sagittal, frontal and horizontal planes.
Note: * indicates the significant difference between HBM and SBM, p<0.05

DISCUSSION: This study is to mainly focus the influence of different foot morphology on the vertical jump performance. Experimental results support our hypothesis that the differences of foot morphology can produce different influences on GRF, knee and ankle joints kinematics during take-off phase.

Although no significant differences of peak force in GRF were found among HBM and HSM, HBM showed single-peak pattern and HSM showed double-peak pattern. Ground reaction force resulted from the reaction of the foot with ground, the different GRF’s curves between foot and ground reflected different role mechanism. The different GRF trajectories of HBM and HSM in this study indicated that there were different force mechanisms between HBM and HSM in take-off phase. Existing study proved that the feature of foot morphology was associated with the lower-limb biomechanical variation (Werkhoven et al, 2017); the distance between hallux toe and other toes and the toe length can all increase push force of foot during running, sprint and jump (Shu et al., 2016; Lee et al., 2009; Mei et al., 2015). For instance, Shu et al (2016) has found that HBM showed higher plantar loading under hallux and medial forefoot and HSM showed higher plantar loading under medial and central forefoot. These suggest that HBM mainly utilising the hallux and HSM mainly utilising other toes to produce push force in jump and running. Recently, several studies suggested that the foot toe length could influence on performance (Lee et al., 2009; Werkhoven and Piazza, 2017); the longer toes increases the ground contact time and the propulsive impulse when sprinter accelerates at start phase (Lee et al., 2009; Werkhoven and Piazza, 2017). From this view, we can confirm that the longer toes of HBM and HSM can produce the positive influence on performance in this study, they generate impulse force and also provided push-off force in motion. Besides this common factor, the distance between HBM and HSM is the most significant different factor, and study has proven that it also can influence on the complete of jump. Therefore, we can further speculate that the subject`s different modes of GRF during take-off phase may be caused by the long toe and the distance between hallux and other toes.

It is widely acknowledged that lower-limb joints are in compliance with hip, knee and ankle. The kinematics difference of joint among lower-limb joints can lead to the differences in other joins kinematic. Compared with HSM during jump, HBM showed significant bigger inversion and external rotation in ankle. The knee joint also showed eversion, and accompany with ankle inversion and external rotation. However, no significant difference of knee eversion between HSM and HBM was found, which demonstrated that the knee eversion during jump was not the main factor leading the difference in ankle kinematics. CMJ is mainly depending on forefoot area to complete (Gross et al., 1988), the feature of forefoot morphology can produce influence on jump (Werkhoven et al., 2017; Liang et al, 2019)). Shu et al. (2016) proved that the HBM has smaller contact area of hallux than HSM. And the overall jumping performance needs the optimal range of motion and the muscular strength to support (Tomioka, Owings & Grabiner, 2001). The smaller contact area contributes to ankle motion and the completion of jump movement. And this differences of forefoot morphology lead to different ankle variation and further result in different knee variations. Although our findings are useful for understanding the motion mechanics of barefoot population; we only analyse the kinematics of knee and ankle and the GRF and do not select female subjects to take test. Therefore, there still needs to consider own to these limitations existing in this study when apply those results.

CONCLUSION: Overall, the significant different kinematics in knee and ankle and GRF demonstrated that the foot morphological differences of HSM and HBM has influence on CMJ performance, subject`s the distance between hallux and other toes and the toe length all can influence lower-limb joint biomechanics. And practitioners should pay attention on these biomechanical differences when use CMJ to test or train athlete's performance.

REFERENCES

Bradley, P.S., Olsen, P.D. and Portas, M.D., (2007) The effect of static, ballistic, and proprioceptive neuromuscular facilitation stretching on vertical jump performance. *Journal of Strength and Conditioning Research*,21(1), 223-226.

Church, J.B., Wiggins, M.S., Moode, F.M. and Crist, R. (2001) Effect of warm-up and flexibility treatments on vertical jump performance. *Journal of strength and conditioning research*,15(3),332-336.

Garrick, J.G. and Requa, R.K., (1988) The epidemiology of foot and ankle injuries in sports. Clinics in sports medicine, 7(1), 29-36.

Lieberman, D.E., Venkadesan, M., Werbel, W.A., Daoud, A.I., D'andrea, S., Davis, I.S., Mang'Eni, R.O. and Pitsiladis, Y. (2010). Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature*,463(7280),531.

Luebbers, P.E., Potteiger, J.A., Hulver, M.W., Thyfault, J.P., Carper, M.J. and Lockwood, R.H. (2003). Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *Journal of strength and conditioning research*,17(4),704-709.

Mei, Q., Fernandez, J., Fu, W., Feng, N. and Gu, Y. (2015) A comparative biomechanical analysis of habitually unshod and shod runners based on a foot morphological difference. *Human movement science*, 42, 38-53.

Shu, Y., Zhang, Y., Fu, L., Fekete, G., Baker, J.S., Li, J. and Gu, Y. (2016) Dynamic loading and kinematics analysis of vertical jump based on different forefoot morphology. *SpringerPlus*,5(1), 1999.

Tam, N., Wilson, J. L. A., Coetzee, D. R., Pletsen, L. V., & Tucker, R. (2016). Loading rate increases during barefoot running in habitually shod runners: individual responses to an unfamiliar condition. *Gait & Posture*,46, 47-52.

Tomioka, M., Owings, T.M. and Grabiner, M.D. (2001). Lower extremity strength and coordination are independent contributors to maximum vertical jump height. *Journal of Applied Biomechanics*,17(3), 181-187.

Wong, CK., Weil, R., De Boer, E. (2012) Standardizing foot-type classification using arch index values. *Physiother Can*. 64,280–283.

Gross, T. S., & Nelson, R. C. (1988). The shock attenuation role of the ankle during landing from a vertical jump. *Medicine and science in sports and exercise*, 20(5), 506-514.

Werkhoven, H. V. , & Piazza, S. J. . (2017). Foot structure is correlated with performance in a single-joint jumping task. *Journal of Biomechanics*, 57,27-31.

Lee, S. M., & Piazza, S. J. (2009). Built for speed: musculoskeletal structure and sprinting ability. *Journal of Experimental Biology*, 212(22), 3700-3707.

Shelburne, K. B. , Torry, M. R. , & Pandy, M. G. (2005). Effect of muscle compensation on knee instability during acl-deficient gait. *Medicine & Science in Sports & Exercise*, 37(4), 642-648.

Liang, Z. Q., Meng, Y., Popik, S., & Chen, F. F. (2019). Analysis of Foot Morphology in Habitually Barefoot Group. *Journal of Biomimetics, Biomaterials and Biomedical Engineering*, 41, 1-9.