EFFECT OF THONG STYLE FLIP-FLOPS AND SUPPORTIVE SHOES ON CHILDRENS BAREFOOT SIDESTEP KINEMATICS

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Thongs and supportive shoes have been shown to alter children's barefoot motion. However, the effect of thongs on other types of activities such as sidestepping are unknown. The purpose of this study was to evaluate the effect thong style flip-flops and supportive shoes have on childrens knee and foot motion during a jogging sidestep task when compared to barefoot. Eleven healthy children with no foot deformity (aged 8 to 13 years) were recruited. Motion and force capture was used to record knee and multi-segment foot motion. Motion adaptations while thongs were worn were restricted to the hallux and while supportive shoes were worn, occurred with knee, midfoot and hallux motion. All footwear conditions increased ankle inversion magnitude. Thongs had less effect on children's barefoot sidestep motion than supportive shoes.

KEY WORDS: cutting, gait, biomechanics, footwear, multi-segment, foot-model.

INTRODUCTION: Jogging accompanied by directional change or sidestepping is typical of children's physical activity and play and has been linked with ankle injuries (Spinks, Macpherson, Bain, & McClure, 2006) which represent 18% of injuries incurred by children (Taylor & Attia, 2000) and is the second most frequently injured joint following the knee (Fong, Hong, Chan, Yung, & Chan, 2007). Many ankle injuries involved lateral ankle sprain during sport with the typical mechanism of injury involving extreme inversion and plantar flexion and usually both (Lundberg, Goldie, Kalin, & Selvik, 1989).

Barefoot activity is considered preferable for healthy children's foot function and development. (Walther, Herold, Sinderhauf, & Morrison, 2008) While footwear is regarded as necessary apparel for foot comfort and protection and has been shown to alter children's natural barefoot motion. (Wegener, Hunt, Vanwanseele, Burns, & Smith, 2011) The effect sidestepping has on children's barefoot and shod motion compared to jogging has been reported (Smith, Tong, O'Meara, Vanwanseele, & Hunt, 2013). Sidestepping exhibited increased hip abduction and restricted motion for the ankle, midfoot and first metatarsal phalangeal joint in the sagittal plane. Supportive shoes reduced midfoot sagittal plane range of motion and midfoot inversion during the stance phase.

Thong style flip-flops are the preferred footwear of Australian children and have been shown to alter children's barefoot jogging with increased ankle dorsiflexion and midfoot inversion during contact, increased midfoot plantarflexion during midstance and propulsion indicating a retention effect at the ankle and gripping effect of the midfoot and hallux. (Chard, Greene, Hunt, Vanwanseele, & Smith, 2013) However, overall findings suggest children's foot motion while walking and jogging in thongs is more replicable of barefoot motion than supportive shoes. Thongs may be preferable to other children's footwear types, since the ideal footwear for a child's developing feet is believed to be that which allows natural motion of the foot.

In this study we examine the effect of thongs on healthy children's knee and multi-segment foot kinematics during a sidestep task compared with supportive footwear utilising barefoot kinematics as baseline. We hypothesise that there will be fewer kinematic differences to barefoot when wearing thongs compared to supportive shoes.

METHODS: Study participants were 11 healthy children (7 girls and 4 boys) between 8 and 13 years of age (mean age 10.6±1.4SD years) recruited from the metropolitan area of Sydney Australia. The University of Sydney Human Ethics Committee granted ethics approval for this study and a parent of the participant gave written consent prior to participation.

Forefoot, rearfoot, shank and thigh segments were defined using 3 non-collinear reflective markers each (Chard et al., 2013) and is based on a previously described marker set with moderate to high inter session reliability (O'Meara, Smith R, Hunt, & Vanwanseele, 2007; Rattanaprasert, Smith, Sullivan, & Gilleard, 1999), where the ankle joint has three degrees of freedom and uses a detachable wand triad marker on the rearfoot.

Participants practiced the jogging sidestep along the 12 metre walkway at a self-selected pace while visually attending to a distant line bisecting the lab to maintain direction prior to reaching the force plate area and side stepping at approximately 45 degrees. Participants conducted five sidestep trials while barefoot, wearing thongs (Figure 1a) or supportive shoes (Figure 1b) with the footwear condition randomised between participants.

Figure 1. Example of a. simple non contoured unrestrictive thong and b. supportive shoe

Motion (Cortex Version 1.1, Motion Analysis Corporation, Santa Rosa, USA) and force (Model 9281B, Kistler, Winterthur, Switzerland) were captured at 200 Hz using a 14 camera motion analysis system. Residual error for the motion analysis system was <0.5mm across all testing sessions.

Sidestep resultant velocity was calculated and 3D relative angles calculated according to the method reported in Chard et al., (2013). The mean and 95% confidence intervals of five trials were calculated for each subject and the ensemble mean and 95% confidence intervals across participants were computed. Four events were used to define the three stance sub-phases: foot contact (heel contact to foot flat), mid-stance (foot flat to heel rise) and propulsion (heel rise to toe off). A three by five nested repeated measures analysis of variance was used (SPSS Version 22, IBM SPS Inc., USA) and Bonferroni adjustments were made for multiple comparisons with a threshold of $p<0.05$.

RESULTS: Results of resultant sidestep velocity and mean joint range of motion during stance are shown in Table 1. Time series for sidestep and previously reported barefoot jogging (Chard et al., 2013) appear in Figure 2a,b,c,e,f, together with, Figure 2d; an example of a single participant's, single trial, sidestep displacement path.

Mean differences of joint motion during the contact phase were an increase of 2º in peak knee adduction when supportive shoes were worn ($p=0.013$, 95% CI [0, 3]) and 8º less hallux dorsiflexion when supportive shoes were worn ($p=0.001$, 95% CI [4, 13]) and 10º greater hallux dorsiflexion when thongs were worn ($p=0.005$, 95% CI [3, 16]) compared to when supportive shoes were worn. During midstance the hallux was 7º less dorsiflexed when supportive shoes were worn ($p=0.022$, 95% CI [1, 14]) and while wearing thongs the hallux was 8º more dorsiflexed compared to when supportive shoes were worn ($p=0.033$, 95% CI [1, 16]). At toe-off the hallux was 5º less dorsiflexed when thongs were worn ($p=0.009$, 95% CI [1, 9]).

DISCUSSION: The purpose of this study was to examine the effects of wearing unsupportive thongs and supportive shoes on knee and foot kinematics while children performed a sidestepping task. Motion seen during the sidestepping task in the present study are similar to results previously reported (Smith et al., 2013) for knee frontal, ankle and midfoot motion.

For the present study reduced midfoot sagittal plane and frontal plane range of motion was seen during stance when supportive shoes were worn. (Table 1) This may be in part, due to constraints of the supportive shoe's upper (Wegener et al., 2015) and the contoured arch support included within the shoe. Reduced hallux range of motion when wearing the supportive shoe may also be due to constraints of the shoe upper. This restriction may have implications for reduced ground clearance theorised to be related to trips and falls (Barrett, Mills, & Begg, 2010) and mechanical fatigue of intrinsic foot muscles (Caravaggi, Leardini, & Crompton, 2010).

Table 1. Mean velocity and joint range of motion and in three planes for barefoot, thong and supportive shoe while sidestepping.

	Sidestep							
Variable	**Barefoot**		**Thong**			**Supportive Shoe**		
	Angle (°)	*SD*	*Angle (°)*	*SD*	***p<0.05***	*Angle (°)*	*SD*	***p<0.05***
Knee Sagittal	39	6	37	6	0.178	40	7	1.000
Knee Frontal	7	4	7	4	1.000	8	4	0.333
Knee Transverse	15	5	14	5	1.000	16	4	1.000
Ankle Sagittal	31	5	29	5	0.670	33	5	1.000
Ankle Frontal	11	4	10	4	0.586	11	4	1.000
Ankle Transverse	9	4	7	4	0.032	9	4	1.000
Midfoot Sagittal	29	5	26	5	0.237	16	5	0.000*
Midfoot Frontal	10	4	9	4	0.556	7	4	0.003*
Midfoot Transverse	2	5	2	6	1.000	4	6	0.974
Hallux Sagittal	24	5	19	6	0.048*	13	5	0.002*
Mean velocity (m/s)	2.4		2.4		0.997	2.5		0.538

*indicates significant difference of $p< 0.05$ compared to barefoot

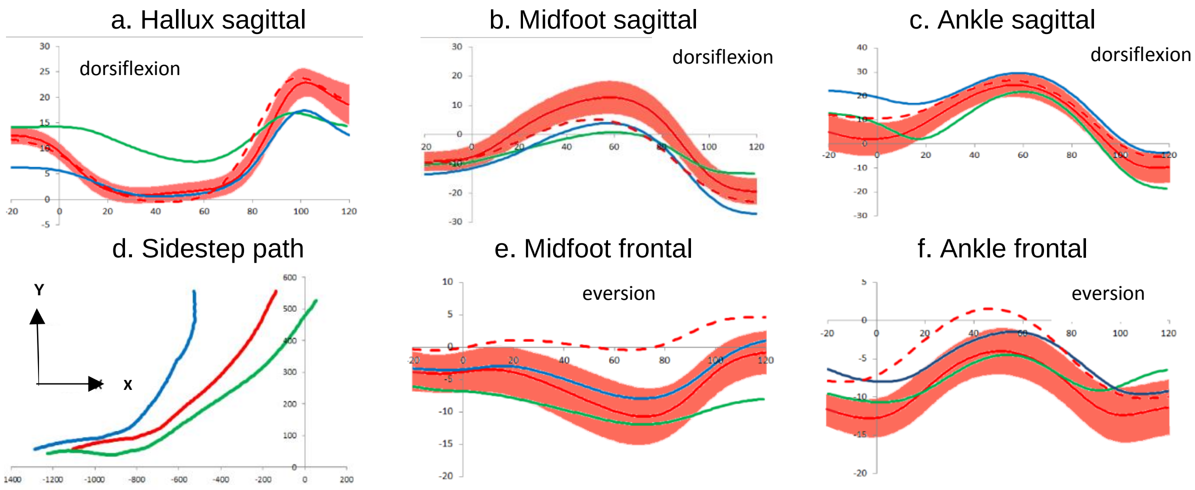

Figure 2. Mean joint angles for sidestep while barefoot (red) with 95% CI's (shaded red), wearing thongs (blue), supportive shoes (green) and barefoot jog (red dash). (d) Sidestep path of the sacral marker while barefoot (red), wearing thongs (blue) and supportive shoes (green).

Greater magnitudes of ankle inversion (Figure 2f), were seen during the sidestep task when barefoot, wearing thongs or supportive shoes compared to barefoot jogging. As children prepare for directional change, a shift in centre of mass away from the supporting leg in the lab orientated X direction to the Y direction occurs (Figure 2d Sidestep Path). This is achieved with increased hip abduction which has been shown to have a different frontal plane movement pattern during sidestepping compared with jogging. (Smith et al., 2013) Increased ankle inversion magnitudes are necessary to support body weight during this change in direction may place sidesteppers at greater risk of traction overuse of protective soft tissue everting structures necessary to resist inverting motion irrespective of footwear choice.

CONCLUSION: Footwear did not affect ankle foot motion significantly during the sidestep when compared to barefoot. Thongs had a minor effect of barefoot sidestep with reduced hallux range of motion adaptations seen over the stance phase and less hallux dorsiflexion evident at toe-off. Supportive shoes had a splinting effect (Wolf et al., 2008) with reduced midfoot sagittal, frontal and hallux ranges of motion. Sidestepping saw a large magnitude of ankle inversion across conditions when compared to barefoot jogging. Clinicians, coaches and trainers should place greater emphasis on conditioning ankles for the sidestepping action than focus on footwear.

REFERENCES:

Barrett, R. S., Mills, P. M., & Begg, R. K. (2010). A systematic review of the effect of ageing and falls history on minimum foot clearance characteristics during level walking. *Gait & Posture, 32*(4), 429-435. doi: http://dx.doi.org/10.1016/j.gaitpost.2010.07.010

Caravaggi, P., Leardini, A., & Crompton, R. (2010). Kinematic correlates of walking cadence in the foot. *Journal of Biomechanics, 43*(12), 2425-2433. doi: 10.1016/j.jbiomech.2010.04.015

Chard, A., Greene, A., Hunt, A., Vanwanseele, B., & Smith, R. (2013). Effect of thong style flip-flops on children's barefoot walking and jogging kinematics. *Journal of Foot and Ankle Research, 6*(1), 8.

Fong, D.-P., Hong, Y., Chan, L.-K., Yung, P.-H., & Chan, K.-M. (2007). A Systematic Review on Ankle Injury and Ankle Sprain in Sports. *Sports Medicine, 37*(1), 73-94. doi: 10.2165/00007256-200737010-00006

Lundberg, A., Goldie, I., Kalin, B., & Selvik, G. (1989). Kinematics of the ankle/foot complex: Plantarflexion and dorsiflexion. *Foot and Ankle, 9*(4), 194-200.

O'Meara, D., Smith R, Hunt, A., & Vanwanseele, B. (2007). *In Shoe Motion of the Child's Foot when Walking*. Paper presented at the 8th Footwear Biomechanics Symposium, Taipei, Taiwan.

Rattanaprasert, U., Smith, R., Sullivan, M., & Gilleard, W. (1999). Three-dimensional kinematics of the forefoot, rearfoot, and leg without the function of tibialis posterior in comparison with normals during stance phase of walking. *Clinical Biomechanics, 14*(1), 14-23.

Smith, R., Tong, S. Y., O’Meara, D., Vanwanseele, B., & Hunt, A. (2013, July 07 – July 11, 2013). *Effect of footwear on lower limb kinematics in children during sidestep.* Paper presented at the 31 International Conference on Biomechanics in Sports, Taipei, Taiwan, .

Spinks, A. B., Macpherson, A. K., Bain, C., & McClure, R. J. (2006). Injury risk from popular childhood physical activities: results from an Australian primary school cohort. *Injury Prevention, 12*(6), 390-394.

Taylor, B. L., & Attia, M. W. (2000). Sports-related injuries in children. *Academic Emergency Medicine, 7*(12), 1376-1382.

Walther, M., Herold, D., Sinderhauf, A., & Morrison, R. (2008). Children sport shoes. A systematic review of current literature. *Foot Ankle Surg, 14*, 180 - 189.

Wegener, C., Greene, A., Burns, J., Hunt, A. E., Vanwanseele, B., & Smith, R. M. (2015). In-shoe multi-segment foot kinematics of children during the propulsive phase of walking and running. *Human Movement Science, 39*, 200-211. doi: 10.1016/j.humov.2014.11.002

Wegener, C., Hunt, A., Vanwanseele, B., Burns, J., & Smith, R. (2011). Effect of children's shoes on gait: a systematic review and meta-analysis. *J Foot Ankle Res, 4*, 3.

Wolf, S., Simon, J., Patikas, D., Schuster, W., Armbrust, P., & Doederlein, L. (2008). Foot motion in children shoes: A comparison of barefoot walking with shod walking in conventional and flexible shoes. *Gait Posture, 27*, 51 - 59.

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