SAGITTAL HIP – KNEE COORDINATION DURING A 45 DEGREE CUTTING TASK

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Concurrent extension at the hip and flexion at the knee has been suggested as a high risk coordination pattern for the anterior cruciate ligament (ACL). Nine elite female athletes performed ten 45° cutting tasks before and after a multidirectional fatiguing protocol. Force and kinematic data were captured. Vector coding was used to calculate sagittal hip – knee coordination for the first 40 ms of foot contact of the dominant limb and percentage time spent in each coordination pattern was extracted. Hip extension – knee flexion was the dominant coordination pattern pre- and post-fatigue (p<0.05) but the time spent in this coordination pattern did not change as a result of fatigue. The hypothesised high risk hip extension – knee flexion was the dominant coordination pattern during the 45° cutting task.

KEYWORDS: ACL, vector coding, change of direction, fatigue

INTRODUCTION: For many non-contact sports injuries, the exact mechanisms of injury are not well understood and anterior cruciate ligament (ACL) injury represents a classic example of this. Video analyses of injury events, cadaver specimen loading and computer simulation modelling have all been used to progress understanding of non-contact ACL injury (Yu and Garrett, 2007) and contrasting theories of injury mechanism have emerged from their findings. Yet, these methods have not been able to identify a set of physiologically realistic conditions under which the injury would consistently occur and thus researchers are still uncertain as to the true mechanism/s of injury. Hashemi et al. (2011) critiqued a number of mechanistic theories for their lack of alignment with other pieces of evidence in ACL research. In the same paper a new theory of injury mechanism, named the 'hip extension knee flexion paradox', was put forward that attempted to integrate and align itself with the most convincing findings in ACL research. This theory of mechanism stated that non-contact ACL injury would occur when the following four criteria are simultaneously met: 1) the tibial plateau has a posterior slope 2) the knee is near full extension upon application of a dynamic ground reaction force 3) activation of musculature about the knee is delayed and 4) hip extension and knee flexion occur concurrently. Whilst there have been publications surrounding the first, second and third conditions, there is a sparsity of research detailing common movement coordination strategies with reference to the fourth condition, i.e. the presence of concurrent hip extension and knee flexion. In their paper, Hashemi et al. (2011) also suggest that fatigue may play an important role in increasing the risk of non-contact ACL injury by delaying activation of musculature about the knee joint (Nyland et al., 1997). The effect of fatigue on hip-knee coordination has, however, not previously been investigated. Thus, the purpose of this study was to explore the application of vector coding to quantify hip – knee coordination in the sagittal plane during a movement commonly associated with ACL injury, namely, cutting.

METHODS: Nine female team sports players (23 ± 5 yrs, 1.71 ± 0.04 m, 64.9 ± 5.7 kg, n=6 netball, n=2 hockey, n=1 football) with experience at international or national level and no history of ACL injury were recruited. All participants were training without restriction due to injury and written consent was obtained at the time of testing.
A 12 camera (Oqus 400) infra-red Qualysis system collecting at 200 Hz via QTM (Qualysis AB, Göteburg, Sweden) was set up and calibrated for the collection of motion analysis data. One video camera (Oqus 210c) and a single force plate (Kistler 9287C, Winterthur, Switzerland) were integrated with QTM to capture movements from a frontal perspective (24Hz) and record force data (2000 Hz) respectively. A lower-limb and trunk marker set (Vanrenterghem et al., 2010) was applied before participants completed a ten minute treadmill

warm up followed by their own stretching. Participants were then familiarised with the BORG 15 grade rating of perceived exertion (RPE) scale (Borg, 1982) and wore a heart rate monitor (Polar HR monitor, Kempele, Finland) throughout testing.

A repeated measures design was employed to assess cutting under pre and post fatigue conditions. In each condition, ten successful cuts were captured for each leg in a randomised order. The cutting task involved a three step approach at maximal intensity followed by a 45° change of direction and participants received an instruction prior to each cutting trial indicating in which direction they should cut. A successful cut trial required: no obvious spotting of the force plate, that the change of direction step remained within the boundaries of the force plate and that the participant remained within the designated cutting path for at least two steps after the change of direction step. The requirements were explained in a standardised fashion and participants were familiarised with the task before data collection commenced.

The fatiguing protocol was designed to provide a multidirectional team sports stimulus and comprised six cycles. Each cycle consisted of drop maximal vertical jumps from a 30.5 cm height and a multi-directional short sprint exercise. The total load of each fatigue cycle was: 5 drop vertical jumps, 30 m short sprints, 30 m sideways/backwards travel and 20 rapid changes of direction. RPE and heart rate data were collected immediately after the final fatigue cycle.

Data processing: Data for the participant's dominant leg (as defined by the leg they would chose to kick a football the furthest distance) were analysed for the change of direction step. Markers were tracked and labelled in QTM (Qualysis AB, Göteburg, Sweden) and data were exported to Visual 3D Professional Version 5.00.21 (C-Motion, Germantown, USA). Marker targets were filtered with a 20 Hz cut off, low pass, second order, double pass Butterworth filter. Forces were filtered with a cut off of 200 Hz. These data were exported into MATLAB (R2014b, The Mathworks, USA) where a custom script performed the remaining data analysis. Foot contact frames were determined using a 10 N threshold for vertical force data. Hip and knee sagittal joint angles were extracted between the point of foot contact to 40 ms. This time period was selected as it is the window in which ACL injury is believed to occur (Koga et al., 2010). Vector coding was conducted to calculate hip flexion/extension – knee flexion/extension coordination vector coding coupling angle (Van Emmerik et al., 2014). The vector coding coupling angle covers a 360° range and every 90° subdivision represents a different coordinative pattern. Thus, vector coding coupling angles can be separated or 'binned' into four subdivisions: 1) hip flexion – knee flexion, 2) hip extension – knee flexion, 3) hip extension – knee extension, 4) hip extension knee flexion. The average time that each participant spent in each coordination pattern was calculated and the median coordination pattern was determined for each participant for each 5 ms time window. Wilcoxon tests were executed in SPSS (IBM SPSS Version 22, Armonk, NY) to determine the effect of fatigue on the percentage time spent in hip extension – knee flexion and hip extension – knee extension.

RESULTS: The mean average heart rate and RPE following the fatigue protocol were 176 ± 9 bpm and 16 ± 2 respectively, with 16 indicating an RPE between 'hard' and 'very hard'. This is compared to a heart rate of 87 ± 9 bpm and RPE of 7 ± 1 prior to the fatigue protocol. The mean velocity of the centre of mass prior to foot contact was not significantly different from pre- to post-fatigue (Pre: 4.07 ± 0.40, Post: 4.05 ± 0.39 m/s).

The average modal coordination pattern of the group, both pre- and post-fatigue, was to extend the hip and knee for the first 10 ms after foot contact (Figure 1). By 25 ms, all participants had changed coordination pattern to flex at the knee whilst continuing to extend at the hip. Most participants maintained this coordination pattern until 40 ms after foot contact (Figure 1). Both pre- and post-fatigue, a greater percentage of time ($p<0.05$) was spent in hip extension – knee flexion than in hip extension – knee extension (Table 1). A significantly greater percentage time was spent in hip extension – knee extension post-fatigue compared to pre-fatigue

(p<0.05) but no change was seen in the percentage time spent in hip extension – knee flexion (Table 1).

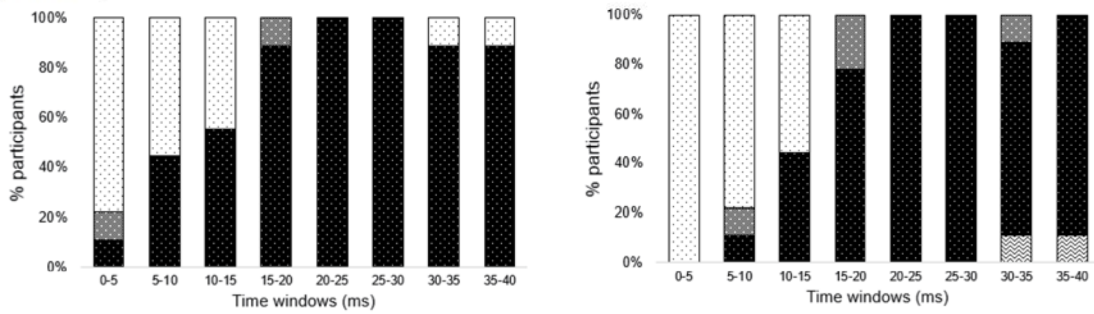

Figure 1. Percentage of participants exhibiting a particular median coordination pattern in each of the 8 time windows from 0 – 40 ms pre- (left) and post- (right) fatigue. ☐ Hip extension – knee extension ▩ Equal use of hip extension – knee extension and hip extension – knee flexion ■ Hip extension – knee flexion ▨ Hip flexion – knee flexion

Table 1. Group analysis of percentage time spent in each coordination pattern under pre- and post-fatigue conditions. Interquartile Range (IQR)

	Percentage time spent in:			
	Hip extension – knee extension		**Hip extension – knee flexion**	
	Pre- fatigue	Post-fatigue	Pre- fatigue	Post-fatigue
Median value [IQR]	34 [15 to 35]	36* [33 to 43]	69** [63 to 88]	63 **[55 to 66]

*p<0.05 Wilcoxon comparison with pre-fatigue value.
**p<0.05 Wilcoxon comparison with fatigue matched hip extension – knee extension percentage time.

DISCUSSION: The purpose of this investigation was to explore hip – knee coordination in the sagittal plane during a cutting movement, pre- and post-fatigue. The common coordination pattern seen at foot contact was of dynamic hip and knee extension but by 25 ms, all participants showed hip extension – knee flexion (Figure 1). The percentage time spent in hip extension – knee flexion was significantly greater than that spent in hip extension – knee extension, thus the coordination pattern that Hashemi et al. (2011) hypothesised to be high risk for ACL injury prevailed for the first 40 ms of foot contact, both in pre- and post-fatigue conditions (Table 1).
The fatigue protocol resulted in similar heart rates and RPE scores (176 bpm and 'hard' to 'very hard', respectively) to the mean heart rate and RPE (176 bpm and 'hard') as has been seen for netball match play (Chandler et al., 2014), providing support for the intensity of the fatiguing protocol in matching the sporting demands of six of the nine participants. Whilst the intensity and the content of the fatigue protocol was representative of netball play, this may not apply to all playing positions or to other team sports. The duration (approximately six minutes) was also far less than that of a netball, football or hockey match. It is not known whether endured fatigue may elicit the same, exaggerated or opposite changes in the parameters measured but the protocol employed is nonetheless relevant as a means of mimicking the effect of a burst of high intensity match play on movement coordination during laboratory testing.
Post-fatigue, participants spent more time (+2%, p<0.05) in hip extension – knee extension. The observation of this coordination pattern is interesting in itself as it represents initial stiffness at both the hip and knee joint, which has been suggested as potentially high risk for non-contact ACL injury (Pollard et al., 2010). This stiffness could be the result of a number of different factors; in the initial moments of contact, the force vector may not be directed in a way which causes knee flexion and/or the ground reaction force may not yet have transferred up the kinetic chain to overcome a net extension moment at the knee. The observed group trend that a greater time percentage was spent in hip extension – knee extension should, however,

be interpreted with caution as a difference of 2% (i.e. 0.8 ms) does not likely represent a meaningful change considering the time resolution of motion capture (i.e. 5 ms). No significant change was observed for the percentage time spent in hip extension – knee flexion as a result of fatigue. If concurrent hip extension and knee flexion is high risk for non-contact ACL injury (Hashemi et al., 2011), the absence of change after fatigue suggests this risk factor is not accentuated as a result of a short duration fatiguing protocol in an elite, healthy population.
Future studies should look to investigate hip – knee coordination during other high risk movements for non-contact ACL, such as landing, and the effect of conditions such as anticipation and attentional distraction on this parameter.

CONCLUSION: This abstract has detailed hip – knee coordination patterns during the first 40 ms of a 45° cutting manoeuvre and the effect of fatigue on these coordination patterns. Most players adopted a hip extension – knee extension pattern at foot contact before switching to hip extension – knee flexion. This latter coordination pattern has been hypothesised as high risk for non-contact ACL injury and was dominant both pre- and post-fatigue. The fatigue protocol did not, however, elicit meaningful group changes in the time spent in a particular coordination pattern in this healthy population of elite athletes. Further work will be required to support the importance of hip – knee coordination in the sagittal plane with regards to ACL injury but the binning of vector coding coupling angles into coordination patterns represents a simplified and more practical method of relaying coordination data to practitioners.

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