

KNEE JOINT LOADINGS OF ATHLETES PERFORMING THE SIDE-STEP CUTTING MANOEUVRES UNDER TWO DIFFERENT CONDITIONS

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The purpose of this study was to determine differences in knee joint loading of athletes performing the side-step cutting manoeuvres under two different conditions (fatigued vs. non-fatigued). Lower limb joint kinematics and kinetics of 12 inter-varsity soccer players (6 males and 6 females) performing side-step tasks in two conditions were quantified using 10 optical cameras and Kistler™ force-platform. Fatigue conditions elicited significantly higher sagittal knee joint loadings (M_{ext} , $F_{Peak_GRF_Z}$, $F_{Peak_AP_GRF}$ and $\theta^{\circ}_{GRF_Z_IC}$) than non-fatigued suggesting that athletes when fatigued adopted different strategies to compensate the changes to their environment.

Keywords: Neuromuscular fatigue; Side-step manoeuvres, Joint moments

INTRODUCTION: Performing evasive manoeuvres (side-step cutting action) to fake the direction opposite to the intended movement to evade opponents places excessive loading on the knee joint resulting in ruptured anterior cruciate ligaments (Woo, et al., 1991; McLean et al., 1999). As fatigue affects both the peripheral and central processing systems (Chaudhuri & Behan, 2004), the ability to initiate the appropriate sequence of actions may be hampered by situational stress such as a high level of neuromuscular fatigue (Thomson et al., 2009). Central fatigue critically contributes to the degradation of the neuromuscular control of athletes (Mclean & Samorezov, 2009) by affecting their concentration (Chaudhuri & Behan, 2004). Studies on shoulder joint reported that fatigue affects the perceptual-cognitive skills of an athlete due to overloading of the central control mechanism and its degrading effect on proprioception (Myers et al., 1999). It was also reported that fatigue may also inhibit the ability to dynamically stabilize the knee joint effectively when performing the side-stepping task (Hiemstra et al., 2001), thereby increasing knee joint loading (Boden et al., 2000; Besier et al., 2001a). Insufficient activation of appropriate muscles to counter this increase may escalate the risk of sustaining ACL injuries (Borotikar et al., 2008; Brown et al., 2009). While the influence of fatigue on injury and performance has been the focus of many studies in the literature, only two (Borotikar et al., 2008; Mclean & Samorezov, 2009) have investigated the effects of fatigue on decision-making in relation to injury risk and performance of female athletes. The objective of this study was to quantify differences in knee joint loading of athletes performing the side-step cutting manoeuvres under two different conditions. It was hypothesized that fatigue increases knee joint moments as well as other related biomechanical parameters (e.g. vertical ground reaction force and knee extension at initial contact)

METHODS: Ethics were obtained from Nanyang Technological University and School of Sports Health and Leisure in-house ethics review committees. Twelve healthy inter-varsity soccer players participated in this study. A Kistler™ force platform positioned at the 12th meter mark along a 14m x 1.2m artificial turf walkway filled with sand/rubber infill to a depth of 4cm (sand/rubber – 50%/50%) was synchronized with 10 Eagle-4 optical cameras. Sampling frequency of force platform and optical cameras were 1000Hz and 250Hz respectively. Four sets of light gates (Smart Speed™), adjusted to the height of 1.0m from the laboratory floor, were positioned along the walkway (Figure 1). Heart rate was measured using a wireless heart rate monitor (Polar®, FT4).

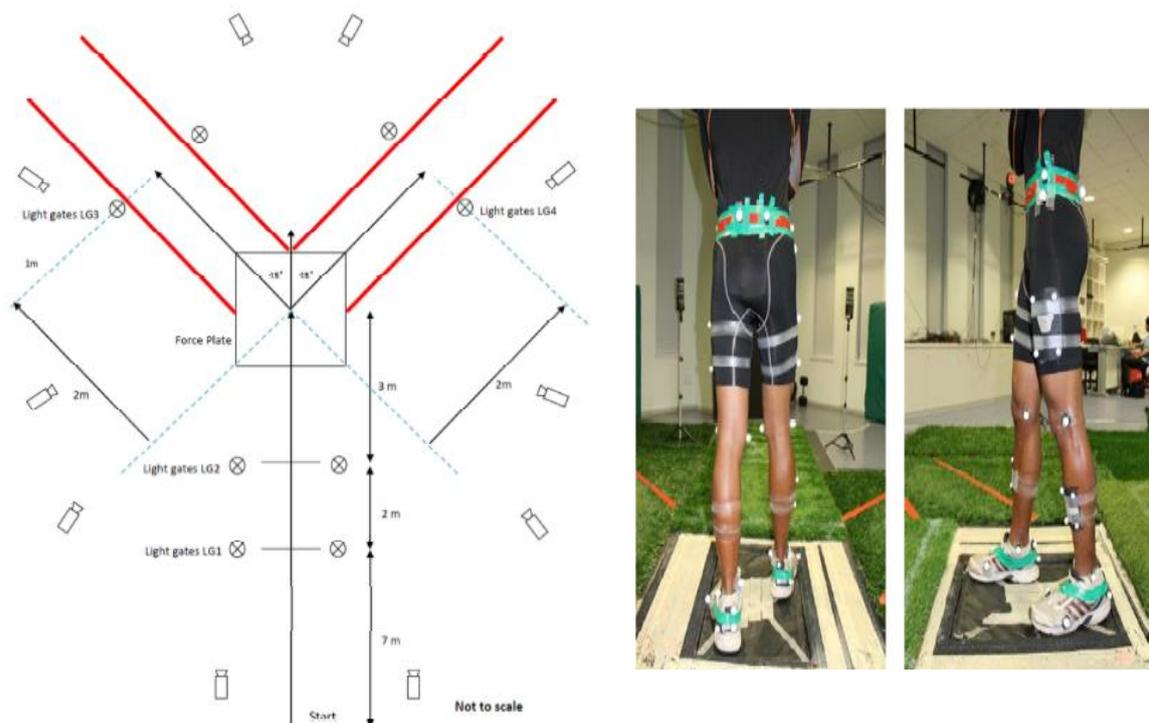


Figure 1 Equipment and Laboratory Set-up (left) and placement of markers (right)

Non-collinear cluster tracking markers were placed on thigh, shank and heels of shoe. Additional tracking markers were placed on iliac crest and posterior superior iliac spine. Static markers, placed on the bilateral greater trochanters, femoral epicondyles, malleoli, and the first and fifth metatarsal of each foot (Figure 1), were removed prior to the tracking trials. Familiarisation sessions were conducted three days prior to actual data collection which consisted of a pre-fatigue (F_{Pre}) test and a post-fatigue test (F_{Post}). A fatiguing protocol (Yo-Yo intermittent recovery Level 1) was administered between tests as intervention. For both tests, subjects ran at 4.5m/s to 5.5m/s, plant their dominant leg on the platform and performed the side-stepping task at an angle of 45°. Subjects performed 20 randomized trials in total. Heart rate was recorded immediately (within 1 minute) after the end of the fatigue protocol. Between fatigue trials, subjects ran on the treadmill (HP cosmos Gaitway) at 10km/h for two minutes. Both kinematic and kinetic data were post-processed using the Visual3D™ software. A fourth-order, zero-lag, 12 Hz low pass Butterworth filter was used to filter marker and force-plate data. Knee angles in sagittal plane were calculated using Cardan x-y-z rotation sequence. Knee joint moments were calculated using a Newton-Euler inverse dynamics procedure. All moments and forces were normalized with respect to participants' mass and height. For each trial, the weight acceptance (WA) phase, peak-push-off (PPO) phase and the initial contact (IC) point were identified from the vertical ground reaction force (GRF) of the stance foot. All peak moments, forces and decelerations were identified within these two phases. The WA phase was defined from IC to the first minima of the resultant GRF and PPO phase was defined from 10% from either side of the maximum resultant GRF. IC and TO points were defined as the points when the vertical GRF force exceeded 10% and dropped below 10% of the participants' body weight respectively. The independent variables were fatigue (F) and non-fatigue (NF) conditions. The dependent variables were heart rate (HR), peak internal knee moments in the three planes: sagittal (M_{ext}), frontal (M_{valgus} , M_{varus}) and transverse ($M_{internal}$, $M_{external}$), knee flexion/extension angle at IC ($\theta_{GRF_Z_IC}$), stance foot peak vertical GRF ($F_{Peak_GRF_Z}$), stance foot vertical GRF at IC ($F_{GRF_Z_IC}$), stance foot peak anterior/posterior (AP) GRF ($F_{Peak_AP_GRF}$), and stance knee peak proximal tibia AP shear

force ($F_{Peak_AP_Tibia}$). One-way ANOVA was used to determine difference between the two conditions using the SPSS software. All data were analysed at the level of $\alpha = 0.05$ with *Sidak* correction.

RESULTS: Peak extension moments of the knee ($F(1, 50) = 4.583, p = 0.038, \eta_p^2 = 0.083$), the peak vertical GRF force ($F(1, 50) = 5.783, p = 0.020, \eta_p^2 = 0.104$), the peak AP GRF force ($F(1, 50) = 4.970, p = 0.030, \eta_p^2 = 0.090$) and the knee extension angle at IC ($F(1, 50) = 15.692, p < 0.001, \eta_p^2 = 0.239$) were significantly larger when fatigued then non-fatigued (Table 1). A summary of selected variables between conditions are highlighted in Table 1.

Table 1 Summary of differences of selected variables between conditions

	Conditions		<i>p</i> -value
	Non-fatigued	Fatigued	
M_{ext}	1.56 ± 0.4	1.67 ± 0.3	0.038*
M_{valgus}	0.24 ± 0.1	0.34 ± 0.1	0.065
M_{varus}	0.43 ± 0.1	0.48 ± 0.1	0.169
$M_{internal}$	0.25 ± 0.0	0.31 ± 0.1	0.289
$M_{external}$	0.23 ± 0.1	0.16 ± 0.0	0.009*
$F_{Peak_GRF_Z}$	2.13 ± 0.5	2.28 ± 0.5	0.020*
$F_{Peak_AP_GRF}$	0.74 ± 0.2	0.82 ± 0.2	0.030*
$F_{Peak_AP_Tibia}$	1.11 ± 0.3	1.12 ± 0.2	0.872
$F_{GRF_Z_IC}$	1.27 ± 0.2	1.23 ± 0.2	0.243
$\theta^{\circ}_{GRF_Z_IC}$	148.62 ± 11.7	151.91 ± 9.3	0.000*

NOTE: * $p < 0.05$. Moments ($Nm \cdot kg^{-1} \cdot m^{-1}$), forces ($N \cdot kg^{-1}$), $\theta^{\circ}_{GRF_Z_IC}$ is in degrees.

DISCUSSION: The objective of this study was to determine differences in knee joint loadings of athletes performing the side-step cutting manoeuvres under two different conditions. It was hypothesized that fatigue increases knee joint moments and other related biomechanical parameters (e.g. vertical ground reaction force and knee extension at initial contact). Significant increase in the $F_{Peak_GRF_Z}$, $F_{Peak_AP_GRF}$ and M_{ext} when fatigued suggest that the presence of neuromuscular fatigue could have reduced the sensitivity of the muscle spindles within the skeletal muscles groups that needs to be pre-activated prior to the side-step manoeuvre. This may have caused a loss in efficiency and a possible delay in the activation of the medial and lateral hamstrings and the gastrocnemius muscles (Lephart et al., 2002; Gehring et al., 2009). Co-activation of these muscles is required to counter-balance the external knee flexion moment and to dynamically stabilize the knee joint. Significant increases in sagittal plane parameters (M_{ext} , $F_{Peak_GRF_Z}$, $F_{Peak_AP_GRF}$ and $\theta^{\circ}_{GRF_Z_IC}$) due to neuromuscular fatigue suggest that in general, fatigue could increase the overall non-contact ACL injury risk (Yu & Garrett, 2007). Indeed, there is empirical evidence to suggest that, independently, both neuromuscular fatigue and perceptual-cognitive skills, do contribute to the increase in the ACL injury risk, especially during a fast-paced task such as a cutting manoeuvre (Besier et al., 2001b; Borotikar et al., 2008). However, some investigators have predicted that the sagittal plane biomechanics *per sé* does not contribute to such risk (McLean et al., 2004). The current study's results did not provide sufficient evidence to indicate that frontal and transverse plane biomechanics could also be affected by neuromuscular fatigue. This is in contrast to the major findings of Sanna and O'Connor (2008), who reported that most fatigue effects were observed in the transverse plane. These differences could be attributed to the differences in the tasks employed between the two studies.

CONCLUSION: The complexities involved in a realistic sporting/games conditions (fatigued vs. non-fatigued) introduces challenges in addressing the potential injury risk involved to athletes when performing the side-step cutting manoeuvres. The experimental conditions were modelled to simulate the effects of team sports related fatigue and cognitive stress. Significant increase in the $F_{Peak_GRF_Z}$, $F_{Peak_AP_GRF}$ and M_{ext} suggest that athletes when fatigued may adopt different strategies to compensate for the changes to the conditions. Future studies investigating differences between conditions should include specific protocols to identify and quantify lower limb anatomical as well as muscular strength differences between conditions.

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