FOOT FUNCTION ASSESSMENT THROUGH KINEMATIC AND KINETIC ANALYSIS

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The purpose of this study was to investigate toes' function while performing barefoot and shod running between habitually unshod and shod runners. Seven habitually male shod runners and six habitually male barefoot runners participated the running test. Kinematic and kinetic analysis were synchronously conducted. The habitually unshod runners showed significantly higher ankle eversion-to-inversion angle in the pushing-off phase than habitually shod runners. And forefoot loading reduced as the big toe of habitually unshod runners pushing ground under shod condition, with similar function of other toes among habitually shod runners. It is noted that the work of big toe and other toes lead to the decreased loading to the forefoot. This might be beneficial for the prevention of foot injuries, like plantar fasciitis and metatarsal fatigue fracture.

KEY WORDS: toe, barefoot running, ankle, kinematic, kinetic.

INTRODUCTION: Toes were believed to be designed with prehensile and ambulatory functions (Lambrinudi, 1932). One distinct foot morphological difference between habitually barefoot populations and shod populations was proven to exist in the toes part regarding the difference of foot length and width (D'Août et al., 2009), that the great toe of habitually barefoot populations was quite separate from other four toes (Ashizawa et al., 1997), or even in an abducted position through analysis of early hominin footprints (Bennett et al., 2009). Toes-related feet morphological characteristics differed among populations of different ethnicities, living environment or running style (Hoffmann, 1905; Rolian et al., 2009; Lieberman et al., 2010). Amateur running is now gaining its popularity as one of the most accessible physical activities in daily life, meanwhile, running-related lower extremity injuries are becoming more common among runners. As previously reported, habitually barefoot runners show a lower injury rate owing to daily long-distance running ability for hunting from the evolutionary perspective (Tam et al., 2014). And it has been accepted that habitually barefoot runners could alleviate the impact collision to the lower extremity via its 'barefoot' running style (Lieberman et al., 2010; Cheung et al., 2014), yet toes' functions while running haven't been thoroughly clarified. The purpose of this study was to investigate the toes' functions while habitually shod and unshod runners conducting shod and unshod running test via the kinematic and plantar pressure analysis.

METHODS: A total of thirteen participants, with seven habitually male shod (rearfoot) runners and six habitually male barefoot (forefoot) runners both joined in this running test with shoes (normal flat shoes without any cushioning system) and barefoot (with normal socks to fix insole to plantar surface). Before the test, informed written consent were obtained and participants knew the procedures and objective of the experiment. The foot morphological difference existing to toes were quantitatively exposed with great significance of Hallux Angle (HA) ($p<0.001$) and minimum Distance between hallux and other toes ($p<0.001$) through foot scan with Easy-Foot-Scan, Ortho Baltic (Kaunas, Lithuania) (Figure 1). Participants were required to run five minutes on the testing ten-meter walkway to get familiarization and control the running speed at 3.0 ± 0.2m/s according to timing meter and metronome. The stride length and cadence were preferred by subjects so as to illustrate their normal gait characteristics. An eight-camera *Vicon* motion analysis system was taken to capture the lower limb kinematics at the frequency of 200Hz. The standard reflective markers were pasted to anterior-superior iliac spine, posterior-superior iliac spine, lateral mid-thigh, lateral knee, lateral mid-shank, lateral malleolus, second metatarsal head and calcaneus of the left and right lower limbs. A static-standing trial was conducted in the middle of the walkway, where data of running step were collected and used for analysis, so as to define the referenced markers' anatomical positions for dynamic-running test. While running under shod (shoes) or barefoot (socks) conditions, the markers were pasted to the corresponding anatomical position on the shoes or socks. And an insole plantar pressure measurement system was simultaneously employed to record the force and pressure exerted on the insole pressure sensors with the frequency of 50Hz. During the running test, subjects randomly selected shoes or barefoot (socks) to conduct running trials, and a high speed camera (Fastcam SA 3, Photron, Japan) was mixed in a three-meter distance of right lateral side to ensure the strike patterns (HBR shod and unshod forefoot running and HSR shod and unshod rearfoot running) of both group participants. Six trials of shod and same for unshod running were collected and averaged within corresponding (shod or unshod and rearfoot or forefoot running) trial-running for statistical analysis. One gait cycle was defined using the right rearfoot (for habitually shod runners) or forefoot (for habitually unshod runners) successively contacting the ground twice and normalised to 100%. The SPSS 17.0 software was used for statistical analysis. The significance level was set at 0.05.

RESULTS: Prior to the running test, foot morphological difference between habitually shod runners (Figure 1-A) and habitually unshod runners (Figure 1-B) was illustrated with Hallux Angle (HA' for HSR and HA for HBR) and minimum distance (Distance' for HSR and Distance for HBR) between hallux and other toes.

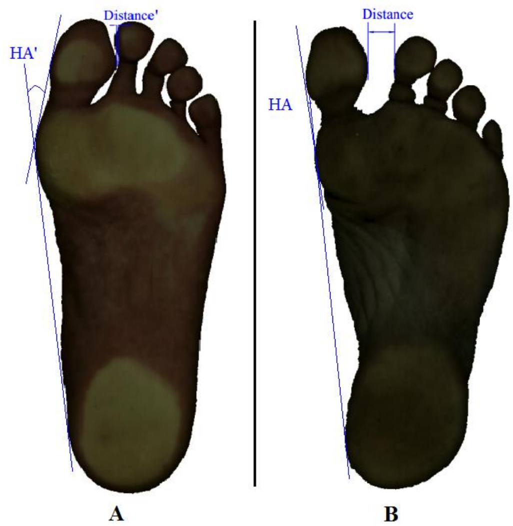

Figure 1: The 2D footprint images of habitually shod runners (A) and habitually unshod runners (B) obtained from the Easy-Foot-Scan.

The habitually barefoot runners (HBR) showed greater eversion-to-inversion angles compared with habitually shod runners (HSR) in the pushing-off period (Figure 2, the mean ankle inversion and eversion angle in the normalised and averaged gait cycle). But habitually shod runners (HSR) showed higher peak eversion angles -14.95°±0.33 (RFS-shod) and -14.49°±0.29 (RFS-unshod). The Figure 3 shows that under unshod condition, both HBR (A) and HSR (C) show greater foot loading to the forefoot in the pushing-off phase. However, the pressure to the hallux and other toes parts significantly increased with reduced loading to the forefoot area under HBR (B) and HSR (D) shod running conditions.

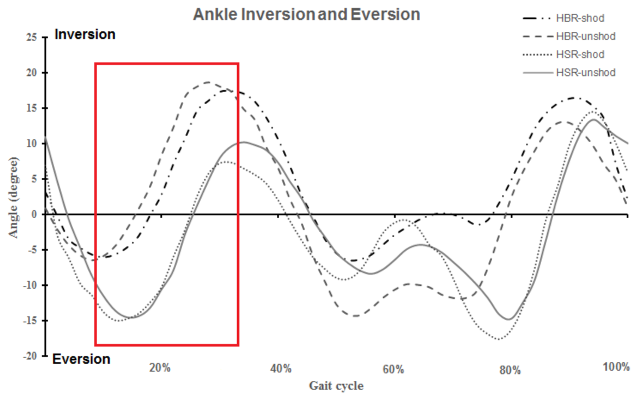

Figure 2: The mean inversion and eversion angle curve of ankle while habitually barefoot runners (HBR) and habitually shod runners (HSR) running under shod and unshod conditions. (The red square indicates the difference while forefoot pushing off the ground)

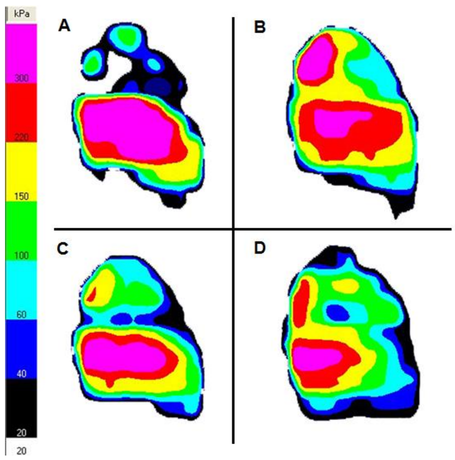

Figure 3: The mean peak pressure to forefoot and toes regions in the pushing off phase. (A-HBR unshod running, B-HBR shod running, C-HSR unshod running and D-HSR shod running)

DISCUSSION: In this study, participants demonstrated different running styles or foot landing patterns as previously reported (D'Août et al., 2009; Lieberman et al., 2010; Tam et al., 2014), without strike patterns alteration though running under shod or unshod conditions. The hallux of HBR showed unique roles compared with that of HSR in the pushing-off stage (Hoffmann, 1905; Lambrinudi, 1932), which was the very final and critical stage of running (Novacheck, 1998; Dugan et al., 2005). It was characterized by the peak pressure of the hallux of HBR shod running being larger than that under unshod conditions (Figure 3-B) and greater ankle eversion-to-inversion in push-off phase (Figure 1) (Sinclair et al., 2013). Following this, the peak pressure to forefoot of HBR shod running was lower than that of unshod condition. This could be explained with the windlass mechanism, which raised the arch of foot and contributed to the stiffening of foot with the tension and contraction of the plantar aponeurosis around the metatarsals' heads during toes' gripping action (Hicks, 1954; Mann, et al., 1979; Caravaggi, et al., 2009). The hallux gripping action in the push-off phase thus expanded and firmed the supporting base (Ku, et al., 2012), which was previously focused on the metatarsals head that lead to running foot injuries (Novacheck, 1998; Tam et al., 2014). Combining with greater ankle eversion-to-inversion angle of HBR in the pushing-off stage, this could be explained with great toe's pushing action resulting into the increased pressure to the big toe and decreased loading to the forefoot part (Dugan et al., 2005). As to the less ankle inversion, the other toes of HSR worked similarly to reduce the forefoot loading under shod condition, as reported by Rolian et al (2009). Future study shall investigate and testify the loading-dispersion from the hallux's pushing-ground training effect.

CONCLUSION: This study found out that forefoot loading reduced with toes pushing-ground or gripping function. The big toe of habitually barefoot runners took significant part of forefoot loading, which could be the reason of lower injury risks to metatarsal region. This should be of greatly practical importance for the training of recreational or athletic runners. Through the training of hallux pushing-ground movement, it would be beneficial for injury prevention and running performance improvement.

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