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In-shoe multi-segment foot kinematics of children during the propulsive phase of walking and running

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ABSTRACT

Certain styles of children's shoes reduce 1st metatarsophalangeal joint (MTPJ) and midfoot motion during propulsion of walking. However, no studies have investigated if the splinting effect of shoes on children's 1st MTPJ and midfoot motion occurs during running. This study investigated the effect of sports shoes on multi-segment foot kinematics of children during propulsion of walking and running. Twenty children walked and ran at a self-selected velocity while barefoot and shod in a random order. Reflective markers were used to quantify sagittal plane motion of the 1st MTPJ and three-dimensional motion of the midfoot and ankle. Gait velocity increased during shod walking and running and was considered a covariate in the statistical analysis. Shoes reduced 1st MTPJ motion during propulsion of walking from 36.0° to 10.7° and during running from 31.5° to 12.6°. Midfoot sagittal plane motion during propulsion reduced from 22.5° to 6.2° during walking and from 27.4° to 9.6° during running. Sagittal plane ankle motion during propulsion increased during shod running from 26.7° to 34.1°. During propulsion of walking and running, children's sports shoes have a splinting effect on 1st MTPJ and

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midfoot motion which is partially compensated by an increase in ankle plantarflexion during running.

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1. Introduction

Conventional gait analysis assumes that the propulsive force is generated by plantarflexion of the ankle and is transferred to the ground via a rigid lever function of the foot. However, three dimensional multi-segment foot kinematic and kinetic research has shown that the foot is not rigid during propulsion and that the joints in the midfoot contribute to propulsion (Hunt, Smith, Torode, & Keenan, 2001; MacWilliams, Cowley, & Nicholson, 2003). During the propulsive phase of barefoot walking the midfoot plantarflexes 17–21°, which is comparable to the amount of ankle plantarflexion of 18–24° during propulsion (Dubbeldam et al., 2010; Stebbins, Harrington, Thompson, Zavatsky, & Theologis, 2006). The plantarflexion of the midfoot contributes 35–48% of the combined peak power of the foot and ankle during propulsion of walking and running (Bruening, Cooney, & Buczek, 2012; Dixon, Boehm, & Doederlein, 2012; MacWilliams et al., 2003; Smith & McConnell, 2007). Considering the magnitude of midfoot plantarflexion and the power that the midfoot contributes to propulsion, alterations to midfoot motion may have implications for the efficiency and/or effectiveness of the foot during gait.

Midfoot plantarflexion during propulsion is believed to occur in part due to the windlass mechanism of the plantar aponeurosis (Hicks, 1954). The windlass mechanism is dependent on dorsiflexion of the metatarsophalangeal joints (MTPJ) to increase plantar aponeurosis tension, which in turn increases midfoot plantarflexion and inverts the rearfoot. Hicks (1954) stated that plantarflexion of the metatarsals, primarily the 1st metatarsal, provided an additional 'flick and downwards thrust' at take-off over and above that of the ankle joint (Hicks, 1954). This observation has been confirmed by inverse dynamic calculations (Bruening et al., 2012; Dixon et al., 2012; MacWilliams et al., 2003; Smith & McConnell, 2007). In addition to the windlass mechanism, contraction of the plantar intrinsic foot muscles work as a group to support the midfoot during propulsion (Mann & Inman, 1964). Contraction of the tibialis posterior, flexor digitorum longus, flexor hallucis longus (Thordarson, Schmotzer, Chon, & Peters, 1995) and peroneus longus (Hunt, Smith, & Torode, 2001) have a synergist action in plantarflexing the joints of the midfoot. Caravaggi, Pataky, Günther, Savage, and Crompton (2010) hypothesized, based on indirect modeling, that the storage and release of elastic energy in the plantar aponeurosis alone could not result in the extent of midfoot plantarflexion during propulsion and that muscular contribution is required.

Shoes have been shown to reduce 1st MTPJ and midfoot motion of children during the propulsive phase of walking (Wegener et al., 2011; Wolf et al., 2008). Wolf et al. (2008) reported that children's shoes reduced 1st MTPJ motion, foot torsion, forefoot pronation and the change in length of the medial longitudinal arch of foot during propulsion, a measure mechanically linked to midfoot plantarflexion. Interestingly, the reduction of midfoot motion during propulsion is still present while wearing flexible shoes designed to complement children's barefoot function (Wolf et al., 2008). Compared to walking barefoot, leather lace up Oxford style shoes reduce children's midfoot plantarflexion from 20° to 11° and midfoot adduction from 10° to 4° during propulsion (Wegener et al., 2011). However, the findings from both of these studies are compromised by the placement of some markers on the shoe during shod walking. The reduction in 1st MTPJ and midfoot motion during propulsion does not extend to thong style flip-flops (Chard, Greene, Hunt, Vanwanseele, & Smith, 2013). Further confirmation of the restriction in midfoot plantarflexion during children's shod walking in other shoe styles is important as the midfoot produces 35–48% of the peak power produced at the foot and ankle region during propulsion of children's walking (Bruening et al., 2012; Dixon et al., 2012; MacWilliams et al., 2003). However, no studies have investigated whether the reduction in children's midfoot motion due to shoes while walking also occurs during running.

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