JOINT LOADING WHILE PERFORMING A SIDE-STEP CUTTING MANOUEVRE ON ARTICIAL GRASS TURF WITH DIFFERENT INFILL DEPTHS

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The aim of this study was to determine differences in the joint loadings when performing side-step action on artificial grass turf with different infill depths. Significant changes in the ankle inversion angle ($\text{Ankle}_{\text{Angle\_Y}}$; p=0.01; ES=0.73), ankle inversion/eversion moment ($\text{Ankle}_{\text{Moment\_Y}}$; p=0.03; ES=0.54) and ankle abduction-adduction moment ($\text{Ankle}_{\text{Moment\_Z}}$; p=0.01; ES=0.76) at $\text{GRF}_{\text{zPeak}}$ suggests greater loadings, in particular, at the ankle joint when performing the side-step manoeuvres on artificial grass turfs with thicker infill depths; indicating that all of the lower extremity adaptations to execute the step-side occurs at the ankle rather than the knee. A change in infill depths will cause the body posture to adopt a change in technique when executing the side-step manoeuvre. It is possible that greater joint moments elicited could be of risk to the athletes.

KEY WORDS: joint loading, side-step, artificial grass turf, biomechanics

INTRODUCTION: Studies on side-step cutting action on hard court-like surfaces using non-turf shoes and how it elicits stresses on the knee joint have been well-documented. When overstressed, the ligaments responsible for knee joint stabilization were speculated to exceed normal levels due to excessive internal rotation and varus-valgus moments elicited in conjunction with anterior tibial force. This was thought to cause injury. Surface-to-shoe traction has been correlated with increased incidence of injury as higher traction places a greater stresses in the secondary planes of movement on lower extremity ligaments (Orchard and Powell, 2003; Powel and Schootman, 1992;). Torsional injuries also have been linked to side-step cutting action on astro turfs made of rubber-like materials (Villwork et al., 2009; Smeets, 2012) possibly due to increased surface-to-shoe traction (Schoukens, 2009). Recently, improvements in turf characteristics such as moisture, hardness, grass cover, root density, naps in the turf, type, distribution, compaction and depths of sand and rubber granules infills (Simon, 2010) have contributed to the resurgence of artificial grass turf. Surface type and shoe-surface interactions when performing the side-step on artificial grass turfs are likely to be different. With infill depth being a major factor in determining surface hardness (Simon, 2010), it may be that the thicker the infill depths, the greater the cushioning effect; thereby, possibly reducing joint loading as increases in infill depth have been associated with reductions in surface hardness due to this effect (Brosnan et al., 2009). The objective of this study, therefore, was to determine differences in the ankle and knee positions and loading when performing the side-step cutting manoeuvres on a new generation artificial grass turf with different infills depths. We realize that joint moments do not directly measure joint loading and so these parameters are used as surrogate measures. We hypothesized that the peak ankle and knee varus-valgus and internal-external angles and moments would be affected by changes in infill depths. Such results could provide insight into surface type and shoe-surface interactions, and the possible etiology of an injury.

METHODS: Seventeen trained male inter-college soccer players (18 ± 0.7 yrs; 69.4 ± 5.9 kg; 1.70 ± 0.01 m) with no history of low back or lower-limb musculoskeletal injury participated in this study. Limb dominance was established by kicking a ball with their preferred limb. Ethical clearances were sought from the institution's ethics committee. All participants provided informed consent to participate. Data were collected in the Sports Biomechanics Laboratory. An artificial grass turf runway (14m x 1.2m), filled with sand and rubber granules infills (ratio 50:50), was secured on the walking board laid across the lab using double-sided Velcro tape. The boards were fastened together using in-build board clips and anti-slip mats. A force-plate (Kistler Instrument Corporation, Amherst, NY, USA) was positioned near the end of the runway flushed with the boards lying beneath the turf. The force plate amplifier was reset to zero once the turf is placed on top of it. The distance between the start point and the center of the force-plate was 7 meters. Time to distance was recorded using a stop watch. White paint was sprayed on the artificial grass to highlight force-plate position. Force-plate sampling frequency was set at 1000 Hz. Ten high-speed optical cameras (Motion Analysis Corporation System, Santa Rosa, CA, USA) were used to capture all side-step cutting actions. All cameras were mounted on overhead railings and strategically positioned to ensure a convergence of field of view between at least two cameras and provided a 360 degrees area of foci on the force platform representing a three-dimensional (3D) volume sufficient to capture the entire cutting manoeuvre. Motion capture system sampling frequency was set at 250 Hz. Calibration of 3D space was conducted at the beginning of data collection day. All cameras were synchronized with the force-plate. Passive reflective ball markers were placed on iliac crest, greater trochanter of femur, lateral and medial epicondyle of femur, lateral and medial malleolus as well as on 1st and 5th metatarsal to determine local coordinate systems for pelvis, thigh, shank and foot segments. Participant's mass and height (measured using SECA), briefing on test protocol and familiarization session were conducted on testing day prior to data collection. All participants wore the same FIFA approved artificial turf shoes and performed 10 side-step trials for Condition A (infill depth of 2 cm) and for Condition B (infill depth of 4 cm). The order of these conditions blinded and was randomized. Instruction were to run as fast as possible, plant dominant foot onto the force plate and change direction at a 45° angle. The best 3 trials with consistent average speeds were selected for final analysis. Kinematic and kinetic data captured were processed using Visual 3D software (C-motion, MD, USA). All trajectory data as well as force-plate data were filtered using a Butterworth low-pass digital filter at a cut-off frequency of 7 Hz and interpolated with a maximum gap fill of thirty frames using a 3rd polynomial established within the Visual 3D software. Joint angles were calculated using a joint coordinate system protocol and joint moments were derived using a Newton-Euler inverse dynamics procedure (Robertson et al., 2014). Joint angles measured were $\text{Ankle}_{\text{Angle\_X}}$ (dorsi/plantar flexion), $\text{Ankle}_{\text{Angle\_Y}}$ (inversion/eversion) and $\text{Ankle}_{\text{Angle\_Z}}$ (abduction/adduction), $\text{Knee}_{\text{Angle\_X}}$ (flexion/extension), $\text{Knee}_{\text{Angle\_Y}}$ (abduction/adduction) and $\text{Knee}_{\text{Angle\_Z}}$ (Internal/external rotation) at $\text{GRF}_{\text{Zpeak}}$. Joint moments measured were $\text{Ankle}_{\text{Moment\_X}}$ (dorsi/plantar flexion), $\text{Ankle}_{\text{Moment\_Y}}$ (inversion/eversion) and $\text{Ankle}_{\text{Moment\_Z}}$ (abduction/adduction), $\text{Knee}_{\text{Moment\_X}}$ (flexion/extension), $\text{Knee}_{\text{Moment\_Y}}$ (abduction/adduction) and $\text{knee}_{\text{Moment\_Z}}$ (internal/external rotation) at $\text{GRF}_{\text{ZPeak}}$. Variables measured at $\text{GRF}_{\text{zPeak}}$ were used because it represented the greatest instant of impact loading. Data were analyzed from the instant of foot contact until instant at toe-off (Besier et al., 2001a). Paired *t*-tests ($P<0.05$) were used to determine statistical differences in measured variables between conditions. Cohen's *d* was calculated to determine effect size of each variable between conditions. A Cohen's *d* of ≤0.4, 0.5–0.7, and ≥0.8 indicated a small, moderate, and large effect size, respectively.

RESULTS: Statistical analysis revealed significant differences in the ankle inversion angle ($p = 0.01$; ES = 0.73) between conditions at $\text{GRF}_{\text{zPeak}}$; with the larger angle occurring in Condition A, but not in the ankle plantar flexion and axial rotation angles at $\text{GRF}_{\text{zPeak}}$ ($p > 0.05$). Although not significant, differences were also reported for knee joint angles ($p > 0.05$; ES < 0.20) at $\text{GRF}_{\text{zPeak}}$. However, knee joint angles were larger when participants performed side-step on turf with lesser infill depths (condition A). Statistical analysis further revealed significant difference in ankle inversion/eversion ($\text{Ankle}_{\text{Moment\_Y}}$; $p=0.03$; ES = 0.54) and abduction-adduction moments ($\text{Ankle}_{\text{Moment\_Z}}$; $p=0.01$; ES = 0.76) at $\text{GRFz}_{\text{Peak}}$; with the mean value greater in Condition B (i.e. with greater infill depth). Although not significant ($p>0.05$; ES < 0.20), the mean value for the plantar/dorsiflexion moment ($\text{Ankle}_{\text{Moment\_X}}$) was also larger on the turf with greater infill depth. Similarly, although not significant, the flexion-extension and abduction/adduction knee moment components at $\text{GRFz}_{\text{Peak}}$ were both larger whereas the internal/external rotation moment was smaller for condition B (Table 1).

Table 1 Summary of peak joint angles and moments at GRF$_{\text{ZPeak}}$ between conditions

		Condition A (2cm)	Condition B (4cm)	P value	ES (Cohen's *d*)
Angles at GRF$_{\text{ZPeak}}$ (Θ)	**Knee$_{\text{Angle\_Y}}$** (abduction-adduction)	10.0 ± 5.0	9.9 ± 4.5	0.46	0.01
	Knee$_{\text{Angle\_X}}$ (flexion-extension)	36.3 ± 6.7	34.3 ± 7.7	0.18	0.20
	Knee$_{\text{Angle\_Z}}$ (internal-external)	10.1 ± 5.6	9.7 ± 5.3	0.33	0.07
	Ankle$_{\text{Angle\_Y}}$ (inversion-eversion)	20.0 ± 6.2	16.1 ± 4.4	0.01*	0.73
	Ankle$_{\text{Angle\_X}}$ (dorsi-plantarflexion)	22.4 ± 6.3	22.7± 4.6	0.41	0.05
	Ankle$_{\text{Angle\_Z}}$ (abduction-adduction)	12.7 ± 5.2	12.1 ± 4.7	0.21	0.10
Moments at GRF$_{\text{Zpeak}}$ (NM)	**Knee$_{\text{Moment\_Y}}$** (abduction-adduction)	105.6 ± 55.6	108.2 ± 61.1	0.30	0.07
	Knee$_{\text{Moment\_X}}$ (flexion-extension)	76.8 ± 46.5	84.1 ± 48.8	0.20	0.15
	Knee$_{\text{Moment\_Z}}$ (internal/external)	74.1 ± 31.5	69.6 ± 23.6	0.10	0.16
	Ankle$_{\text{Moment\_Y}}$ (inversion-eversion)	54.3 ± 24.7	73.7 ± 44.4	0.03*	0.54
	Ankle$_{\text{Moment\_X}}$ (dorsi-plantarflexion)	83.0 ± 26.8	89.4 ± 42.9	0.22	0.17
	Ankle$_{\text{Moment\_Z}}$ (abduction-adduction)	5.0 ± 4.1	10.5 ± 9.3	0.01*	0.76

DISCUSSION: It was hypothesized that performing the side-step on 4cm infill depths would elicit significantly greater ankle (eversion, dorsiflexion and axial rotation) and knee (i.e. varus-valgus; flexion-extension, and rotational) joint moments than on 2cm infill depths. However, for the most part, only part of these hypotheses was supported. Between conditions, there were no significant differences in knee joint moments (Table 1). Nevertheless, the knee joint moments at GRF$_{\text{zPeak}}$ elicited in condition B were larger when compared to condition A. Ankle joint moments, however, were significant only for y- and z-axes, but not z-axis (Table 1). This clearly suggests that there were greater loadings, in particular for the ankle joint, when performing the side-step manoeuvres in condition B. One possible explanation for this may be due to greater leg-stiffness. Given the larger knee and significantly larger ankle joint moments, it may be that the leg may have become stiffer when performing the side-step cutting action on artificial grass turfs with greater infill depth (condition B), thus, ensuring consistent execution of side-step action despite on different infill depth. Indeed, studies have reported that this adaptation is the desire to maintain the same combined leg-surface stiffness as surface stiffness increases and has also been observed for single steps and hopping (Farley, et al.,1998; Ferris et al., 1998).

It should be highlighted that the ankle joints were indeed stiffer in condition B as indicated by a significantly lower inversion-eversion ankle angle during the GRF$_{\text{ZPeak}}$ and GRF$_{\text{ZPeak}}$ occurred almost at the same time as GRF$_{\text{YPeak}}$ (Sujae et al., 2015). Kinematic adaptations could have occurred at the ankle (similar to what was reported by Farley et al. (1998) and this may explain why ankle joint moments were significantly larger when performing the side step action on artificial grass with greater infill depth (Table 1). The magnitudes of ankle inversion-eversion moments and abduction-adduction moments were significantly larger when performing the side-step manoeuvres in condition B (Table 1). The increase in breaking and traction forces, in addition to a larger ankle joint angle, could have contributed to the overall significant increase in inversion-eversion moments experienced at the ankle joint (p = 0.03). This indicated that the lower extremity adaptations to execute the step-side manoeuvre is highly associated with the ankle rather than the knee. Although insignificant, smaller knee angles reported for condition B (Table 1) further suggests a change in technique when performing the side-step. Similar findings were reported by Dempsey et al. (2007). Although different techniques and not infill depths were investigated, this increase in magnitude may be due to a change in body posture. A change in knee and ankle joint angles may also suggest an altered body posture i.e., adopting a change in technique when planting their foot onto the turf whilst performing the side-step manoeuvre in condition B.

CONCLUSION: Significant changes in the ankle inversion angle, ankle inversion/eversion and abduction-adduction moments between conditions at GRF_{zPeak}; suggests greater loadings, in particular for the ankle joint. This indicated that the lower extremity adaptations to execute the step-side is associated with the ankle rather than the knee; hinting that the body posture adopted a change in technique when performing the side-step manoeuvre on different infill depths. It is possible that the greater joint moments elicited in condition B could be of risk to the athletes.

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