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A comparative biomechanical analysis of habitually unshod and shod runners based on a foot morphological difference

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Running is one of the most accessible physical activities and running with and without footwear has attracted extensive attention in the past several years. In this study 18 habitually male unshod runners and 20 habitually male shod runners (all with dominant right feet) participated in a running test. A *Vicon* motion analysis system was used to capture the kinematics of each participant's lower limb. The in-shoe plantar pressure measurement system was employed to measure the pressure and force exerted on the pressure sensors of the insole. The function of a separate hallux in unshod runners is analyzed through the comparison of plantar pressure parameters. Owing to the different strike patterns in shod and unshod runners, peak dorsiflexion and plantarflexion angle were significantly different. Habitually shod runners exhibited a decreased foot strike angle (FSA) under unshod conditions; and the vertical average loading rate (VALR) of shod runners under unshod conditions was larger than that under shod conditions. This suggests that the foot strike pattern is more important than the shod or unshod running style and runners need to acquire the technique. It can be concluded that for habitually unshod runners the separate hallux takes part of the foot loading and reduces loading to the forefoot under shod conditions. The remaining toes of rearfoot strike (RFS) runners function similarly under unshod conditions. These morphological features of shod and unshod

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runners should be considered in footwear design to improve sport performance and reduce injury.

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1. Introduction

Amateur running is an increasingly popular activity worldwide. Associated with this extensive participation are increased injury rates. Numerous studies investigating running, such as the work of Lieberman et al. (2010), found that habitually unshod runners and habitually shod runners have different foot strike patterns (FSP). The former often landing on the fore-foot (fore-foot strike, FFS) before bringing down the heel, sometimes landing with a flat foot (mid-foot strike, MFS) or, less often, on the heel (rear-foot strike, RFS). The latter mostly landing with rear-foot strike (RFS), which was believed to be facilitated by the elevated and cushioned heel of the modern running shoe. The different foot strike patterns between shod and unshod running has typically been evaluated through kinematics, kinetics and spatiotemporal parameters. The FSP was initially classified via visual observation into RFS, MFS and FFS (Altman & Davis, 2012). There has been increasing interest in the relation between FSP and injury, and the FSP has been analyzed with the strike index (SI), ranging from 0% to 100% (from extreme rearfoot to extreme forefoot) by measuring the center of pressure (COP) from a force plate (Cavanagh & Lafortune, 1980; Lieberman, 2012; Munro, Mille, & Fugleva, 1987). The FSP can also be classified through a foot strike angle (FSA) (the striking angle of foot in the dorsiflexion or plantarflexion position compared to the normal standing position) in sagittal plane kinematics. It has also been verified that the FSA was related with SI under both unshod and shod conditions (Altman & Davis, 2012). Further, it was widely accepted that unshod running with FFS had shorter contact times, shorter stride length and higher cadence compared to shod running with RFS (Cronin & Finni, 2013; Lieberman et al., 2010; Lohman, Sackiriyas, & Swen, 2011). However, few studies were conducted to analyze the difference between RFS and FFS running under unshod and shod conditions.

Concerning the injury rate of different running patterns, FFS running, which is characterized by smaller collision forces than RFS running was believed to protect the feet and lower limbs from some of the impact-related injuries now experienced by a high percentage of runners (Lieberman et al., 2010). The vertical ground reaction force (GRF_V) and vertical loading rate (VLR) of RFS running were also confirmed to be higher than FFS running (Hall, Barton, Jones, & Morrissey, 2013; Lieberman, 2012; Samaan, Rainbow, & Davis, 2014). This was thought to contribute to high incidences of stress injuries to the feet and lower limb, especially the metatarsals, tibial stress fracture, patellofemoral pain, Achilles tendinopathy, and plantar fasciitis (Nunns, House, Fallowfield, Allsopp, & Dixon, 2013; Revill, Perry, Edwards, & Dickey, 2008; Tam, Wilson, Noakes, & Tucker, 2014; Willson et al., 2014). Studies concerning barefoot running concluded that barefoot running could minimize impact peaks through a FFS pattern (Lieberman et al., 2010), increased proprioception via direct contact with the running surface and increased foot and leg muscle strength (Sousa, Silva, Macedo, Santos, & Tavares, 2014; Sousa, Tavares, Macedo, Rodrigues, & Santos, 2012; Tam et al., 2014), thus reducing injury regardless of the choice of footwear (Lieberman, 2012; Sousa & Tavares, 2014). Considering the benefits of barefoot running, the public media, runners, sports community and footwear companies have shown increasing interest in barefoot running technology. Furthermore, inspired by the preventive effect of barefoot running, footwear companies have designed and manufactured a series of barefoot shoes or minimal shoes to imitate barefoot running, such as the Vibram Five-Fingers, New Balance Minimus and Nike Free. They were originally designed to make shod runners perceive the FFS running pattern, provide momentum towards the 'minimalist movement' (Lohman et al., 2011) and encourage reduced injuries. However, few longitudinal studies have been conducted to predict the outcome of long-term use of barefoot shoes.

Successive studies have questioned whether the FSP is the same between barefoot running and running with minimal shoes (Larson, 2014), and if the FSP is more important than the actual act of

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