FOOT STRIKE POSTURE AND LOWER-LIMB DYNAMICS DURING SIDESTEPPING AMONG ELITE FEMALE ATHLETES: IMPLICATIONS FOR ACL INJURY RISK

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The purpose of this study was to compare the lower-limb dynamics between fore-foot (FF) and rear-foot (RF) strike patterns during unplanned sidestepping. Three-dimensional (3D) motion capture data were collected from 16 elite female hockey players. Ankle, knee, and hip: angle at initial foot contact (IC), range of motion (ROM), peak moment, and negative peak net joint power during weight acceptance phase were compared between athletes using natural RF and FF strike techniques. Results showed ankle and hip angle at IC, ankle ROM, peak ankle and knee extension moments, peak knee valgus moments, and ankle and knee negative peak net power between RF and FF strike patterns were significantly different ($\alpha < 0.05$). These findings show foot strike technique during unplanned sidestepping can effect athlete lower-limb dynamics, where RF strike athletes may be at higher risk of ACL injury.

KEY WORDS: rear-foot, fore-foot, knee loading

INTRODUCTION: Non-contact sidestepping is a common movement pattern among team sport athletes, where over one-half of non-contact ACL injuries occur (Cochrane *et al.*, 2007; Shimokochi and Shultz, 2008; Griffin *et al.*, 2006). Peak knee valgus moments in combination with extension moments have been shown to elevate ACL strain more than either loading pattern in isolation (Markolf *et al.*, 1995). Laboratory analysis of sidestepping have shown that peak valgus knee moments are significantly elevated when compared with straight line running and more than double than that performed during unplanned versus planned sidestepping scenarios (Besier *et al.*, 2001). Female athletes have a higher rate of ACL injuries relative to their male counterparts (Arendt *et al.*, 1999; Ireland, 1999) and interestingly, more experienced female athletes may be at greater risk of injury (Sigward and Powers, 2006).

There is large amount of research investigating the influence of technique and injury risk during dynamic sporting tasks. Simulation research has highlighted the importance of appropriate upper body dynamics towards peak knee valgus moments and ACL injury risk during unplanned sidestepping (Donnelly *et al.*, 2012). Foot placement close to the midline and an upright torso during cutting has been reported to reduce peak knee valgus moments (Jamison *et al.*, 2012; Dempsey *et al.*, 2009). A greater and rapid initial hip flexion, internal rotation, and larger initial knee valgus angle has also been shown to produce elevated peak knee valgus loading (McLean *et al.*, 2005; Kipp *et al.*, 2011). Finally, Kristianslund et al., (2012) in a study of cutting technique, reported that narrow cuts with low knee valgus angle and toe landing may decrease knee valgus moments. Though fore-foot landing a popular and common coaching technique recommendation that has been shown to redistribute lower limb loading during running (Stearne *et al.*, 2014), the influence of foot strike posture on an athlete's ACL injury risk during unplanned sidestepping has yet to be investigated. The purpose of this study was to compare differences in lower-limb dynamics and ACL injury risk variables among athletes who adopt a natural fore-foot and rear-foot strike technique during unplanned sidestepping.

METHODS: Sixteen elite female hockey players participated in this study (22.2±2.9 yrs, 1.69±0.08 m, 62.88±7.13 kg). A 12 camera Vicon MX system (Oxford Metrics, Oxford, UK) capturing at 250 Hz was synchronised with a 1.2 m x 1.2 m force plate (AMTI, Watertown, MA) recording at 2,000 Hz. Each participant performed a series of planned and unplanned straight line and change of direction running tasks as per a previously published sidestepping protocol (Besier *et al.*, 2001; Dempsey *et al.*, 2009; Donnelly *et al.*, 2012). Five successful unplanned side step cutting tasks were used for further analysis. Based on their natural foot strike patterns, participants were classified into; 1) habitual rear-foot (RF) or 2) habitual fore-foot (FF) strike groups. A RF strike sidestepping technique was characterised using the orientation of 3D ground reaction force trace as per figure 1A, whereas FF strike sidestepping technique was characterised as per figure 1B. Trials were removed from analysis where no clear RF or FF strike pattern could be identified resulting in 9 participants classified as RF and 7 in the FF groups. Kinematic and ground reaction force data were low pass filtered with a zero-lag fourth order Butterworth filter at 14 Hz with residual analysis conducted to determine the appropriate cut-off frequency. Hip, knee and ankle joint angles, moments, and net power were calculated during the weight acceptance (WA) phase of unplanned sidestepping in accordance with the phase definition approach to the greatest risk of ACL injury (Dempsey *et al.*, 2009). Joint moments and negative joint net power were normalised to body mass. Between group differences were evaluated using independent sample *t*-tests ($\alpha < 0.05$) accounting for unequal samples in SPSS statistical software (Chicago, IL, USA).

RESULTS AND DISCUSSION: A number of significant differences in lower-limb kinematics and kinetics were observed between habitual RF and habitual FF strike athletes (Table 1). *Joint Kinematics:* Unsurprisingly, the RF strike group were dorsi-flexed at IC (7.1±*8.5*°) compared with the plantar-flexed posture of the FF strike (-16.0±*6.5*°). At IC, on average the hip was also 10° more flexed in the RF group when compared with the FF-fall group (p=0.01). Ankle joint flexion ROM following initial foot contact for the FF strikers (35.6±*7.9*°) was 42% higher (p<0.001) than the RF strikers (20.5±*1.8*°).

Table 1: Summary RF v FF lower-limb variables during sidestepping (mean±SD)

Variable	Rear-Foot N=9	Fore-Foot N=7	t	*p*	95% CI diff
Joint angle at IC (°)					
- **Ankle**	**7.1±8.5**	**-16.0±6.5**	**5.94**	**<0.001**	**14.7 to 31.4**
- Knee	18.2±6.3	18.2±6.8	0.16	0.988	-7.0 to 7.1
- **Hip**	**58.7±6.8**	**48.8±6.3**	**2.98**	**0.010**	**2.8 to 17.1**
ROM at WA phase (°)					
- **Ankle**	**20.5±1.8**	**35.6±7.9**	**-5.58**	**<0.001**	**-20.9 to -9.3**
- Knee	37.5±6.1	33.3±4.8	1.48	0.160	-1.9 to 10.3
- Hip	10.7±4.8	7.2±3.1	1.65	0.121	-1.0 to 8.0
Peak extension moment (Nm/kg)					
- **Ankle**	**0.7±0.3**	**1.7±0.3**	**-6.66**	**<0.001**	**-1.3 to -0.7**
- **Knee**	**4.5±0.6**	**3.6±0.5**	**3.38**	**0.004**	**0.3 to 1.5**
- Hip	2.4±0.6	2.8±1.2	-0.84	0.411	-1.4 to 0.6
Peak knee valgus moment (Nm/kg)	**1.4±0.5**	**0.5±0.4**	**4.32**	**.001**	**0.5 to 1.4**
Negative net peak joint power (Watt/kg)					
- **Ankle**	**-5.8±1.8**	**-15.3±4.4**	**5.99**	**<0.001**	**6.1 to 12.9**
- **Knee**	**-68.8±18.5**	**-32.0±7.5**	**-4.9**	**<0.001**	**-52.8 to -20.7**
- Hip	-16.3±9.5	-13.8±13.7	-0.43	.673	-14.9 to 9.9

Joint Moments: Peak extension (plantar-flexion) ankle moments were significantly (143%) higher in the FF strikers compared with the RF group (0.7±*0.3* vs 1.7±*0.3 Nm/Kg respectively*; $p<0.001$). In contrast, RF strikers peak knee extension moments were 22% higher than the FF striking group (4.5±*0.6* vs 3.6±*0.5 Nm/kg respectively;* $p=0.004$). Similar to the finding reported by Kristianslund *et al.* (2012), peak knee valgus moments in the RF strike group (1.4±*0.5 Nm/kg*) were significantly elevated (64%) relative to the FF strikers (0.5±*0.4 Nm/kg*) ($p=0.001$), supporting previous recommendations of the adoption of a toe-landing technique as one strategy to facilitate lower peak knee valgus moments. *Joint Power:* FF strike negative net peak ankle joint power (absorption) was 62% higher than the RF group (-15.3±*4.4* vs -5.8±*1.8 Watt/kg respectively*; $p<0.001$). Conversely, negative net peak knee joint power was 53% greater among the RF group (-68.8±*18.5 Watt/kg*) when compared with the FF group (-32.0±*7.5 Watt/kg*) ($p<0.001$), a finding consistent with the results of similar studies examining foot strike kinematics and kinetics during straight-line running (Stearne *et al.*, 2014; Kulmala *et al.*, 2013).

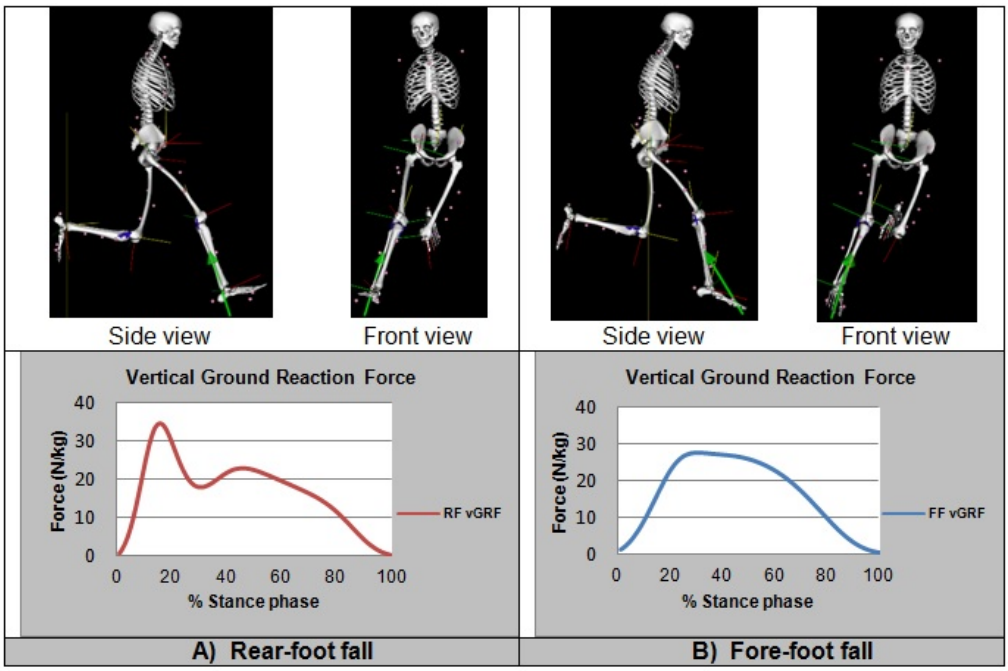

Figure 1: Foot-strike posture during unplanned sidestepping A) Rear-foot strike and B) fore-foot strike.

CONCLUSION: Foot strike posture during unplanned-sidestepping is an important consideration for an athlete's lower limb dynamics during unplanned sidestepping. Athletes with a habitual RF strike technique absorbed greater power through the knee joint, flexed more at the hip at IC which was accompanied by elevated peak valgus knee moments, measures contributing to an increased ACL injury risk in this group compared with athletes who adopt a FF strike posture.

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