# The effect of a simulated soccer match on Anterior Cruciate Ligament injury risk factors

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**Abstract**

To investigate the effect of within match fatigue on knee kinematics and jump kinetics in girls' soccer players, a quasi-experiment time series design was employed collecting data before, after and at fifteen-minute intervals during a 90-minute simulated soccer match. Fifteen girl players (age 13.1 ± 1.4 years) performed a counter movement jump and a single-leg drop jump. Mean concentric force and flight time to contraction time ratio were derived from the counter movement jump. Knee valgus and flexion angles were calculated during the single-leg drop from three-dimensional motion capture. Subjective ratings of perceived exertion (RPE) and readiness were collected at each time series. Small to large increases in RPE and reductions in readiness were observed throughout the match from baseline. Moderate to large improvements in mean concentric force were shown at 15, 75 and 90-minutes when compared to baseline. Flight time to contraction time ratio increased moderately at 15 minutes. Changes in kinematics were typically trivial or unclear however, small increases in knee valgus were shown after 30 minutes compared to baseline. Subjective measures may provide useful information to understand the physical response of young players to match play. .

**Key words**: Knee Joint; RPE; Injury Prevention; Adolescents; Fatigue.

## Introduction

The incidence of Anterior Cruciate Ligament (ACL) injury in female soccer continues to remain high, especially in young players, despite the plethora of research in this area [31]. Soccer specifically has one of the highest ACL incidence and female athletes are two to three times more likely to suffer this injury [27]. Nearly 80% of all ACL injuries are non-contact and often occur during landing or cutting manoeuvres [18,31]. These injuries are multifactorial but modifiable risk factors include neuromuscular and biomechanical aspects including inadequate landing patterns due to decreased strength and fatigue [10,14]. Neuromuscular force characteristics are also associated with injury risk as females are less able to attenuate ground reaction forces when landing and show a plateau in jump performance post puberty [15].

Typically non-contact ACL ruptures occur when the knee is at or near full extension and suffers from valgus collapse [2,18]. Valgus collapse is a predominant loading pattern in approximately half of all ACL injuries [2] with females having five times higher relative risk of sustaining a valgus collapse [18]. Knee flexion angle is another important kinematic marker with a low amount of knee flexion observed at the point of injury [29]. Extension of the knee close to initial contact with the ground appears to reduce the effectiveness of the hamstrings to resist tibial translation, increasing ACL shear force [28,29]. It is reported females land with less knee flexion [29] although Krosshaug and colleagues [18] presented the opposite trend during ACL rupture stating knee flexion alone may not be predictive of injury. Despite this, it is likely a combination of factors are important with video analysis showing that ACL injuries tend to occur with minimal knee flexion and with knee valgus [2,29]. As such knee valgus and knee flexion angles are likely both important kinematic markers of neuromuscular control [16] and ACL risk.

Fatigue is associated with increased injury risk [7] and can cause alterations in varus-valgus knee angles, knee shear forces, proprioception and neural activation [5,24]. Fatigued landing patterns occur with excessive knee valgus suggesting degradation in peripheral and central processing mechanisms [5,10,25]. Under fatigue female athletes demonstrate increased knee abduction and internal rotation in comparison to males [24] and an increase in knee valgus during drop jumps [10] which may result in greater peak anterior shear force on the proximal tibia and increased ACL strain [7]. However, the protocols employed to induce fatigue have not matched the demands of sports competition. Despite the high incidence of ACL injury in female soccer the effect of fatigue on knee joint stability has not been investigated directly under match specific loading. Understanding the times within a game where fatigue has its greatest influence on ACL risk factors would provide valuable information to practitioners prescribing training programmes to increase physical capacity and robustness of girls' soccer players.

This study aimed to measure change in kinematic markers of neuromuscular control and force characteristics associated with ACL injury over a 90-minute simulated soccer match. In doing so we aimed to identify the impact of fatigue on knee control.

## Materials and Methods

### *Participants*

Seventeen players registered to an FA Girls Centre of Excellence were recruited and the study was carried out in accordance with ethical standards for sport and exercise science research [13]. Approval was obtained from the ethics committee at Teesside University, School of Social Sciences, Business and Law. Written informed consent was gained for all players from their parents or guardians. Players with prior history of knee injury or surgery were excluded and all participants indicated no lower-extremity injury at the time of data collection. Preseason medicals had been conducted by a medical practitioner. All players were informed of their right to withdraw at any point without reason, of which two players dropped out as a precaution on medical advice. There were no repercussions of symptoms and both players were available to take full part in their next training session. A total of fifteen players (age 13.1 ± 1.4 years; stature 158.0 ± 7.9 cm; body mass 50.3 ± 13.4 kg) were included for analysis.

*Study design*

A quasi-experiment time series design was employed where outcome measures were collected before, after and at 15-minute intervals during a 90-minute soccer match simulation test ($SAFT^{90}$) [20] (Figure 1). The $SAFT^{90}$ was selected due to its validity in replicating the physiological and mechanical demands of soccer match-play [20]. The protocol incorporates acceleration, deceleration, cutting, side-stepping and backwards and forwards running in a randomised and intermittent fashion [21]. The activity pattern was dictated by commands from a 15-minute audio file. Each half consisted of three 15-minute periods with a full 15-minute half-time period. Previously research has shown fatigue induced through the $SAFT^{90}$ effects electro-mechanical variables within the musculature required to stabilise the knee in girls' soccer players [9]. However, how this effects knee kinematic variables is unknown. A standardised warm-up included parts one and three of the FIFA 11+ (F-Marc) and five bilaterally and unilaterally vertical jumps. Players also performed familiarisation of the $SAFT^{90}$. During half-time players rested passively and consumed fluid freely. Testing was completed as soon as possible to minimise recovery and ensure the $SAFT^{90}$ protocol most closely represented a real soccer match.

*Procedures*

Testing procedures consisted of a counter movement jump (CMJ) and a single-leg drop jump (SLDJ) and were performed in a counterbalanced order. Players performed three to five familiarisation trials before testing and were required to perform two successful trials of each jump per time interval. The CMJ provides a reliable indication of lower limb power output and neuromuscular performance [8]. The SLDJ can simulate the deceleration encountered during match play [33] and its unilateral nature may provide a more sensitive measure of multi-segment mal-alignment given the smaller based of support [11]. Prior to testing at each time series retro-reflective markers (30 mm diameter) were placed superficially on the anterior-superior-iliac-spine, the centre of the patella and midpoint of the ankle malleoli [37]. Markers were placed directly on the players' skin using commercially available double-sided tape by the same physiotherapist throughout to ensure inter-rater reliability.

The CMJ was performed on a force platform (Kistler 9281CA Kistler Instrument Corporation New York USA) and players jumped as high as possible with their hands on their hips to isolate lower extremity muscle power. A jump was deemed successful if a stretch shortening cycle was achieved. This was defined on visual inspection of the force trace as the presence of a clear eccentric phase prior to the concentric (jumping) action [8]. Raw data was exported to Microsoft Excel from the force platform software (Bioware v5.1.0 Kistler Instrument Corporation New York USA) and relative mean concentric force (N/kg) and flight time to contraction time ratio (s) were identified using the methods described by Cormack et al. [8]. These are both reliable measures of neuromuscular performance and mean concentric force is highly sensitive with a typical error lower than the small worthwhile change [8] and maybe a useful measure for identifying fatigue in team sport athletes [36]. Flight time to contraction time ratio from a single jump may be an appropriate alternative to flight time to contact time ratio over repeated jump to measure reactive jump performance [8].

During the SLDJ the starting position of the players was always fixed specifically with the foot on a 15cm box and toes facing forward. A successful SLDJ trial was defined as one in which the participant dropped off the box (i.e. did not jump down) on the dominant leg before maximally exploding vertically and landing with both feet. By standardising this procedure for each jump we ensured the subjects always landed in the same position on the floor in relation to the global reference frame. The trajectories of the retro-reflective markers were tracked using a 100Hz, six-camera, motion capture system (Vicon MX13 and Vicon Nexus 1.7 Vicon Motion Systems UK) with each camera set at a height of 1.9 metres. The system was calibrated prior to every session following manufacturers' guidelines to ensure image error was below 0.18 mm. ACL injuries usually occur within 50 milliseconds [18] of initial contact thus the three-dimensional co-ordinates of the marker trajectories over this period were exported into Microsoft Excel for analysis. Projected angle for knee valgus and flexion were estimated from the angle between two, two-dimensional vectors. The medial-lateral and inferior-superior co-ordinate data were used for the calculation for knee valgus and the anterior-posterior and inferior-superior co-ordinates for knee flexion. The dot product of the two vectors was calculated as: $dot = x_1 * x_2 + y_1 * y_2$ and the angle between these vectors as: $angle = aCos\left(\frac{dot}{Length_1 * Length_2}\right) * \frac{180}{\pi}$. For knee flexion, the angle was subtracted from 180º.

Rating of perceived overall (RPE O) breathlessness (RPE B) and leg (RPE L) exertion were collected at each time interval using the CentiMax scale (CR100®) [4] on a tablet-based application [23]. Differentiating RPE enables monitoring of central and peripheral exertion in team sport athletes [22,23]. All players had used the application to monitor training load during their regular training programming. Readiness was collected using the same CR100® scale but in this case the verbal anchors were replaced with two phrases "ready" or "not ready" which were equivalent to "maximal" and "light". This simple method was used by the players previously during their regular training sessions.

*Statistical analyses*

Raw data was checked visually for normality before analysis and seen to follow normal distribution. A general linear model (SPSS c.23 Armonk NY: IBM Corp.) was chosen to compare differences in each measure as a fixed effect over the time series. Uncertainty of the estimate was expressed as 90 percent confidence limits. Inferences were based on the disposition of the confidence limit for the mean difference to the smallest-worthwhile change, which was set a priori as 0.2 between-players standard deviations at baseline. The magnitude-based inferences approach was applied [1] with descriptors assigned using the following scales: 0.5%–5% very unlikely; 5%–25% unlikely; 25%–75% possibly; 75%–95% likely; 95%–99.5% very likely; >99.5% most likely. Clinical inferences were chosen for knee flexion and knee valgus given their association with ACL injury. Here the probabilities of declaring an effect beneficial were >25% for benefit with <0.5% for harm. Thus effects were deemed unclear if they were possibly beneficial (>25%) with an unacceptable risk of harm (>0.5%). For jump data ratings of perceived exertion and readiness an effect was deemed unclear if the confidence limits overlapped the smallest positive or negative change by ≥5%. The magnitude of responses was evaluated through standardised differences in the means using the following thresholds: <0.2 trivial; <0.6 small; <1.2 moderate; <2 large; <4 very large; ≥4 extremely large [17].

## Results

Raw data at baseline ± standard deviations are presented in Figure 2. Changes in RPE ranged from possibly trivial to most likely or very likely large increases in RPE O and RPE B respectively. Possibly trivial to most likely moderate increases were recorded for RPE L. Possible small to most likely large decreases in overall readiness were observed (Table 1). There was a possibly small decrease in readiness and a possibly small increase in RPE L at the end of the first half and a likely small increase in RPE O for the final 15 minutes of the match simulation.

Very likely moderate improvements were observed in mean concentric force from baseline at 15 and 75 minutes and very likely large improvements at 90 minutes. A moderate increase in flight time to contraction time ratio was observed from baseline at 15 minutes with possibly small decrements at 30 minutes and after half-time. A possibly small increase in knee valgus was observed at 30 minutes from baseline and between 75 and 60 minutes (likely). All other observations were trivial or unclear (Table 2).

## Discussion

Fatigue from a simulated soccer match effects electro-mechanical delay in the musculature required to stabilise the knee joint in girls soccer players but further research was required to directly measure joint control [9]. This study assessed neuromuscular control by quantifying knee kinematics during a single leg drop jump and neuromuscular performance through a countermovement jump in girls' soccer during a simulated soccer match. Main findings showed that while subjective measures demonstrated incremental increases in exertion and a subsequent decrement in readiness, markers of neuromuscular control and jump performance did not follow this trend. These finding were unexpected and contradict previous literature. Dicken et al. [10] report significant increases in knee valgus angle post fatigue and Chappell et al. [7] reported a 12% decrease in knee flexion angle and significant increases in knee valgus moment after jumping and sprinting to voluntary exhaustion. However, knee flexion has previously increased under fatigue in female basketball players and the ability for the musculature to retain a strong capability to resist imposed lengthening maybe an important ACL injury prevention mechanism [12].

Previously studies have focused on inducing peripheral fatigue [10] [7] whilst we chose to simulate a soccer match in order to ensure ecological validity. The $SAFT^{90}$ protocol was challenging, overall RPE for the first 15-minute period was rated between "hard" and "very hard" (59.4 ± 17.8). However, this appeared to be influenced by central (RPE B; 61.4 ± 17.3) rather than peripheral (RPE L; 47.1 ± 19.2) mechanisms [22]. RPE legs was consistently lower than breathlessness throughout the stages (Figure 1A) and mean concentric force from the CMJ was elevated above baseline throughout. This would suggest that whilst the players may have been fatigued, this did not reduce their neuromuscular performance. These data are consistent with McLaren et al. [22] who found that after treadmill exercise the RPE B was 13 points higher than the RPE L. CMJ performance reduced after the largely peripheral cycling but not the largely centrally demanding treadmill protocol despite a moderately higher overall RPE (92 ± 11 vs 86 ± 12). Furthermore, decrements in glycolytic capacity during a soccer match in female soccer players may not be detected during the CMJ [19].

Injuries in soccer have been repeatedly shown to increase in the final quarters of each half [24] and are greater in the second half in comparison to the first [30]. Neuromuscular control is a key risk factor in females [16] while fatigue may reduce neuromuscular performance in jumping and may be associated with fatigue [36] or injury risk [14]. Therefore it was expected that the knee kinematic and CMJ measures would deteriorate throughout a simulated soccer match, which was not the case. This contradiction compared to previous studies might be explained by the difference in methodology as it has been shown that peripheral and central fatigue develops quicker during maximal voluntary contractions compared to submaximal exercise [35]. However, De Ste Croix et al. [9] also used the $SAFT^{90}$ in a comparable population and found a decrement in electromechanically delay in the hamstrings and gastrocnemius during resisted knee extension. This is attributed to a failure somewhere in the muscle contraction process. In contrast to resisted knee extension exercise, jumping is a complex multi-joint action and it is possible that players were able to use compensatory mechanisms [3] despite fatigue related decrements in local muscular contractions. For example, it has been suggested that the stretch shortening cycle can attenuate exercise-induced muscle damage [6]. This theory is supported by a previous study in amateur soccer players demonstrating reduction in quadriceps muscle activity and squat jump but not counter-movement jump performance [32].

Subjective measures of exertion and readiness showed clear change throughout the match simulation in contrast to the measures of neuromuscular control or jump performance. This supports previous research that suggest there is no consistent relationship between subjective and objective markers [34]. Subjective measures of the response to training have demonstrated greater sensitivity than objective markers [34] and our findings support this. RPE and readiness followed more closely to the aforementioned patterns of injury in soccer. The readiness scale detected moderate to large decrements from baseline and also a small decrement towards the end of the first half, with overall RPE increasing at the end of the second half. Elite players may have access to expensive monitoring systems but at lower levels (Semi-Professional and Amateur for example) simple subjective markers hold practical importance for practitioners and fitness coaches. The subjective measures taken in this study could be useful in monitoring the acute response to the physical demands of a soccer match in girls. Given the importance of player well-being in youth athletes these findings suggest further research into the validity of measures of RPE and readiness for assessing acute responses to training or match play in girls' soccer is warranted.

Limitations to this study must be acknowledged. A full body marker set and integrated force platform and kinematic data to calculate joint moments is desirable. This was impractical given the requirement to test players within a short time period to limit recovery and maintain the ability of the SAFT$^{90}$ protocol to closely replicate the demands of soccer match. Application of further joint markers is more intrusive and raised ethical considerations given the adolescent population. The three sites chosen do not represent the true joint centre but are commonly cited in the literature to estimate projected angle and demonstrated adequate reliability in single-leg squat and both dynamic unilateral and bilateral assessments [26,37]. A key difference in these studies was that knee joint centre was estimated from the 2D video capture. In the current study the joint makers, placed upon the skin, were tracked but not the centre of the joints. However, this approach did enable these marker trajectories to be tracked in three-dimensions before calculating projected angles. The 3D motion capture system needs the trajectories of each marker from a minimum of three cameras per time series in order to generate a global 3D position in relation to the origin within the calibrate floor space. Despite this, the quantification of knee valgus and flexion angles here may be erroneous and comparison between studies should be made with caution. The standardised nature of application by the same physiotherapist and the quasi-experimental design of this study may allow within-player comparisons to be made but noise or measurement error in these data may explain why harmful within-match changes were not observed. Finally, it is also important to interpret these data within their context and the findings should not be extrapolated beyond the cohort characteristics in this study. These data represent adolescent female soccer players all of whom had been training within a talent development programme and exposed to soccer specific strength and conditioning.

## Conclusions

We were unable to detect harmful within-match change in jump-landing strategies associated with ACL injury risk. The SAFT$^{90}$ was predominantly centrally demanding which may explain why peripheral control was not reduced but these data also question the usefulness of the measures collected in this study to identify fatigue related increase in ACL injury risk. Limitations to the simplistic method of calculating knee valgus and flexion angle in this study may have increased the noise in the data and masked true changes. Subjective measures of RPE and readiness may provide coaches with useful information to understand the physical response of young players to match play. Furthermore, neuromuscular performance measured during a CMJ improves during a simulated match and may not be a valid measure of fatigue in girls' soccer players.

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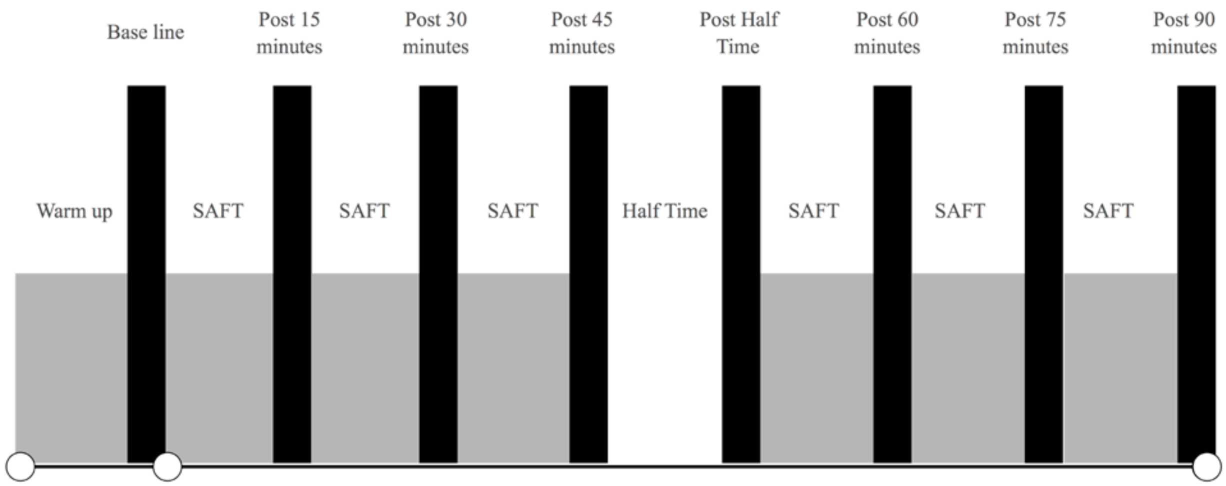
**Figures**

*Figure 1:* Illustration of the quasi-experimental time-series design of the study. Black columns indicate data collection at each time-series.

*Figure 2.* Time series data (mean ± standard deviation) for A: RPE; B: Readiness; C: knee kinematics and D: counter movement jump parameters.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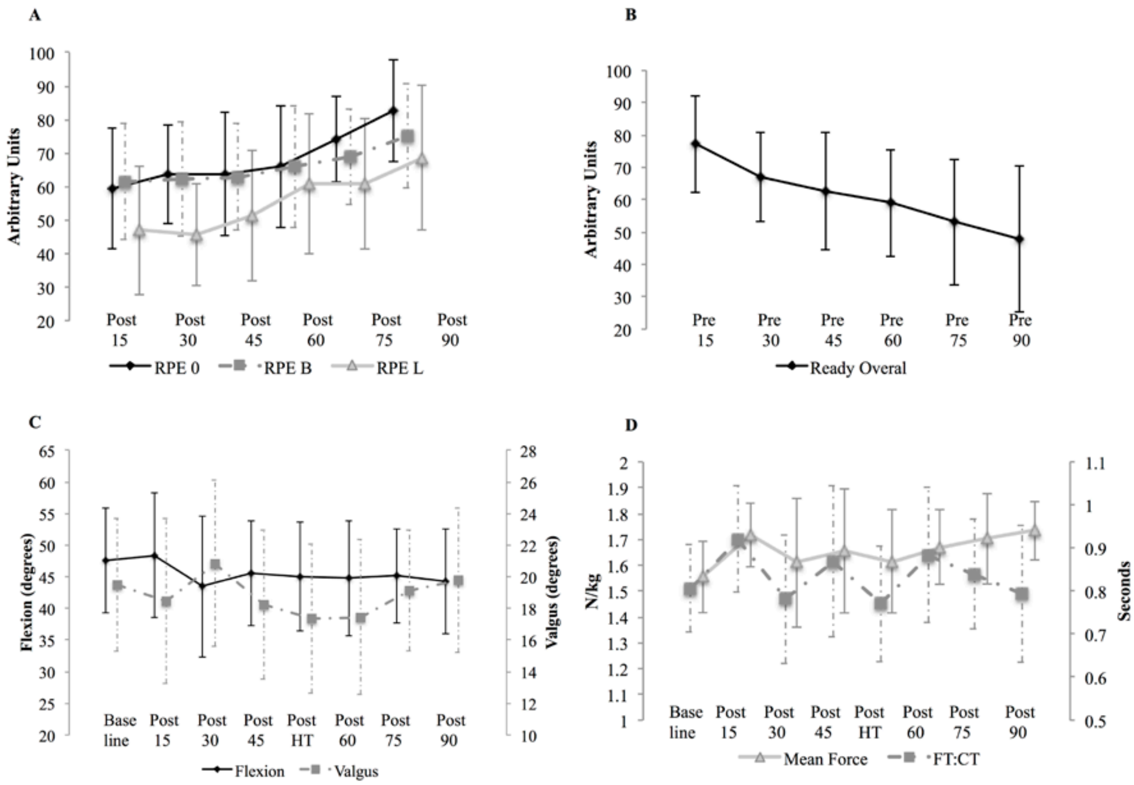
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Valgus (degrees)
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Base line
Post 15
Post 30
Post 45
Post HT
Post 60
Post 75
Post 90
Flexion
Valgus
D
N/kg
2
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1.7
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Seconds
1.1
1
0.9
0.8
0.7
0.6
0.5
Base line
Post 15
Post 30
Post 45
Post HT
Post 60
Post 75
Post 90
Mean Force
FT:CT

*Table 1.* Raw changes (±90% Confidence Limits) in arbitrary units for subjective measures of d-RPE and readiness between each time series and A: the first 15 minute interval of the SAFT$^{90}$ protocol B: the proceeding 15 minute interval of the SAFT$^{90}$ protocol.

| **A** | **Between time series differences** | | | | |
|---|---|---|---|---|---|
| | Post 30 minutes | Post 45 minutes | Post 60 minutes | Post 75 minutes | Post 90 minutes |
| **RPE 0** | 4.4 ±10 | 0.002 ±0.3 | 6.6 ±10 | 15 ±10 * | 23 ±9.3 ** |
| | Unclear | Very likely trivial | Likely small | Very likely moderate | Most likely large |
| **RPE B** | .95 ±10 | 1.5 ±10 | 4.6 ±10 | 8.2 ±10 | 14 ±10 * |
| | Possibly trivial | Possibly trivial | Unclear | Possibly small | Very likely large |
| **RPE L** | -1.4 ±12 | 4.4 ±12 | 14 ±12 | 14 ±12 | 22 ±12 ** |
| | Possibly trivial | Possibly small | Likely moderate | Likely moderate | Likely moderate |
| | Pre 15 to 30 minutes | Pre 30 to 45 minutes | Pre 45 to 60 minutes | Pre 60 to 75 minutes | Pre 75 to 90 minutes |
| **Readiness** | -10 ±11 | -15 ±11 * | -18 ±11 ** | -24 ±12 ** | -29 ±12 ** |
| | Likely moderate | Very likely moderate | Very likely large | Most likely large | Most likely large |
| Significance *p<0.05 **p<0.01 | | | | | |

| **B** | | | | |
|---|---|---|---|---|
| | Post 45 – post 30 minutes | Post 60 - post 45 minutes | Post 75 – post 60 minutes | Post 90 – post 75 minutes |
| **RPE 0** | 0.002 ±0.3 | 2.2 ±10 | 8.3 ±10 | 8.3 ±10 |
| | Very likely trivial | Very likely trivial | Likely small | Likely small |
| **RPE B** | .53 ±9.9 | 3.1 ±10 | 2.9 ±5.2 | 6.2 ±10 |
| | Possibly trivial | Possibly trivial | Possibly trivial | Unclear |
| **RPE L** | 5.8 ±12 | 9.4 ±12 | 0.026 ±11 | 5.7 ±7.0 |
| | Possibly small | Likely small | Possibly trivial | Unclear |
| | Pre 30 to 45 – pre 15 to 30 minutes | Pre 45 to 60 – pre 30 to 45 minutes | Pre 60 to 75 – pre 45 to 60 minutes | Pre 75 to 90 – pre 60 to 75 minutes |
| **Readiness** | -4.3 ±11 | -3.6 ±11 | -5.9 ±11 | -5.3 ±11 |
| | Possibly small | Unclear | Unclear | Unclear |
| Significance *p<0.05 **p<0.01 | | | | |

Table 2: Raw changes (±90% Confidence Limits) in knee kinematic and countermovement jumps measures between each time series and A: baseline and B: the proceeding 15 minute interval of the SAFT[90] protocol.

| **A** | **Between time series differences** | | | | | | |
|---|---|---|---|---|---|---|---|
| | Post 15 minutes | Post 30 minutes | Post 45 minutes | Post HT minutes | Post 60 minutes | Post 75 minutes | Post 90 minutes |
| **FT:CT Ratio** | .11 ±.086 *<br>Very likely moderate | -.026 ±.088<br>Possibly small | .062 ±.086<br>Unclear | -.037 ±.087<br>Unclear | .077 ±.088<br>Unclear | 032 ±.086<br>Unclear | -.013 ±.087<br>Possibly trivial |
| **Mean Force (N/kg)** | .16 ±.11 *<br>Very likely moderate | .056 ±.11<br>Unclear | .10 ±.11<br>Unclear | .059 ±.11<br>Unclear | .12 ±.11<br>Unclear | .15 ±.11<br>Very likely moderate | .18 ±.11<br>Very likely large |
| **Flexion (degrees)** | .76 ±5.5<br>Unclear | -4.1 ±5.4<br>Unclear | -2.0 ±5.4<br>Unclear | -2.6 ±5.4<br>Unclear | -2.8 ±5.4<br>Unclear | -2.5 ±5.4<br>Unclear | -3.3 ±5.5<br>Unclear |
| **Knee Valgus (degrees)** | -1.3 ±5.3<br>Possibly trivial | 1.4 ±5.2<br>Possibly small | -1.2 ±5.2<br>Possibly trivial | -2.1 ±5.2<br>Unclear | -2.0 ±5.2<br>Unclear | -.33 ±5.2<br>Possibly trivial | 34 ±5.3<br>Possibly trivial |

Significance *p<0.05 **p<0.01

| **B** | | | | | | |
|---|---|---|---|---|---|---|
| | Post 30 – post 15minutes | Post 45 – post 30 minutes | Post HT - post 45 minutes | Post 60 – post HT minutes | Post 75 – post 60 minutes | Post 90 – post 75 minutes |
| **FT:CT Ratio[b]** | -.14 ±.086<br>Very likely large | .088 ±.087<br>Unclear | -.099 ±.086<br>Likely moderate | .11 ±.086<br>Unclear | -.045 ±.087<br>Possibly small | -.045 ±.086<br>Possibly small |
| **Mean Force (N/kg)** | -.11 ±.11<br>Likely moderate | .044 ±.11<br>Unclear | -.04 ±.11<br>Unclear | .056 ±.11<br>Unclear | .032 ±.11<br>Unclear | .032 ±.11<br>Unclear |
| **Flexion (degrees)** | -4.9 ±5.5<br>Unclear | 2.1 ±5.4<br>Possibly small | -.51 ±5.4<br>Unclear | -.27 ±5.4<br>Unclear | .36 ±5.4<br>Unclear | .89 ±5.5<br>Unclear |
| **Knee Valgus (degrees)** | 2.7 ±5.3<br>Unclear | -2.6 ±5.2<br>Unclear | -.88 ±5.2<br>Possibly trivial | .12 ±5.2<br>Possibly trivial | 1.7 ±5.2<br>Possibly small | .68 ±5.3<br>Possibly trivial |

**Abbreviations:** FT:CT: flight time to contraction time; N/kg: Newton's per kilogram of body weight; HT: Half-Time
Significance *p<0.05 **p<0.01

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