CHANGES IN HAMSTRING ECCENTRIC PEAK TORQUES AND ANGLES OF PEAK TORQUE FOLLOWING 90 MINUTES OF SOCCER SPECIFIC EXERTIONS

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Abstract

This study aimed to investigate the effects of a ball-oriented soccer match-play simulation on the hamstrings eccentric torque production. Seven male recreational athletes volunteered for this study. Participants completed 90-minutes of the ball-oriented soccer simulation interceded by a 15-minute half time interval with five successful trials of hamstrings eccentric contractions on an isokinetic dynamometer at selected time points throughout the simulation. A 2 (limb: dominant; non-dominant) $\times$ 4 (time: 0 min; 45 min; 60 min; 105 min) "split-plots" analysis of variance (SPANOVA) revealed significant reductions in hamstrings eccentric peak torques over time, while no significant change was apparent in hamstrings eccentric angles of peak torque. There was also no interaction effect of limb dominance over time for both peak torque and angles of peak torque parameters. The observed changes suggest that exertions from a ball-oriented soccer match-play simulation may have detrimental effects on the hamstrings eccentric strength parameters thus may increase risk of ACL injury. High variabilities in angles of peak torques were also observed in this study. Future exploration is warranted in order to address the extent of variabilities that may be present in larger sample sizes thus providing a better understanding of the influence of these variabilities on the muscular strength parameters of ACL injury risk. The findings suggest firstly, that fatigue from soccer-specific exertions during match-play may increase an athlete's susceptibility to ACL injury, and secondly, that with accumulating fatigue, the nondominant limb may be equally at risk of injury as the dominant limb, contradicting previous findings from epidemiological studies.

Keywords: Hamstrings, eccentric, ACL injury, peak torque, soccer

Introduction

Noncontact Anterior Cruciate Ligament (ACL) injury in soccer has been identified to be multifactorial in nature. Risk factors of noncontact ACL injury are categorized into internal and external factors (Alentorn-Geli et al., 2009; Dai et al., 2012; Shultz et al., 2012), all of which would uniquely contribute to the loading of the ACL. External factors may vary vastly to include playing surface, the selection of gear, environment conditions and the profile of the game, as was observed by Herrero et al. (2014), that match-play injuries appear to be more prevalent than injuries sustained during practice sessions, and as mentioned by Bjordal et al. (1997) who found that higher levels of competitions witness more incidences of injury, likewise, more injuries tend to occur while players were on the offensive. These conditions suggest that noncontact ACL injuries may be caused by the increased physical demand imposed on the players.

Whereas internal factors to noncontact ACL injury refer to physiological (i.e. hormonal, biochemical), or biomechanical (i.e. posture, muscular activation) changes that players may experience in the prior moments leading up to the incidence of injury, such as increased knee joint laxity (Shultz & Schmitz, 2009; Shultz et al., 2013) and reduced muscular torque production during concentric contractions of the hamstrings and the quadriceps (Rahnama et al., 2003; Söderman et al., 2001) following exertions in soccer. In line with the observation by Hawkins et al. (2001) that the injuries tend to occur more during the later stages of match-play, these studies have shown support for the idea that repeated exertions over long durations may have adverse effects on the muscles and joints, making them vulnerable to injuries. Specifically, in the interest of this study, biomechanical risk factors are investigated as they may be modifiable through interventions or prevention programs.

Through previous epidemiological studies, noncontact ACL has been identified to happen during instances of deceleration, with the knees and hips extended and abducted; often represented by landings during tasks such as side-cutting, countermovement jumps and bounding (Blackburn & Padua, 2008; Quatman et al., 2010). It was proposed by Hashemi et al. (2011) that co-contraction of the lower limb muscles, especially the hamstrings and the quadriceps, play a role in protecting the ACL from vulnerabilities during these landing tasks. With the knees extending out as players prepare for landing, the large torque magnitude produced by the quadriceps concentric contractions need to be facilitated by the eccentric contraction from the hamstrings. Thus explains why Tsepis et al. (2004) suggested that the hamstrings eccentric torque production is a key factor for ACL injury. Studies investigating the effects of soccer-specific exertions on hamstrings eccentric torque production have simulated match-play have previously replicated soccer-specific running profiles (i.e. sprinting, walking, striding and jogging) in match-play duration simulations (Greig, 2008; Greig, 2019; Raja Azidin et al., 2014; Raja Azidin et al., 2013; Small et al., 2010). Such simulations conducted on overground surfaces have also incorporated utility movements and multidirectional components to the simulation to further interrogate the effects of fatigue on the hamstrings eccentric torque production variables (Bossuyt et al., 2015; Raja Azidin et al., 2014; Small et al., 2010). Unfortunately, the nature of many injuries in soccer revolves around ball handling actions such as being on the offensive, contesting possession, and landing from a heading, which imposes

additional physical demands on the player, thus demands further investigation. Therefore, this study aimed to investigate the effects of a ball-oriented soccer match-play simulation on the hamstrings eccentric torque production.

Methods

Participants

Seven (n = 7) male recreational athletes volunteered for this study. Mean (± SD) age, height and body mass are 25 ± 2 years' old, 1.69 ± 0.6 m, and 67.9 ± 6 kg respectively. Sample size computation was conducted using the G*Power statistical software (version 3.1.9.2, Universität Kiel, Germany). To achieve a moderate effect size *f* of 0.25 and a statistical power of 80% with the α set at 0.05, 6 participants were required to assess the differences between dominant and nondominant limbs and changes in hamstring eccentric torque production variables over selected time points throughout the soccer match simulation. All participants attended to at least 1 training day per week which lasted approximately 1-2 training hours per session and admitted to no lower limb injury in 6 months prior to the testing session. These criteria were crucial for the validity of the data and to avoid interference in the participants' performance that may lead to a false reading of the data. Throughout the simulation, participants wore tight fitting compression suits and standardized footwear. A written informed consent was obtained from every participant and the study was administered in accordance to the guidelines set by the university ethics committee.

Experimental Design

This study took form of a single group, repeated measures design. Participants attended a familiarization session 4 – 7 days prior to the actual testing session. The familiarization session consisted of a 15-min submaximal trial of the ball-oriented soccer simulation and submaximal isokinetic dynamometer trials. During the actual testing session, participants completed 90-minutes of the ball-oriented soccer simulation interceded by a 15-minute half time interval, the isokinetic testing time points were selected to suit the standard Fédération Internationale de Football Association (FIFA) match-play timeline. Participants were guided through a 15-min standardized dynamic warm-up procedure followed by 10-minutes of passive rest before the soccer simulation commences. Immediately before the simulation, (0 min), at the end of the first half (45 min) immediately before the second half (60 min) and at the end of the simulation (105 min), participants performed 5 hamstrings eccentric (H_{ecc}) contractions on the isokinetic dynamometer using both their dominant and nondominant limbs, which were defined uniformly across participants as their preferred limb to kick a ball (Figure 1).
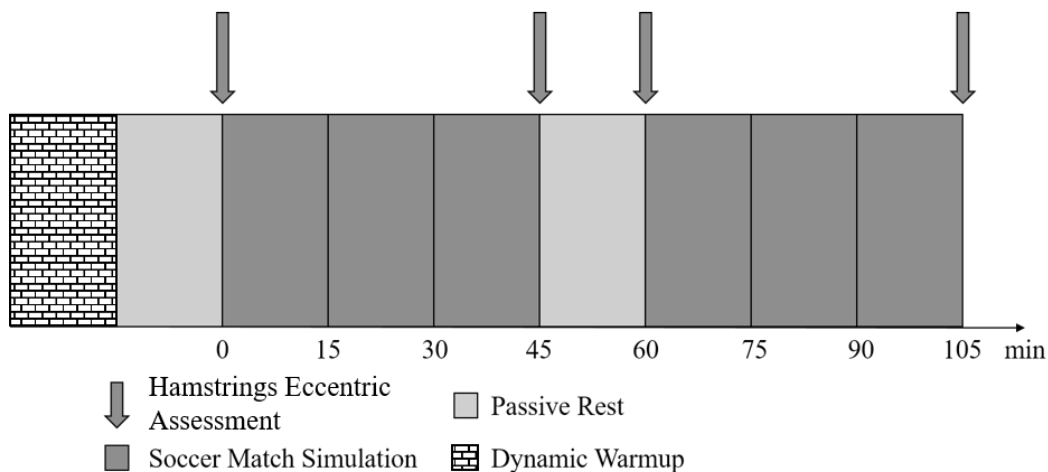
Figure 1: Timeline of data collection procedure

Throughout the soccer simulation, the participants' physiological responses were monitored using a heart rate monitor (Polar Heart Rate System, Electro, Finland) and the rate of perceived exertion (RPE, 20-point Borg Scale). During the 15-min passive half time interval, participants were instructed to remain seated and were allowed to drink water.

Ball Oriented Soccer Simulation

The Ball Oriented Soccer Simulation (BOSS) used in this study was adapted from the overground soccer match-play simulation by Raja Azidin et al. (2015) to include ball handling actions observed in actual soccer match-play such as heading, shooting, dribbling and passing (Figure 2). The overground soccer match-play simulation consisted of similar running profiles to that of an actual soccer match to reproduce physiological (Raja Azidin et al., 2015) and physical (Barreira et al., 2016) demands of soccer in a controlled setting. Ball handling actions were integrated into the overground soccer match-play simulation to match similar frequencies of actions (i.e. heading, passing, shooting) and total distance travelled with a ball (i.e. dribbling) per player per match as according to the data reported by Di Salvo et al. (2007), Link and Hoernig (2017) and Ruiz et al. (2017).
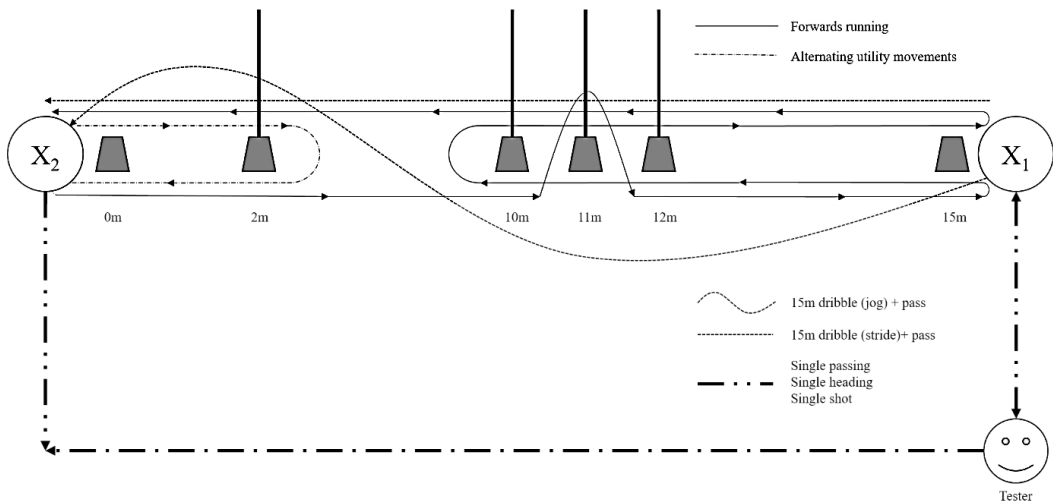
Figure 2: A schematic diagram of the BOSS layout.

Hamstrings Eccentric Strength Assessment

Maximal eccentric torque generated by the hamstrings was measured on an isokinetic dynamometer (EasyTech Prima Plus, Easytech, Italy). Participants were seated on the dynamometer with their trunk reclined at 85° and the test positions recorded and repeated for each participant in subsequent assessments. The crank axis was initially aligned with the axis of rotation of the medial femoral epicondyle using a resting position, which was then determined as the 90° knee flexion angle, and then followed up by and active submaximal effort of extension and flexion movement. During these movements, the average position of the knee joint axis was qualitatively monitored to be as close to the crank axis as possible. The dynamometer cuff was secured near the ankle, approximately 5cm proximal to the malleoli. The participants were strapped with restraints across their chest, hip and thighs, proximal to the knee joint. All participants were instructed to grasp on to either the chest straps or the handles next to the seat during all maximal trials. All maximal eccentric contraction trials were performed through a range of 90° to 0° knee flexion and extension at $120°·s^{-1}$. This test speed was adopted as it was proven to be accepted as one of the fastest, yet safest, speed to test eccentric hamstrings muscle contraction reliably (Rahnama et al., 2003; Small et al., 2010).

Data Analyses

Paired t-tests were used to assess the baseline assumption of similar pretest values between the dominant and non-dominant limbs. A 2 (limb: dominant; non-dominant) × 4 (time: 0 min; 45 min; 60 min; 105 min) split-plots analysis of variance (SPANOVA) was conducted for each dependent variable using the Statistical Package for Social Sciences (SPSS v. 26, IBM, New York, USA) with the alpha level fixed at 0.05. Equality of variances between limbs were assessed using Mauchly's test of sphericity, where sphericity violations were corrected accordingly to the Greenhouse-Geisser epsilon. An epsilon value of < 0.75 warrants the application of the Greenhouse-Geisser correction while epsilon values > 0.75

deserves the Hyunh-Feldt correction (Girden, 1992). Bonferroni post-hoc correction procedures was applied to control Type 1 errors as similar outcome measures were analyzed at each repeated measure. Limb dominance and time was treated as independent variables in this study, whereas dependent variables were the peak torques and the angles at peak torques for all H_{ecc} maximal contractions.

Results

Physiological Response

Mean heart rates during the BOSS (time 5 min to 105 min) was 149 ± 8 beats $\cdot$ min^{-1} while mean RPE during the simulation was 14 ± 1. Significant elevation in heart rate and RPE readings was observed (HR: $F_{19,114} = 10.892$, $p = 0.000$, partial $\eta^2 = 0.645$; RPE: $F_{19,114} = 16.539$, $p = 0.000$, partial $\eta^2 = 0.734$).

Hamstrings Eccentric Peak Torques

Significant changes were observed in H_{ecc} peak torques during maximal contractions overtime ($F_{2.172,26.021} = 9.706$, $p = 0.001$, partial $\eta^2 = 0.447$). However, no difference was observed for interaction effect of limb dominance on the peak torque production ($F_{2.172,26.021} = 0.280$, $p = 0.775$, partial $\eta^2 = 0.023$). Pairwise comparisons showed that the peak torques at 60 min and 105 min dropped significantly overtime in comparison to pretest values ($p < 0.05$; Figure 3).
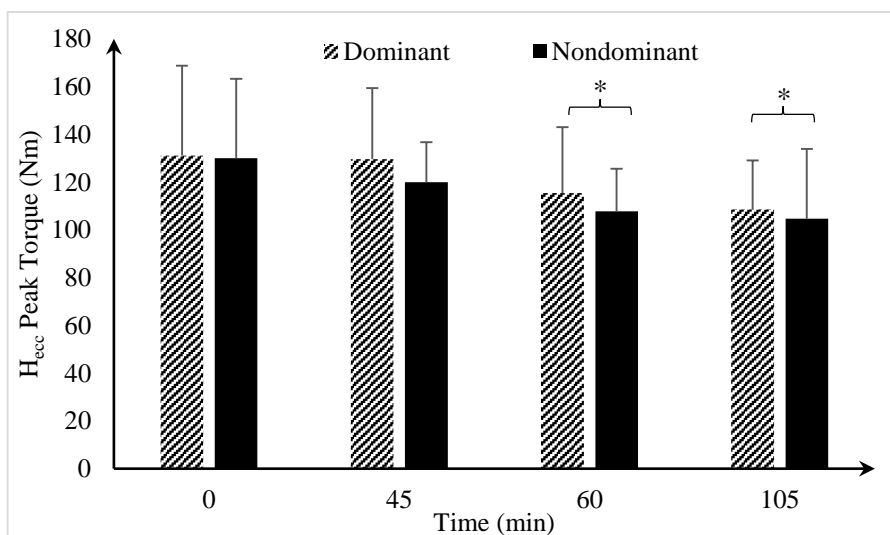

Figure 3: H_{ecc} peak torque profiles across selected time points throughout the BOSS. * represents significant difference compared to 0 min.

Hamstrings Eccentric Angles of Peak Torques

No significant changes were observed in H_{ecc} angles of peak torques during maximal contractions overtime ($F_{1.533, 18.390} = 0.893$, $p = 0.401$, partial $\eta^2 = 0.069$). Similarly, no difference was observed for interaction effect of limb dominance on the angles of peak torques ($F_{1.533, 18.390} = 0.164$, $p = 0.793$, partial $\eta^2 = 0.014$; Figure 4).
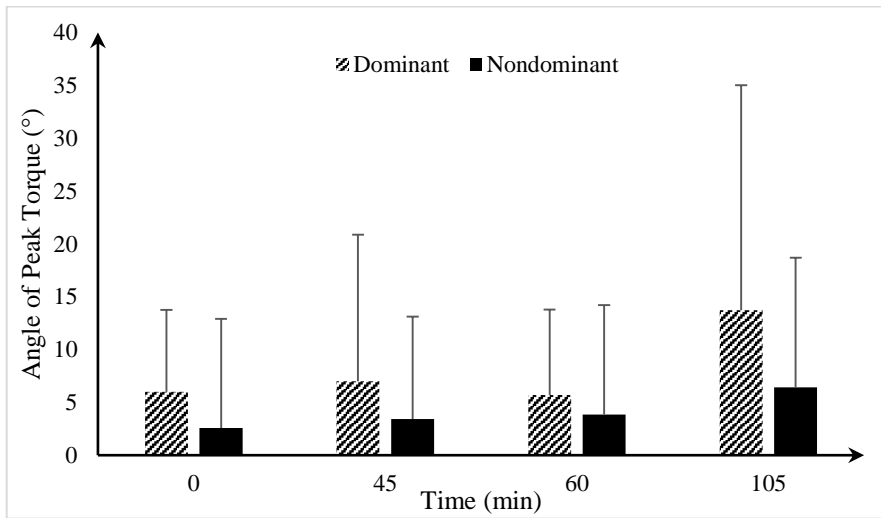

Figure 4: H_{ecc} angle of peak torque profiles across selected time points throughout the BOSS.

Discussion

The main findings of this study indicated that the BOSS induced significant increments in physiological responses and significant impairments in maximal H_{ecc} contraction parameters overtime. A 15 min passive half-time interval appears to have no positive influence in reversing these impairments. These changes have been hypothesized to contribute to an increased risk of ACL injury, and will be discussed in the subsections that follow.

Effects of the BOSS on Physiological Responses

Heart rate and RPE were significantly elevated overtime throughout the BOSS, indicating increased physiological demand. The mean heart rate for the BOSS was 149 ± 9 beats · min^{-1} while mean RPE was 14 ± 1. Rating of perceived exertion matched previous studies by Raja Azidin et al. (2015) which was proven to induce similar physiological and physical demand to an actual soccer match. Mean heart rate for the BOSS simulation was similar to the previous study by Hamdan, Mohd Noh, et al. (2018), Hamdan, Ismail, et al. (2018) and Raja Azidin et al. (2015). The lower heart rate value reported in this study compared to the average range of $156 - 167$ beats · min^{-1} reported by Bangsbo et al. (1991), Mohr et al. (2003), Thatcher and Batterham (2004) and Van Gool et al. (1998) may be attributed

to the difference in playing level of the participants in the reported studies (recreational versus professional players). For example, the work-rates of recreational players in this study may be limited to a lesser amount of high-intensity physical exertion time than professional players, thus totalling to a reduced total of mileage during the simulation.

Effects of the BOSS on H_{ecc} Peak Torque

The SPANOVA revealed a significant main effect of time in H_{ecc} peak torques, however no apparent interaction effect of limb dominance on the changes in H_{ecc} peak torques over time. Similar main effects findings have been reported in previous studies by Greig (2008), Cohen et al. (2015), Raja Azidin (2015), Delextrat et al. (2013), Delextrat et al. (2010), Small et al. (2010) and Rahnama et al. (2003).

It was proposed that the reduction in H_{ecc} peak torques may be caused by the high accelerations and decelerations in multiple directions during the simulation, demanding high utility of eccentric hamstrings contractions in order to execute the tasks. Furthermore, the utility of ball-handling actions in the BOSS (i.e. kicking the ball, jumping for a header, and sprinting) would require eccentric hamstrings contractions during explosive knee extensions (Draganich & Vahey, 1990). These eccentric contractions are required to actively stabilize the knee and its passive restraints (Goldfuss et al., 1973; Hashemi et al., 2011; Markolf et al., 1978; Wojtys et al., 2002) and the reduction in torque may translate to loss of tibiofemoral stability, thus increasing the reliance of the passive restraints (i.e. the ligaments connecting the distal femur to the proximal tibia). This reliance, when combined with a myriad of possible conditions during initial foot contact (i.e. an extended knee, an erect landing posture, posteriorly shifted centre of mass, sudden perturbated activations) could create a moment of vulnerability that may overwhelm the ACL, leading to the structure's failure (Hashemi et al., 2011). Therefore, these reductions in H_{ecc} peak torques may be a key indicator in justifying the increased prevalence of injury as a function of match-play progression reported by Hawkins et al. (2001) and Ekstrand et al. (2011).

Effects of the BOSS on H_{ecc} Angle of Peak Torque

No significant effect of time in H_{ecc} angles of peak torques throughout the BOSS. Likewise, no interaction effect was detected between dominant and nondominant limbs for the parameter. This finding comes in agreement with previous report by Raja Azidin (2015) who investigated the effects of fatigue on angles of H_{ecc} peak torque. However, it should be noted that a range of between 128% to 151% increase in angles of peak torque for the dominant (6° vs. 13.7°) and nondominant (2.6° vs 6.4°) limbs respectively between pretest and post-simulation trials. This observation comes in agreement with that observed by Small et al. (2010), who implicated that the increment translates to a shorter muscle length with the accumulation of fatigue, which further translates to a greater risk of ACL injury as Brockett et al. (2001) and Proske et al. (2004) believe that athletes who produce peak torque at shorter muscle lengths are more susceptible to injury.

Brughelli and Cronin (2007) coined that the peak torque production with a reduced muscle length would implicate that the muscles are inclined to operate at the descending limb of the length-tension curve. With such combination as a reduced angle of peak H_{ecc} torque, a

reduced H_{ecc} peak torque (Small et al., 2010) and increased knee extension during single-legged task landings (Greig, 2009; Hamdan, Ismail, et al., 2018; Hamdan, Mohd Noh, et al., 2018; Raja Azidin et al., 2015; Sanna & O'Connor, 2008) during later stages if match-play, the muscles are forced to work in a lengthened state (Garrett, 1990) – outside their favourable range, thus maybe explaining the increased prevalence of injuries in later stages of match-play.

Effects of Limb Dominance on H_{ecc} Parameters' Deteriorations

The SPANOVA interaction effects revealed no significant effects of limb dominance on both H_{ecc} parameters over time. This finding implies that unlike a previous epidemiological observation by Brophy et al. (2010), the nondominant limb may actually be equally susceptible to injury as the dominant limb regardless of the fatigue condition. Similar reports of equal peak torque values across limb dominance has been reported by Hageman et al. (1988) among healthy, recreational participants, however, Grace et al. (1984) reported up to 10% difference between dominant and nondominant peak torques during preseason stage among high school football players and Wyatt and Edwards (1981) also noted significant differences between limbs of male participant with no prior participation in sport at any level. We attribute the discrepancies in results reported between this study and that of Grace et al. (1984) and Wyatt and Edwards (1981) to the characteristics of the population tested. The participants in this study were collegiate recreational athletes who attended to regular training sessions while Grace et al. (1984) observed high school athletes and the participants in the study by Wyatt and Edwards (1981) had no prior involvement in sport nor training.

Practical Implications

Reductions in H_{ecc} strength parameters observed in this study occurred in the later stages of match-play. This suggests that fatigue may inhibit eccentric contraction, which may be buffered with improved tolerance to fatigue which could be achieved by training the hamstrings eccentrically (i.e. eccentric hamstrings curls, Nordic hamstrings curls) in a fatigued state (i.e, at the end of training sessions, after small-sided game sessions) (Greig & Siegler, 2009; Schmitt et al., 2012; Small et al., 2009).

Limitations

Several limitations should be considered in this study. Firstly, this study used a small sample to be observed (n = 7). Although the sample size calculation revealed that the number is sufficient, we observed high variabilities in H_{ecc} angles of peak torque between the participants. These variabilities may be reflective of different fatigue-induced strategies altered by each participant in order to cope with the requirements of the exertions (Adlerton et al., 2003). Future exploration is warranted in order to address the extent of variabilities that may be present in larger sample sizes thus providing a better understanding of the influence of these variabilities on the muscular strength parameters of ACL injury risk.

The utility of the isokinetic dynamometer model in thus study also did not allow for a smoothed averaged reading of peak torques which may allow better reproducibility rather than taking a single highest value (Sole et al., 2007). This limitation also meant that the analysis was only able to be conducted in a scalar perspective. Perhaps a vector analysis of a time-series data, using one-dimensional statistical parametric mapping (SPM1D, (Pataky, 2012; Pataky et al., 2013)) may provide a richer understanding of the role of fatigue on the H_{ecc} peak torque production parameters.

Conclusion

The findings of this current study revealed reductions in H_{ecc} peak torques and alterations in its angles of peak torque. These deteriorations, however, do not seem to be affected by limb dominance. The findings suggest firstly, that fatigue from soccer-specific exertions during match-play may increase an athlete's susceptibility to ACL injury, and secondly, that with accumulating fatigue, the nondominant limb may be equally at risk of injury as the dominant limb, contradicting previous findings from epidemiological studies. Thus, further exploration of data may be warranted on the role of limb dominance on ACL injury risk and the role of inter- and intra-participant task execution variabilities in regard to ACL injury risk.

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