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Research paper

Knee and Hip Extension Responses to Prolonged Simulated Soccer Match-Play: a 2D Study

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Abstract

The first part of this study was a reliability study to compare inter-software, inter- and intra- tester measurements using intraclass correlation coefficients ($ICC_{2,1}$). All, $ICC_{2,1}$ values showed excellent scores thus supporting the utility of a two dimensional motion analysis system using an open-source, free software. In the second part of this study, the effects of a 120-minute simulated match-play simulation on knee and hip kinematic was investigated. Eighteen participants consented to this study and were required to complete a 120 minutes of simulated soccer match-play. Knee and hip angles were measured at initial contact during 45° anticipated side-cutting tasks throughout the simulation. A 2 × 7 SPANOVA was utilized. Both knee and hip extension angles were significantly altered over time. No significant differences were observed between dominant and non-dominant sides. A more extended knee and hip landing posture suggested a greater risk of ACL injury during match-play over time. Findings from this study suggest that the non-dominant limb is as likely to suffer non-traumatic ACL injury as the dominant limb. Further interrogations of the biomechanical differences in the knees and hips across limb dominance are warranted for more comprehensive understanding of the changes in multiplanar perspectives following fatigue inducing exertions.

Keywords: *Anterior Cruciate Ligament, ICC, Fatigue, Injury, Kinematics*

1. Introduction

Anterior Cruciate Ligament (ACL) injuries in soccer athletes may account for up to 32% of total injuries in a soccer match (Herrero, Salinero, & Del Coso, 2014). Most cases of ACL injury in soccer are observed to be non-traumatic in nature (Agel, Evans, Dick, Putukian, & Marshall, 2007; Boden, Dean, Feagin, & Garrett, 2000; Brophy, Silvers, Gonzales, & Mandelbaum, 2010; Faunø & Wulff, 2006; Griffin, Agel, Albohm, Arendt, Dick, Garrett, Garrick, Hewett, Huston, & Ireland, 2000; Waldén, Hägglund, Magnusson, & Ekstrand, 2011), especially among male athletes (Brophy et al., 2010). Epidemiological studies have highlighted that the likelihood of non-traumatic ACL injury can get to at least 4 to 6 times greater in competitive matches compared to during practice (Agel et al., 2007; Ekstrand, Hägglund, & Waldén, 2011) suggesting that high intensity exertions may be a crucial factor in increasing non-traumatic ACL injury incidence risk among players. Studies have thus investigated on the matter, attributing the influence of fatigue to the alterations of various ACL markers of injury risk (Cone, Berry, Goldfarb, Henson, Schmitz, Wideman, & Shultz, 2012; Cortes, Greska, Kollock, Ambegaonkar, & Onate, 2013; Cortes, Quammen, Lucci, Greska, & Onate, 2012; Greig, 2008; Greig, 2009; Raja Azidin, Sankey, Drust, Robinson, & Vanrenterghem, 2015; Sanna & O'connor, 2008; Shultz, Schmitz, Cone, Copple, Montgomery, Pye, & Tritsch, 2013; Shultz, Schmitz, Cone, Henson, Montgomery, Pye, & Tritsch, 2015; Small, Mcnaughton, Greig, & Lovell, 2010)

In a biomechanical perspective, non-traumatic ACL injury risk is perceived to be increased as a result from a combination of a number of impaired structural alignment in the lower limbs (Blackburn & Padua, 2008; Boden et al., 2000; Boden, Torg, Knowles, & Hewett, 2009; Donnelly, Elliott, Ackland, Doyle, Beiser, Finch, Cochrane, Dempsey, & Lloyd, 2012) during a dynamic, decelerating maneuvers (Alentorn-Geli, Myer, Silvers, Samitier, Romero, Lázaro-Haro, & Cugat, 2009; Boden et al., 2000; Dai, Herman, Liu, Garrett, & Yu, 2012; Silvers & Mandelbaum, 2007). Specifically, most non-traumatic ACL injuries are reported to occur at initial contact (IC) with an extended knee (Boden et al., 2000), with the foot maintaining contact with the ground (Waldén et al., 2011), a valgus collapse at knee with the proximal tibia internally rotated while the distal femur externally rotated during a change of direction maneuver (Faunø & Wulff, 2006). These observed orientations are most commonly present in a dynamic maneuver such as the side-cut as reported by Cochrane, Lloyd, Buttfield, Seward, and Mcgivern (2007), Faunø and Wulff (2006) and Hawkins, Hulse, Wilkinson, Hodson, and Gibson (2001). Other studies in existing literature have also proposed that an extended hip or a more erect posture at IC would increase shear forces acting on the ACL (Dai et al., 2012; Hashemi, Breighner, Chandrashekar, Hardy, Chaudhari, Shultz, Slauterbeck, & Beynnon, 2011; Quatman, Quatman-Yates, & Hewett, 2010). Hence, in light of biomechanical understandings of the ACL injury and existing epidemiological findings, research has drawn much attention on the speculation that fatigue from repeated high intensity exertions in soccer may have adverse influences on the biomechanical markers of non-traumatic ACL injury risk.

Studies addressing biomechanical alterations from soccer match-play exertions replicated soccer-specific fatigue using various sets of activities that mimic the activities in soccer such as walking, jogging, running, striding and sprinting (Cone et al., 2012; Greig, 2009; Shan & Zhang, 2011; Shultz et al., 2013; Shultz et al., 2015) with integration of multidirectional maneuvers such as side-stepping and backpedaling (Cortes et al., 2012; Lucci, Cortes, Van Lunen, Ringleb, & Onate, 2011; Quammen, Cortes, Van Lunen, Lucci, Ringleb, & Onate, 2012; Raja Azidin et al., 2015) and countermovement jumps (Bossuyt, García-Pinillos, Raja Azidin, Vanrenterghem, & Robinson, 2016). Some studies go into the extent of studying the effects of a full soccer match exertion by replicating the duration of a soccer match of 45 minutes (Raja Azidin et al., 2015; Sankey, Raja Azidin, Bradburn, Taibo, Cabeza-Ruiz, Robinson, & Vanrenterghem, 2015b) and 90 minutes (Cone et al., 2012; Greig, 2009; Shultz et al., 2013; Shultz et al., 2015) to mimic a full soccer match duration and observed that the ACL markers of injury risk are indeed altered adversely overtime. A study by Raja Azidin et al. (2015) found that a more erect landing posture and an extended knee can be observed following fatigue from soccer match-play exertion. However, current existing literature have only attributed the biomechanical changes to exertion on a full 90 minutes of exertion.

According to Fédération Internationale de Football Association (FIFA) regulations, soccer matches are conventionally played over 90 minutes with a 15-minute passive half-time period interceding two 45-minute halves. However, in decisive matches as knockout stages of the FIFA World Cup or the Union of European Football Associations (UEFA) Championship, an additional 30 minutes of extra time (ET) is awarded when the teams are tied and a winner has to be decided. Extra time is composed of two 15-minute halves that is played after a 5-minute rest period following full time of a soccer match. In the World Cup since 2006, a minimum of 25% and up to 50% of all knockout round matches have been extended into ET (www.FIFA.com). Although studies have extensively investigated the changes occurring about the body from a full 90-minute soccer match-play exertions, whether or not the occurring changes may induce further adverse effects on the markers of ACL injury risk is still unknown.

Unfortunately, information is relatively crude regarding the reliability of side cutting data available with inconsistent analysis methods (i.e. coefficients of multiple correlations (CMC), average intra-class correlations coefficients (ICC), and coefficients of multiple determinations (R2) revealing varied components of reliability through a number of unique quantification methods (Sankey, Azidin, Robinson, Malfait, Deschamps, Verschueren, Staes, & Vanrenterghem, 2015a). According to Weir (2005), in the sport sciences, the test-retest reliability or otherwise understood as the simple reliability study is most commonly of interest. Hence the ICC is highlighted in this study with supporting data provided by the standard error of measurement (SEM) and the smallest detectable difference (SDD). The test-retest reliability can be assessed by using several models and forms, each model justified by the objective of the study and methodological differences in the data collection (Weir, 2005). Several literature reporting the reliability and validity of the 2D motion analysis in injury risk assessment procedures are readily available (Dingenen, Malfait, Vanrenterghem, Robinson, Verschueren, & Staes, 2015b; Dingenen, Malfait, Vanrenterghem, Verschueren, & Staes, 2014), however these studies have only looked into the frontal plane motion analysis and utilized less dynamic tasks as compared to the more challenging side cutting maneuvers.

This study aimed to investigate the consistency between the two motion analysis systems in measuring the kinematics of the knee and hip during side cutting tasks via criterion-based concurrent validity and the reliability of parallel side-cutting analyses by testing them inter-software, inter- and intra- tester. Also, this study explored the reliability of the measurement of the sagittal planes knee and hip extensions during side cutting maneuvers. For the first time, this study investigated the effects of prolonged simulated soccer match-play on the knee and hip extensions during side cutting tasks.

2. Methods

2.1 Participants

Eighteen (n = 18) recreationally active male athletes consented to this study. Using the statistical software, G*Power (version 3.1.9.2, Universität Kiel, Germany), it was calculated that to achieve an estimated, moderate effect size f of 0.25, 80% statistical power with alpha set at 0.05, a minimum total sample size of 18 samples is required. Since this study is observing the preexisting dominant and non-dominant limbs of each individual, each participant represents a dominant and non-dominant category and therefore this study can achieve significant statistical power with a minimum of 9 participants for this study. All participants were required to fulfill at least 1 training day per week with 1 to 2 training hours for every session. The mean (± standard deviation) for age, height and body mass of the participants were 23 ± 4.6 years, 1.72 ± 0.07 m, and 70 ± 10 kg respectively. All participants were inquired for injury background and none had suffered ACL injury and were injury-free for the preceding 6 months around the knee, thigh and lower back region which may render their side cutting tasks unsuccessful and void (i.e. ACL injury, thigh injury). This criterion was crucial as any injury could interfere the participants' performance of the utility movements during the soccer match simulation. All participants wore tight fitting compression suits and standardized indoor footwear. A written informed consent was obtained from every participant and the study was conducted according to the guidelines set by the university ethics committee.

2.2 Experimental Design

This study took form of a single group, repeated measures design. Each participant attended to the laboratory on two separate occasions (one familiarization session, and one testing session). The familiarization session consisted of a pre-exercise screening procedure, side-cutting tasks and a 15-minute simulated soccer match-play exertion. The testing session begins after a Fédération Internationale de Football Association (FIFA) standard procedure of 15-minute dynamic warm-up followed by a 10-minute passive rest preceding the soccer match simulation. Participants completed 120 minutes of simulated soccer match-play with a 15-minute passive half-time rest period interceding at the 45-minute mark and another 5-minute rest period at the end of 90 minutes of simulated soccer match-play. At the beginning of the soccer match simulation (0 minutes), after the first half (45 minutes), immediately after half-time (60 minutes), at the end of the second half (105 minutes), at the beginning of the first half of extra time (110 minutes) in between the extra time halves (125 minutes) and at the soccer match simulation (140 minutes), participants' knee and hip kinematic markers of ACL injury risk were assessed with 5 trials of side cutting tasks using the dominant limb and the non-dominant limb. Limb dominance was determined by the participants' preferred limb to be used when kicking a ball and this was controlled for all participants.

Participants' physiological responses were monitored using a heart rate monitor (Polar Heart Rate System, Electro, Finland) and the rate for perceived exertion (RPE, 20-point Borg Scale). During rest intervals such as half time and before extra time periods, the participants remained seated and were allowed to drink water.

2.3 Side Cutting Tasks

Side cutting tasks were selected for this study because of its maneuvers that reflect most reported kinematics and demands of the lower limb during ACL injury occurrence (Faunø & Wulff, 2006; Hawkins et al., 2001; Mclean, Lipfert, & Van Den Bogert, 2004). Further reports on the reliability of side cutting kinematics have also been published elsewhere (Sankey et al., 2015a).

Approach speed was standardized using timing gates (Swift Performance, USA) which were set up 2 m apart and 2 m from the designated landing box for the side cutting task execution. The approach speed range was set at 4 – 5 ms-1 as it was suggested to be a safe approach speed to perform a cutting maneuver with representative kinematic data for injury risk assessment (Vanrenterghem, Venables, Pataky, & Robinson, 2012). Trials with approach speeds not within the set range were excluded from the analysis. The side cutting tasks utilized were anticipated in nature and consists of a 45˚ change of direction. Cones were also placed at 45˚ of deviation from the runway in addition to floor markings placed to represent a target gate for exiting the 45˚ side cutting task. All participants performed 5 successful trials of side cutting for both dominant and non-dominant limbs. A schematic representation of the side cutting task layout is as represented in Figure 1.

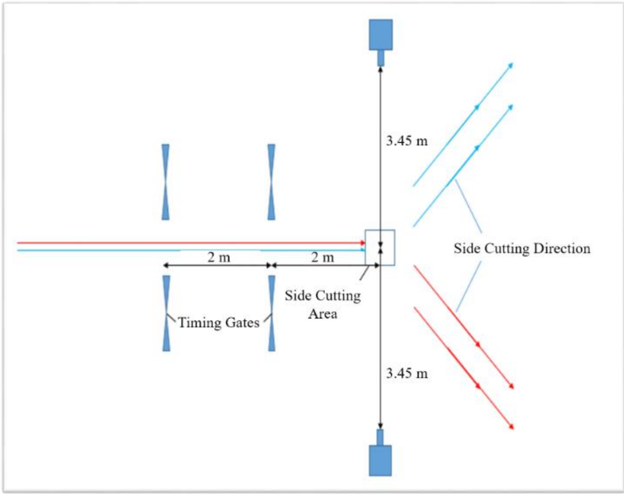

Figure 1: A Schematic Representation of the Side Cutting Task Layout.

2.4 Soccer Match Simulation

The soccer match simulation used in this study was similar to Raja Azidin et al. (2015). This overground soccer match simulation protocol has been proven to be more representative of an actual soccer match-play in both the physical loading (Barreira, Robinson, Drust, Nedergaard, Raja Azidin, & Vanrenterghem, 2016) and the physiological loading aspects (Raja Azidin et al., 2015).

The overground soccer match simulation protocol consists of a 15 m course that includes multidirectional utility movements. A 15-minute audio cue instructs the participants on to perform different activities throughout the 15 m course and is repeated to suit the soccer match-play duration. Several obstacles were incorporated throughout the 15 m course for participants to maneuver themselves through or around using movements as illustrated in Figure 2. Full details of the simulated soccer match-play are described elsewhere (Barreira et al., 2016; Raja Azidin et al., 2015).

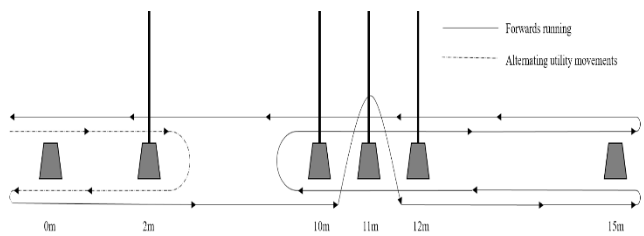

Figure2: A Schematic Diagram of the Multidirectional Overground Simulated Soccer Match-Play.

2.5 Biomechanical Model

10 reflective markers were placed on both sides of the participants' selected body bony landmarks (acromion process, greater trochanter, lateral femoral epicondyle, lateral malleolus and fifth metatarsal) to enable visual access for the observer to process the recorded data.

2.6 Data Collection

All side cutting tasks were performed inside a 0.30 × 0.30 m box marked on the ground with two high-speed cameras (Exilim ZR-800, Casio, USA) set at 240 frames per second (fps) and a pixel resolution of 512 × 384 placed at perpendiculars to both sides (sagittal plane) of the side cutting box. The height and distance of the cameras were set at 1.22m above the floor 3.45 m away from the designated box (Padua, Marshall, Boling, Thigpen, Garrett, & Beutler, 2009) but were adjusted accordingly if needed to fit the full model of the markers into the recorded display in order to ensure that the markers were all visible for processing. A schematic diagram of the side cutting camera placement layout is included as shown in Figure 1

The recorded videos are imported into Kinovea (Kinovea, France) and TEMPLO (Contemplas TEMPLO, GmbH, Germany) and analyzed there. Video playback speed were calibrated to fit the sampling rate.

The hip extension angle was obtained from an angle formed by a straight line originating from the acromion process to the greater trochanter and from the greater trochanter to the lateral femoral epicondyle. Whereas the knee extension angle was determined from the angle formed by a straight line originating from the greater trochanter to the lateral femoral epicondyle and from the lateral femoral epicondyle to the lateral malleolus.

2.7 Data and Statistical Analysis

Initial contact (IC) was defined as the first instance (frame) where the participants' foot touches the ground. The definition and determination of the initial contact phase were practiced as closely and as consistently as possible across all trials for all participants. The markers on the lateral malleoli and the fifth metatarsals aided in determining IC.

The measured angles of the knees and hips on both sides were matched with their respective measured angles on two softwares for each respective participant and trial and with their respective measured angles from the second measurement (intra-observer) other observer (inter-observer) for each respective participant and trial. Inter-trial, inter-observer and intra observer reliability were assessed for this study using correlational analysis and a two-way random effects model, single measures form of intraclass correlation coefficients (ICC2,1), while the standard error of measurement and (SEM) and smallest detectable difference (SDD) were calculated using the respective equations as demonstrated by Weir (2005) as presented in (1) and (2) respectively:

$$SEM = SD \times \sqrt{(1-ICC)} \quad (1)$$

$$SDD = 1.96 \times SEM \times \sqrt{2} \quad (2)$$

Paired t-tests were used to compare the pretest (time 0 min) knee and hip angles between dominant and non-dominant limbs to assess the baseline assumption of similar pretest angles between the two limbs. A 2 (limb: dominant, non-dominant) × 7 (time: 0 min, 45 min, 60 min, 105 min, 110 min, 125 min, 140 min) split-plots analysis of variance (SPANOVA) was conducted for each dependent variable. All data were analyzed using the Statistical Package for Social Sciences (SPSS v. 23, IBM, New York, USA). The equality of variances between limbs and time points were assessed using the Mauchly's test of sphericity. Sphericity violations are corrected accordingly to the Greenhouse – Geisser epsilon. An epsilon value of < 0.75 the Greenhouse – Geisser correction was applied and referred to while epsilon values of > 0.75 are corrected using the Huynh – Feldt correction as elaborated by Girden (1992). Since the similar outcome measures are analyzed for each repeated measure, the Bonferroni post-hoc procedures was used to control Type 1 errors. In this study, limb dominance and time were treated as independent variables while the dependent variables investigated included the knee and hip extension angles at IC. Each successful five trials at every time point were computed for a mean reading. The alpha level was set at 0.05.

3. Results

Data for means and standard deviations are presented as Mean ± SD.

3.1 Validity Study

For all angular kinematics, variability between TEMPLO and Kinovea angles was below 5.5˚ for all angles. Generally, the angular measurements were similar between the two products. Mean knee and hip extension angles are presented as according to Table 1.

Table 1: Descriptive Data on TEMPLO and Kinovea Angle Measurements for Knee and Hip Extensions across Limb Dominance.

	Knee				Hip		
	D		ND		D		ND
Kinovea Reading	166.5 ± 8.6˚		164.3 ± 8.0˚		155.0 ± 9.7˚		155.0 ± 7.6˚
TEMPLO Reading	165.7 ± 9.0˚		164.2 ± 8.0˚		154.5 ± 10.0˚		155.2 ± 7.2˚

D = Dominant; ND = Non-dominant

Angular kinematics variability between the first and second assessments and between the two observers was between 0˚ to 5˚ for all angles. Overall, the knee and hip angles for both dominant and non-dominant limbs were similar in both measurements for both observers. This may suggest consistency in measurements within the observers and also between the observers.

High variability in sagittal plane kinematics of the knee and hip can be observed across the participants at IC, however these variabilities are constantly detected between the first and second measurements as well as between both observers. These variabilities were included for consideration in the discussion section and the drawing of the conclusion in the study. Table 2 presents the descriptive data for the measurements by both observers.

Table 2: Means and Standard Deviations of Knee and Hip Angles.

	Knee				Hip		
	D		ND		D		ND
O1M1	165.4 ± 9.8˚		164.5 ± 7.0˚		156.1 ± 8.0˚		153.7 ± 9.3˚
O1M2	165.8 ± 9.7˚		164.9 ± 6.7˚		156.040 ± 8.3˚		153.8 ± 9.2˚
O2M1	165.2 ± 9.3˚		163.6 ± 6.7˚		156.3 ± 8.8˚		154.0 ± 9.0˚
O2M2	165.1 ± 9.9˚		163.4 ± 6.5˚		156.0 ± 8.6˚		153.5 ± 9.0˚

O1 = Observer 1; O2 = Observer 2; M1 = Measurement 1; M2 = Measurement 2; D = Dominant; ND = Non-dominant

3.2 Reliability of Kinovea vs. TEMPLO Motion Analysis Software

Excellent reliability for the knee and hip assessments was found between Kinovea and TEMPLO motion analysis softwares, with small absolute differences (0.160˚ – 0.760˚), high ICC values (0.981 – 0.988), small SEM (0.138˚ – 0.202˚) and SDD (0.383˚ – 0.560˚) as reported in Table 3.

Table 3: ICC Reliability of the Knee and Hip Assessments across Limb Dominance.

		Absolute difference between measurements (˚)(Mean ± SD)	$ICC_{2,1}$ (95% CI)	SEM (˚)	SDD (˚)
Knee	D	.760 ± 1.363	.988 (.973 - .995)	.149	.413
	ND	.080 ± 1.256	.988 (.972 - .994)	.138	.383
Hip	D	.560 ± 1.635	.986 (.969 - 994)	.193	.535
	ND	.160 ± 1.463	.981 (.956 - .991)	.202	.560

D = Dominant; ND = Non-dominant; ICC = Intraclass correlation coefficient; SEM = Standard error of measurement; SDD = Smallest detectable difference

3.3 Reliability Analysis

Small absolute differences (0.000 – 0.560), high ICC (0.976 – 0.993), and small SEM (0.100 -0.281) and SDD (0.276 – 0.779) are found as reported in Table 4. This allows the deduction of excellent intra-observer reliability for the knee and hip angles at IC during side cutting tasks for both observers. Excellent inter-observer reliability can be concluded with small absolute differences (0.040 – 1.560), high ICC (0.954 – 0.984), and small SEM (0.160 – 0.426) and SDD (0.443 – 1.181) as reported in Table 5.

3.4 Descriptive Statistics

Two participants were unable to complete the full 120-minute protocol. All data presented are for the remaining sixteen participants. Mean kinematic data for knee and hip extension angles throughout the protocol are as presented in Table 6.

3.5 Physiological Responses

The mean heart rates during the simulated soccer match-play exertion (time 5 min to 105 min) was 150 ± 11 beats · min^{-1}. Heart rates were elevated over time throughout the simulation ($F_{6.2,93}$ = 13.7, p = 0.000, η^2 = 0.477) (Figure 3a). Likewise, the mean RPE (time 5 min to 105 min) was 12 ± 2. Rate of perceived exertions were also elevated over time ($F_{4,56}$ = 28, p = 0.000, η^2 = 0.600) (3b).

3.6 Paired T-Tests

Paired t-tests revealed that the knee and hip extension angles were similar across their respective limb dominance. It can therefore be concluded that the pretest extension angles for both knee and hip joints were equal across limb dominance.

3.7 "Split-Plots" Analysis of Variance (SPANOVA)

No interaction between the limb dominance and the knee and hip extension angles over time (knee: $F_{3.333,99.990}$ = 0.401, p = 0.773, η^2 = 0.013; hip: $F_{3.845,115.350}$ = 0.138, p = 0.961, η^2 = 0.005). This means that the changes occurring in the knee and hip extension angles are independent of dominance status of the limb itself. However, significant changes can be observed overtime for both knee and hip extension angles regardless of limb dominance (knee: $F_{3.333,99.990}$ = 7.217, p = 0.000, η^2 = 0.194; hip: $F_{3.845,115.350}$ = 8.607, p = 0.000, η^2 = 0.223). No significant difference in the knee and hip extension angles was found between both dominant and non-dominant limbs (knee: $F_{1,30}$ = 0.189, p = 0.667, η^2 = 0.006; hip: $F_{1,30}$ = 0.099, p = 0.755, η^2 = 0.003).

Table 4: Intra-Observer Reliability of the Sagittal Plane Knee and Hip Angles at IC.

		Absolute difference between measures (˚) (mean ± SD)		ICC$_{2.1}$ (95% CI)		SEM (˚)		SDD (˚)	
		O1	O2	O1	O2	O1	O2	O1	O2
Knee	D	.4 ± 1.2	.2 ± 1.4	.993 (.983 - .997)	.989 (.975 - .995)	.100	.150	0.276	0.417
	ND	.4 ± 1.5	.2 ± 1.3	.976 (.946 - .989)	.977 (.950 - .990)	.233	.202	0.645	0.560
Hip	D	.1 ± 1.4	.3 ± 1.4	.986 (.967 - .994)	.986 (.969 - .994)	.164	.169	0.453	0.469
	ND	.0 ± 1.3	.6 ± 1.9	.990 (.977 - .995)	.978 (.950 - .990)	.132	.281	0.367	0.779

ICC = intraclass correlation coefficient; CI = confidence interval; SEM = standard error of measurement; SDD = smallest detectable difference; O1 = Observer 1; O2 = Observer 2; D = Dominant; ND = Non-dominant

Table 5: Inter-Observer Reliability of the Sagittal Plane Knee and Hip Angles at IC.

		Absolute difference between measures (˚) (mean ± SD)		ICC$_{2.1}$ (95% CI)		SEM (˚)		SDD (˚)	
		M1	M2	M1	M2	M1	M2	M1	M2
Knee	D	.20 ± 1.8	.8 ± 1.8	.982 (.959 - .992)	.984 (.964 - .993)	.245	.223	0.679	0.618
	ND	.9 ± 2	1.6 ± 1.2	.954 (.899 - .980)	.983 (.961 - .992)	.426	.160	1.181	0.443
Hip	D	.2 ± 2	.0 ± 1.5	.972 (.938 - .988)	.984 (.964 - .993)	.330	.191	0.915	0.531
	ND	.4 ± 2.3	.3 ± 2.2	.968 (.928 - .986)	.972 (.937 - .987)	.416	.363	1.153	1.007

ICC = intraclass correlation coefficient; CI = confidence interval; SEM = standard error of measurement; SDD = smallest detectable difference; M1 = Measurement 1; M2 = Measurement 2; D = Dominant; ND = Non-dominant

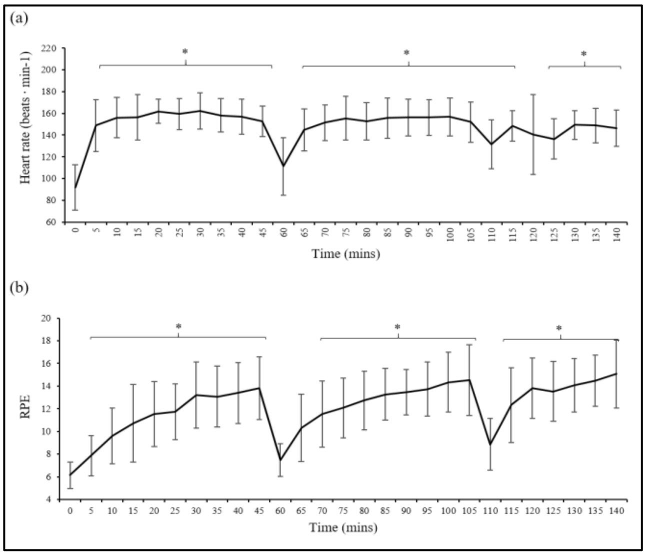

Figure 3: Heart rate (a) and RPE (b) changes over time during simulated soccer match-play with extra time. * Denotes a significant difference compared to 0 min.

3.8 Pairwise Comparisons

The knees are observed to be especially more extended at 125min ($p = 0.001$) and at 140min ($p = 0.023$) compared to 0min (Figure 4a). The hip is observed to be more extended at 60min ($p = 0.006$) and at 105min ($p = 0.009$) when compared to 0min (Figure 4b). The 5-minute rest interval before extra time commences (110min) seems to have little effect on the hip extension angles as they still show a trend to greater extension angles compared to 0min ($p = 0.056$). Greater extension angles than at 0min can also be observed at 125min ($p = 0.002$) and at 140min ($p = 0.001$).

Table 6: Means and Standard Deviations for Knee and Hip Angles.

Angle	Time (min)	Dominant		Non-dominant	
		Mean (˚)	SD (˚)	Mean (˚)	SD (˚)
Knee	0	161.3	7.1	161.6	6.7
	45	163.1	5.6	162.1	6.3
	60	164.4	5.5	162.7	6.6
	105	163.9	5.8	162.9	6.9
	110	164.4	6.5	163.9	6.6
	125	166.1	4.5	164.9	6.3
	140	165.3	5.0	164.4	6.0
Hip	0	152.7	7.7	153.7	7.7
	45	154.4	8.3	155.5	8.2
	60	156.9	6.0	157.0	7.7
	105	156.7	5.9	158.3	7.2
	110	157.8	8.0	158.5	9.3
	125	159.0	7.1	159.0	8.8
	140	158.9	6.0	159.4	7.5

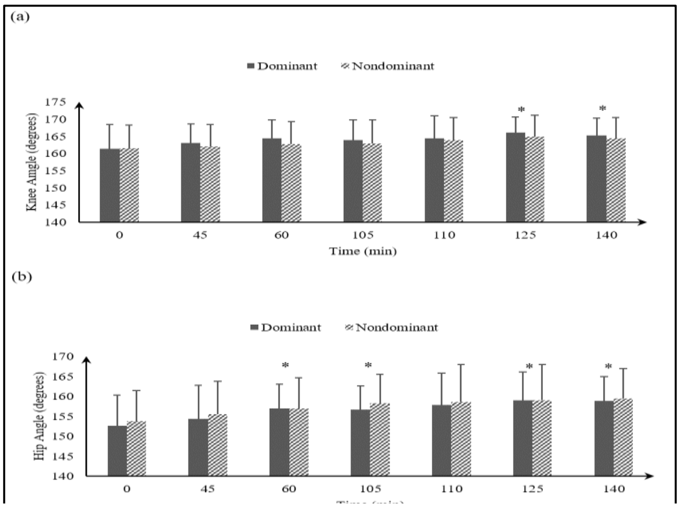

Figure 4: Knee Extension Angles (A) and Hip Extension Angles (B) During Simulated Match-Play. * Indicates Significant Difference Overtime.

4. Discussion

The primary findings of the current study suggest that two 2D motion analysis software's, matched for camera setup, frame rate and pixel resolution, imposed no significant changes in knee and hip angular kinematic values across both dominant and non-dominant limbs. Despite the similarities in the outcomes of the kinematic measurements, TEMPLO requires the fulfilment of rigorous security protocols and is very costly for practising users in sport especially from developing and rising companies and research facilities. Having a complementary product of similar capabilities would appear to be more cost-efficient.

The key findings of this study shows that male recreational soccer athletes executed anticipated side cutting maneuvers with knee and hip extension angles at initial contact increasing over time. Hip extension was observed to increase earlier as shown at the beginning of the second half of the soccer match. These findings support epidemiological studies in addition to demonstrating, for the first time, that ACL injury risk increases following extra time exertion.

4.1 Sagittal Plane Side Cutting Variability

The results of this study reveal a high variability in the sagittal plane side cutting kinematics for both knee and hip joints across limb dominance. This coincides with reports of high variability in side cutting task execution among male athletes by Sankey et al. (2015a). Possible explanations for this outcome may include variability in landing strategies implemented by participants across trials as well as changes in the frontal (varus – valgus displacement) (Greig, 2009) and transverse (internal – external rotation) (Sanna & O'connor, 2008) planes kinematics which were not assessed in this study.

Upon IC, high variability in kinematic angles of both knee and hip joints were observed. This observation is similar to that observed by Sankey et al. (2015a) in side cutting tasks performed under at similar speeds (4 – 5 ms-1) and magnitude of directional change (45˚). Another study by Malfait, Sankey, Azidin, Deschamps, Vanrenterghem, Robinson, Staes, and Verschueren (2014) which utilized dissimilar tasks to side cutting (i.e. drop vertical jumps) also found similar variabilities in the sagittal plane kinematics. These variabilities may be associated to differences in varus – valgus displacement (Greig, 2009), lateral trunk motion (LTM) (Dingenen, Malfait, Nijs, Peers, Vereecken, Verschueren, & Staes, 2015a; Dingenen et al., 2014) in the frontal plane and internal – external rotation (Sanna & O'connor, 2008) in the transverse plane which were not included for observation in this study. Such variabilities detected may also represent hints of compensatory mechanics for different landing strategies implemented between the participants (Kim, Lee, Kong, An, Jeong, & Lee, 2014; Powers, 2010).

4.2 Reliability of TEMPLO and Kinovea 2D Motion Analysis Softwares: A Practical Implication

Since the data recorded were processed under one similar procedure (angular measurements) across two different motion analysis softwares, the angles measured for one instance of the side cutting task were matched for the same instance in the other software. This addresses the question regarding validity of the selected motion analysis software for the subsequent following studies. A close-to-perfect ICC can be observed for all angular measurements, therefore indicating that the free Kinovea is just as valid and reliable as the paid TEMPLO software for the assessment of lower limb angular kinematics from the sagittal perspective.

The primary focus of this study was to assess the reliability of a sagittal knee and hip joint kinematic angles at IC during side cutting tasks. Reliability was investigated using intra-observer (intersession) and inter-observer (inter-therapist). ICC was reported with supporting data and justification using SEM and SDD values. The main findings from this study suggests that sagittal plane side cutting kinematic angles of the knee and hip joints can be assessed with excellent intra- and inter- observer reliability. Other outcomes observed in this study were discussed in this section.

4.3 The Accuracy of the Sagittal Plane Knee and Hip Angular Measurements at IC

SEM and SDD was calculated alongside the intra- and inter-observer reliability (ICC2.1) to investigate measurement error (Weir, 2005). The SEM for all measurements (intra- and inter-observer; knee and hip joints; and dominant and non-dominant limbs) was approximately 0.236˚. This means that observers can be confident that the measured angles are within 1˚ from the theoretical value with regard to the assumption of no measurement error (true angle) at the 95% interval (Weir, 2005). The minimum difference required for the measurements, matched for trials, intra- and inter-observer, knee and hip joints, and dominant and non-dominant limbs, to be identified as statistically significant is represented by the SDD (Weir, 2005). Based on the outcomes of this study, within measurements (intra-observer) and between measurements (inter-observer) can consider differences below 0.5˚ and 1˚ respectively to be insignificant. However, when matched with alternate planes (i.e. frontal and transverse planes); it may reveal more data for the sources of variability in the measurements. For example, the identification of knee and hip joints' kinematics from the frontal plane include knee valgus angles and LTM (Dingenen et al., 2015a; Dingenen et al., 2014). Although the knee requires a similar 3 markers to assess the knee valgus and the knee extension angles, the hip joints require only 2 markers for LTM angles assessment as compared to 3 markers required to illustrate the hip extension angles, consequently revealing a possibility of a source of variability (Dingenen et al., 2014).

4.4 The Utilization of Sagittal Plane Knee and Hip Joint Kinematics for Injury Risk Assessment

The knee and hip extensions have been proposed to play unique roles in loading the ACL. Studies by Bossuyt et al. (2016); Raja Azidin et al. (2015); Sanna and O'connor (2008) and Greig (2009) have assessed ACL injury risks and included reports of the sagittal plane knee kinematics. The inclusion of sagittal plane hip kinematics for injury assessment was proposed by Hashemi et al. (2011). A more extended hip at IC of a landing phase is described to cause a shifting of the center of mass (COM) to posterior the knee and causing disruption in the knee and hip muscles co-activation synchrony.

According to Hashemi et al. (2011), delayed knee and hip joint muscles' co-activation may cause the said mechanism to result in a more flexed knee and a more extended hip upon landing following ground reaction force. The described postural alignment promotes anterior tibial translation which is resisted by the ACL, increasing tension within the ligament, and ultimately causing failure to withstand the shear forces acting on the ligament (Hashemi et al., 2011). In a risk identification practice, it is crucial for testers to understand not only the mechanism of an injury, but also have a reliable tool to detect and identify these risks (Dingenen et al., 2014). The use of a frontal plane alone is insufficient in providing accurate data as highlighted by Dingenen et al. (2014), as the biomechanical impairments during a test can be, as claimed by Ortiz and Micheo (2011), multifactorial in its occurrence. As the transverse plane cannot be observed (Dingenen et al., 2014), the inclusion of a sagittal plane kinematic observation may supplement for insufficient data and provide added value to a test. The sagittal plane mechanics has also been used in testing procedures apart from the frontal plane mechanics to provide a more holistic interpretation of an injury risk assessment data (Padua, Boling, Distefano, Onate, Beutler, & Marshall, 2011; Padua, Distefano, Beutler, De La Motte, Distefano, & Marshall, 2015; Padua et al., 2009).

4.5 Effects of Extra Time Exertions on Knee and Hip Extension Angles

Findings from this study indicated that the knees and hip appear to be more extended in the later stages of simulated soccer match-play. In addition to that, the onset of greater extension of the hip at initial contact was detected as soon as the second half of soccer match-play, affirming epidemiological researches on injury incidences Hawkins et al. (2001) and Ekstrand et al. (2011) claiming that injury incidences tend to be increasingly likely to occur over time in soccer matches. Previous studies in interrogating biomechanical injury risk factors (Bossuyt et al., 2016; Greig, 2009; Hamdan, Ismail, Hassan, Ismail, & Raja Azidin, 2018; Raja Azidin et al., 2015) has proven a more extended knee orientation at initial contact post-exertion compared to pre-exertion state. Although Raja Azidin et al. (2015) has reported no significant differences between an overground soccer match simulation protocol and a treadmill protocol as utilized by Greig (2009) in terms of biomechanical changes during kinematic assessments of side cutting tasks, the nature of testing conducted by Greig (2009) was unfortunately dissimilar to this study as he implemented a 180˚ agility sprint instead of a 45˚ side cutting maneuver as performed in this study. This may help explain the great discrepancy in changes presented in his study (13˚ versus 30˚) in comparison to that observed in this study (15˚ versus 18˚). Similarly, Bossuyt et al. (2016) observed more extended knees during a single leg hop task (11˚ versus 14˚) and a drop vertical jump task (29˚ versus 32˚). Raja Azidin et al. (2015) showed similar changes (5˚ versus 9˚) in comparison to this study which may be attributed to similarities to this study such as the utility of an open 45˚ side cutting maneuver. Furthermore, the extent of exertion in previous researches are very much dissimilar to this study. Bossuyt et al. (2016) utilized a high intensity, short term protocol (SAFT5) while Raja Azidin et al. (2015), included a 45-minute overground versus treadmill soccer match simulation and Greig (2009) and Raja Azidin (2015) implemented a full 90 minutes of treadmill soccer match simulation and a full 90 minutes of overground soccer match simulation respectively. Whilst the changes were similar, the values were noticeably different and may be attributed to the nature of the 45˚ side cutting task performed by in this study (anticipated) as opposed to in his study (unanticipated).

Present understanding of non-traumatic ACL injury insists that a more extended knee loads the ACL with greater strain (Markolf, Burchfield, Shapiro, Shepard, Finerman, & Slauterbeck, 1995) and place the knee in a vulnerable position to anterior shear forces (Hashemi et al., 2011). Increments in knee extension may be caused by the impairment of quadriceps and hamstrings co-activation which act as a counterforce protecting the knees (Wojtys, Ashton-Miller, & Huston, 2002). Following the increment of knee extension at initial contact over time, it was speculated by Blackburn and Padua (2008) that the ACL is loaded due to the elevation angle of the ACL, patellar tendon insertion angle and reduction in hamstrings insertion angle which have been found to increase tibial anterior shear forces (Nunley, Wright, Renner, Yu, & Garrett Jr, 2003; Yu & Garrett, 2007) thus disabling the counterforce potential from the hamstrings against the shear forces on the ACL (Pandy & Shelburne, 1997).

In addition to the more extended knee at initial contact observed following extra time, the hip is also found to be more extended, indicating a more erect posture is prominent in the side cutting task executions. This extended hip is was also observed in the preceding study by Raja Azidin et al. (2015). Interestingly, in this study, it was observed that the more extended hip orientation occurred as early as the start of the second half of the simulated soccer match as compared to the extended knee which took place since the end of the first extra time half. The hip extension is proposed to be a contributing mechanism of ACL injury occurrence by Hashemi et al. (2011), prompting that the hip extensors (i.e. gluteus maximus), in the presence of pre-existing quadriceps and hamstrings impaired co-contraction, becomes isolated and the magnitude of force generated by its contraction may encourage hip extension apart from inhibiting a proper hip flexion rate (Hashemi, Chandrashekar, Jang, Karpat, Oseto, & Ekwaro-Osire, 2007). Another mechanism coined leading up to the proposed injury mechanism is that an upright trunk (more extended) would position the center of mass posterior the knee and enable the ensuing vertical ground reaction forces to encourage dysynchrony in the knee and hip co-activation harmony. This mechanism was founded since Koyanagi, Shino, Yoshimoto, Inoue, Sato, and Nakata (2006) and Shimokochi, Yong Lee, Shultz, and Schmitz (2009) proved that a more anteriorly positioned center of mass would promote both knee and hip flexion. The early onset of hip extension impairment may furthermore be attributed to greater exertion for greater flexion compared to the knees as observed by Blackburn and Padua (2008) where the hip apparently flexes more when compared to the knees at initial contact during landing using their participants' preferred landing strategy.

Overall, extra time soccer match-play exertions apparently induced two major proposed mechanisms of non-traumatic ACL injury risks, an increased knee extension and an increased hip extension at initial contact of a dynamic, pivoting maneuver as a side cut. These configurations combined together support the inferences that a sagittal plane biomechanics leads a vital part in the mechanism of non-traumatic ACL injury (Yu, Lin, & Garrett, 2006). Previous investigations have also highlighted that a combination of multiple loading mechanisms could pose adverse effects to the ACL (Borotikar, Newcomer, Koppes, & Mclean, 2008; Hewett, Myer, Ford, Heidt, Colosimo, Mclean, Van Den Bogert, Paterno, & Succop, 2005; Markolf et al., 1995; Yu et al., 2006). Borotikar et al. (2008) also noted that anticipatory conditions of a side cutting maneuver may have detrimental effects on the lower limb mechanics aside from the level of exertion and this is a crucial note to come alongside the interpretations from this study. Therefore, it is important to note the changes occurring in the biomechanics of the knee and hip as a function of exertion together and with respect to its decision-making nature for more comprehensive and critical interpretations in both future investigations as well as in clinical practice.

4.6 Effects of Extra Time Exertions on Dominant and Non-Dominant Knee and Hip Extension Angles

The findings from this study revealed no biasness in biomechanical alterations in the knees and hips when it comes to limb dominance. All knee and hip extension angles drastically increased over time as s function of fatigue and can be associated with increases in ACL injury risk following previously discussed mechanisms. This finding may hint that doth the dominant and non-dominant knees and hips are equally as likely to sustain ACL injury throughout exertion during a soccer match including throughout the bouts of extra time. This study reveals contradictory findings to an audit of ACL injuries from direct participation in soccer by Brophy et al. (2010) claiming that males are more likely to injure their dominant limb compared to their non-dominant limb (74% versus 26%). Unfortunately, it remains unclear how limb dominance may have an influence towards ACL injury risk as another multicenter retrospective investigation revealed indifferences between the dominant limbs and the non-dominant limbs (Negrete, Schick, & Cooper, 2007). Another study also proved that over 95% of functional tasks and isokinetic tests summed up to reveal symmetrical indices between the dominant and non-dominant limbs (Petschnig, Baron, & Albrecht, 1998). The findings from these studies along with this current study may suggest that contrary to the current consensus, the tendencies of acquiring ACL injury is similar across limb dominance, even throughout the accumulation of prolonged exposure to exertion.

4.7 Limitations

The outcomes of this study has revealed excellent reliability of the sagittal plane knee and hip joint angular measurements for both intra- and inter-observers. Nevertheless, this study did not assess frontal and transverse plane mechanics which may be crucial to reveal greater results therefore sagittal plane alignment may not reveal sufficient data to address multifactorial biomechanical impairments and to be utilized as a stand-alone test for injury risk assessment.

5. Conclusion

The findings of this study suggest that high reliability coexists between the two 2D motion analysis softwares Kinovea and TEMPLO despite the difference in establishment of the producing companies. Thus, in a more cost-effective approach of biomechanical injury assessment, Kinovea would prove to be a more appropriate instrument for the practice.

The findings from this study may suggest that knee and hip extension angles may be assessed with excellent intra- and inter-observer reliability during side cutting tasks while using 2D motion analysis. Including this plane of observation for the analysis of similar dynamic tasks in injury risk assessment tests may be beneficial as it may provide added value to the analysis. It is furthermore recommended to include a test – retest reliability assessment in future studies to further provide a more concrete explanation on whether the differences between trials were due to measurement errors or the participants' own changes in landing strategies to different intrinsic conditions as inter-trial reliability is free from methodological setbacks.

The findings of this study have shown that a more erect and extended landing posture in the knees and hips has been observed throughout extra time during simulated soccer match-play exertions. In a nutshell, the findings from this study showed elevated ACL injury risk over time. Moreover, in addition to the current body of knowledge, this study is the first study to report on the kinematic alterations from extra time exertions with respect to ACL injury risk. The extended knees and hips do not, however, reveal differences between dominant and non-dominant limbs, suggesting that unlike the current consensus, the non-dominant limbs are actually as much affected as the dominant limbs from exertions, with greater exertion leading to increasing of ACL injury risk. However further observations are warranted to provide a more comprehensive understanding of the kinematic impairments in the knees and hips following exertion from a multiplanar perspective.

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