Isokinetic Strength Differences Between Elite Senior and Youth Female Soccer Players Identifies Training Requirements

ABSTRACT

*Objectiv*es: To compare traditional and angle-specific isokinetic strength of eccentric knee flexors and concentric knee extensors in female senior professional and youth soccer players. *Design*: Cross-sectional study design. *Setting:* University's Laboratory. *Participants:* A total of 34 players (17 seniors [age 25.31 ± 4.51 years; height 167.89 ± 7.04cm; mass 63.12 ± 7.79kg] and 17 youths [16.91 ± 1.16 years; height 165.92 ± 4.42cm; mass 60.07 ± 4.48kg]) from the Women's Super League 1 completed strength assessments at 180, 270 and $60°\cdot s^{-1}$. *Main Outcome Measures*: Peak torque (PT), dynamic control ratio (DCR), angle of peak torque (APT), functional range (FR), angle-specific torque (AST) and angle-specific DCR (DCR_{AST}) were compared between age groups. *Results*: The PT (P = 0.016) AST (P = 0.041) were significantly higher in seniors compared to youths; however APT (P = 0.141), DCR (P = 0.524) FR (P = 0.821) and DCR_{AST} (P = 0.053) were not significant between playing age. *Conclusion*: The use of absolute and angle-specific strength measures were able to distinguish between female playing ages, whereas DCR and DCR_{AST} was unable to identify differences. The PT and AST metrics may be the most useful metrics to help identify and inform training needs, particularly in youths.

Key words: age, hamstring, quadriceps, injury risk, screening.

INTRODUCTION

Previous research has identified that thigh muscular and knee ligament injuries are most prevalent in elite senior and youth female soccer players (Faude et al. 2005; LeGall et al. 2008). The higher injury incidence in youths (LeGall et al. 2008) is typically associated with adolescent growth whereby players undergo a maturational change in stature that is disproportionate to strength developments (Hewett et al. 2006), thus creating an increased injury risk (Hewett et al. 2004). Increased muscular strength has therefore commonly been reported as a modifiable risk factor for both thigh muscular (Croisier et al. 2008; Lee et al. 2017) and knee ligament injuries (Söderman et al. 2002; Ryman Augustsson and Ageberg, 2017). Although common in literature specific to male athletes (Gür et al. 1999; Kellis et al. 2001; Eustace et al. 2018), limited literature currently exists assessing differences in thigh muscular strength between youth and senior females.

In elite soccer, isokinetic dynamometry has commonly been considered as the gold standard for strength assessments; however, the use of isokinetic dynamometry for predicting injury has recently been questioned (Van Dyk et al. 2016, 2017; Green et al. 2018). Despite these criticisms, prospective studies utilising isokinetic strength assessments have previously identified significantly lower thigh musculature strength values in injured soccer players when compared to non-injured (Croisier et al. 2008; Van Dyk et al. 2016; Lee et al. 2017). However, the relevance of isokinetic dynamometry has been questioned as these assessments lack application to functional movements (Toonstra and Mattacola, 2013). The aforementioned prospective studies that quantified eccentric knee flexor (eccKF) and concentric knee extensor (conKE) strength at angular velocities of $\leq 120°\cdot s^{-1}$ are substantially lower than the knee angular velocities exhibited during tasks associated with injury ($\sim 400°\cdot s^{-1}$) (Nedergaard et al. 2014). Thus, adopting higher angular velocities for the assessment of eccKF and conKE strength may also identify strength discrepancies that are increasingly relevant to movements performed in soccer, and may subsequently enhance the functional relevance of outcome measures (De Ste Croix et al. 2017).

The choice of outcome measures should also be considered, with measures such as peak torque (PT) and dynamic control ratios (DCR) recently being critiqued due to the lack of consideration for how strength is maintained over an angular range (De Ste Croix et al. 2017). These recent criticisms are attributed to the different angle of peak torques for eccKF (~40° of flexion) and conKE (~70° of flexion) (Eustace et al. 2017; 2018), thus PT and DCR are quantified from different joint angles, and as such, cannot determine co-contraction ability of these musculature. An additional metric that also considers the torque-angle curve is functional range, which quantifies how far 85% of PT can be maintained across range of motion since 15% strength deficits have been previously associated with increased injury risk in soccer (Croisier et al. 2008). As lower limb injury risk is suggested to be greatest at knee joint angles ≤ 40° (Hewett et al. 2010; De Ste Croix et al. 2017), profiling thigh musculature strength across an angular range would determine strength measures where injury is more likely to occur. These metrics have been previously quantified in male soccer players and identified significant differences for the thigh musculature between senior and youths (Eustace et al. 2017, 2018; Van Dyk et al. 2017), but are unexplored in females.

The aim of the current study was to compare bilateral and ipsilateral strength characteristics of the knee flexor and knee extensor musculature between elite senior and youth female soccer players using both traditional and contemporary isokinetic metrics. It was hypothesised that youth female soccer players would demonstrate significantly lower isokinetic strength characteristics when compared to senior aged players.

MATERIALS AND METHODS

Participants

A priori power calculation from pilot data identified a sample size of 17 participants for each age group was required to evaluate the interactions for all dependent variables (for statistical power .0.8; $P \leq 0.05$) were performed in G*Power 3.0.10. Seventeen senior female players (age 25.31 ± 4.51 years; height 167.89 ± 7.04cm; mass 63.12 ± 7.79kg) and seventeen youth players (age 16.91 ± 1.16 years; height 165.92 ± 4.42cm; mass 60.07 ± 4.48kg) were therefore recruited. The participants were recruited from the same club, with the senior squad competing in in the English first division of female soccer. All players were free from lower limb injury for >6 months prior to data collection. In addition to weekly matches, player’s training volumes were >10hr·week^{-1} and >5hr·week^{-1} for seniors and youths, respectively. Prior to the commencement of the study, all participants completed a health, physical activity, pre-exercise control questionnaire. All participants were informed of the risks associated with this study before providing written consent. Parent/guardian assent was also obtained for the youth players aged below 18 years. The current study was approved by the host university ethics committee. Equipment was risk assessed and calibrated in accordance to the manufacturer's guidelines.

Participants attended the laboratory on two occasions to complete a familiarisation trial and an experimental trial, interspersed by a minimum of 96hr. The procedures of the familiarisation trial replicated the experimental condition. To control for circadian variation (Rae et al. 2015), testing was conducted in accordance with the player's regular training times. Participants attended the laboratory in a 3hr post-absorptive state following a 48hr abstinence from exercise. As previous observations have identified that isokinetic strength measures of the thigh musculature are consistent across different phases of the menstrual cycle (Gür et al. 1999; Abt et al. 2007; Gordon et al. 2013) the current study therefore did not control for menstruation. Prior to the start of each trial, participants were required to complete a standardised 5-minute warm-up on a stationary cycle ergometer (Monark, 824E, Sweden) at 60 W.

The experimental trial comprised the completion of bilateral isokinetic (System 4, Biodex Medical Systems, Shirley, New York, USA) strength assessments of eccKF and conKE musculature at angular velocities in the order of 180, 270, and 60°·s^{-1} (Greig, 2008). For each angular velocity and contraction mode, the participants were instructed to provide 3 maximal contractions. A 60 second rest period was provided between each angular velocity (Lee et al. 2017), and no performance feedback or instructions were provided during the experimental procedures due to reported effects on isokinetic torque (Campenella et al. 2000) and due to equivocal results when giving internal and external instructions during isokinetic strength assessments (Marchant et al. 2009; Marchant and Greig, 2017). The range of motion (ROM) of the knee joint was set at 25-90° (0° = full extension) with the anatomical reference set at 90°. Participants was secured in a seated position with approximately 90º hip flexion, with restraints applied proximal to the knee joint, thigh, waist and chest. The lever arm alignment to the lateral femoral epicondyle was conducted in a position between knee extension and flexion to account for potential misalignment that can occur during the completion of the exercise.

Data Analyses

The isokinetic phase of each repetition was analysed, and the repetition eliciting the highest gravity-corrected torque was subject to further analysis. The isokinetic phase was identified at the constant angular velocity by applying a 1% cut-off. The peak torque (PT) and corresponding angle (APT) were identified. The functional range (FR) was defined as the range over which 85% of PT was maintained (Eustace et al. 2017). The dynamic control ratio (DCR) was calculated by dividing eccKF PT by conKE PT for each respective limb and angular velocity. Likewise, eccKF and conKE data recorded for specific knee joint angles were used to calculate the angle-specific DCR (DCR_{AST}) for each respective limb and angular velocity. Angle-specific torque (AST) was identified by exporting the raw data, and the highest torque values for each contraction mode and velocity were used for further analyses. The AST and angle-specific DCR_{AST} were identified at 10° increments between 70-40° that were common across all angular velocities.

Statistical Analyses

To establish if significant differences existed between playing age, the data was analysed using a repeated measures general linear model (GLM), with none of the current measures violating any of the assumptions. Where significant main effects or interactions were observed, post-hoc pairwise comparisons with a Bonferonni correction factor were applied. 95% confidence intervals (CI) for differences were also reported. Partial eta squared (η^2) values were calculated to estimate effect sizes for all main effects and interactions, and classified as small (0.01 to 0.059), moderate (0.06 to 0.137), and large (>0.138) (Cohen et al. 1998). For PT and AST measures, mass was entered as a covariate to account for these effects. For all variables associated with the current study, absolute agreement intraclass correlation coefficients (ICCs) were calculated and interpreted as <0.2 = slight, 0.21–0.4 = fair, 0.41–0.6 = moderate, 0.61–0.8 = substantial, and >0.8 = almost perfect reliability (Landis et al. 1997). Pearson's correlation was used to determine the relationship between strength measures (PT and AST) and playing age across angular velocities, angles, contraction modes and between dominant and non-dominant limbs. Independent T-tests were also performed between height and mass for playing age. All statistical analysis was completed using PASW Statistics Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $P \leq 0.05$. All data is reported as mean and standard deviation unless otherwise stated.

RESULTS

Independent t-tests identified that height (P = 0.123) and mass (P = 0.099) were not significantly different between these groups. The ICC's for all data are presented in Table 1.

[Table 1 here]

Table 2 summarises the influence of playing age on PT for all testing velocities recorded for both lower limbs, and identified a significant three-way interaction for contraction mode, angular velocity and limb (P = 0.016; η^2 = 0.122). The GLM revealed significantly higher values recorded for senior female soccer players when compared to youths across angular velocities, and contraction mode, between dominant and non-dominant limbs. Significant differences between dominant and non-dominants limbs were also identified for the eccKF data recorded for both groups, with increased discrepancies identified in youths. The main effects for angular velocity (P < 0.001; η^2= 0.833) and limb (P = 0.004; η^2= 0.234) were also significant. No significant interactions for age, contraction mode, angular velocity (P = 0.119; η^2 =0.064), age, limb angular velocity (P = 0.555; η^2 = 0.018) or age, limb, contraction mode (P = 0.653;

η^2= 0.006) were identified. No significant main effect for contraction mode was also identified (P = 0.228; η^2= 0.045). In addition, Pearson's correlation identified positive and significant correlations between PT and playing age across contraction modes, angular velocities and between dominant and non-dominant limbs for all data (R = 0.396-0.612; $P < 0.05$). When body mass was entered as a covariate, no significant main effect was identified for all independent variables (P = 0.107; η2 = 0.069).

[Table 2 here]

Table 2 also summarises the influence of playing age on FR for all testing velocities recorded for both lower limbs. A significant main effect for contraction mode was identified ($P < 0.001$; η2 = 0.374) with higher values identified in eccKF (28.91 ± 9.87º) when compared to conKE (23.40 ± 6.86). A significant main effect for angular velocity ($P < 0.001$; η^2 = 0.217) was also identified with data collected at 270°·s^{-1} (23.74 ± 7.19º) being significantly lower when compared to 180°·s^{-1} (27.64 ± 9.23º) and 60°·s^{-1} (27.06 ± 9.25º). However, no significant main effect for limb was identified (P = 0.060; η^2= 0.093). Likewise, no significant two-way interactions for age and angular velocity (P = 0.199; η^2= 0.049), age and contraction mode (P = 0.255; η^2= 0.040), or for age and limb (P = 0.620; η^2= 0.008) were identified. No interactions for age, contraction mode, angular velocity (P = 0.425; η^2 =0.026), age, limb angular velocity (P = 0.333; η^2 = 0.034) or age, limb, contraction mode (P = 0.147; η^2= 0.065) were also identified. Moreover, the GLM identified no four-way interaction for age, angular velocity, contraction mode and limb (P = 0.821; η^2 = 0.006).

For APT, the GLM identified a significant main effect for limb (P = 0.004; η^2 = 0.232), with higher values identified in the non-dominant limb (56.3 ± 0.2º) when compared to the dominant limb (53.5 ± 0.3º; 95%CI: 1.0 to 4.7º). A significant main effect for angular velocity were also identified (P = 0.001; η^2 = 0.206) with data recorded at 270°·s^{-1} (56.9 ± 7.5º) being higher than that recorded at 180°·s^{-1} (52.7 ± 8.6º; 95%CI: 1.6 to 6.8º), and the data recorded at 60°·s^{-1} (55.1 ± 7.7º) being higher than that recorded at 180°·s^{-1} (95%CI: 0.1 to 4.7º). Moreover, a significant main effect for contraction mode ($P < 0.001$;

$\eta^2 = 0.953$) was also identified with the conKE (67.4 to 5.7º) data being higher than the eccKF data (42.4 ± 10.42º; 95%CI: 23.0 to 27.0º). The GLM also identified no two-way interactions for age and angular velocity ($P = 0.178$; $\eta^2 = 0.053$), or age and limb ($P = 0.794$; $\eta^2 = 0.002$). There were also no significant three-way interactions for age, contraction mode, and angular velocity ($P = 0.499$; $\eta^2 = 0.021$), age, limb, and angular velocity ($P = 0.060$; $\eta^2 = 0.084$) and age, limb, and contraction mode ($P = 0.854$; $\eta^2 = 0.001$). The GLM identified no four-way interaction for age, angular velocity, contraction mode and limb ($P = 0.141$; $\eta^2 = 0.059$).

Table 3 summarises the influence of playing age on DCR for all testing velocities recorded for both lower limbs. The GLM identified a significant main effect for angular velocity ($P < 0.001$; $\eta^2 = 0.454$) identified higher values recorded at 270°·s^{-1} (1.30 ± 0.17) when compared to both 180°·s^{-1} (1.16 ± 0.19; 95%CI: 0.27 to 0.73) and 60°·s^{-1} (0.83 ± 0.31; 95%CI: 0.2 to 0.31), and higher values recorded at 180°·s^{-1} when compared to 60°·s^{-1} (95%CI: 0.18 to 0.49). However, there was also no significant main effect for limb ($P = 0.101$; $\eta^2 = 0.085$). Likewise, no two-way interactions for age and angular velocity ($P = 0.679$; $\eta^2 = 0.036$) or age and limb ($P = 0.304$; $\eta^2 = 0.071$) were identified. The GLM also identified no four-way interaction for age, angular velocity, contraction mode and limb ($P = 0.524$; $\eta^2 = 0.050$).

[Table 3 here]

Table 4 summarises the influence of playing age on AST for all testing velocities recorded for both lower limbs, and identified a significant three-way interaction for contraction mode, angle, angular velocity and limb ($P = 0.041$; $\eta^2 = 0.081$). The GLM revealed significantly higher values recorded for senior female soccer players when compared to youth players across angular velocities, knee joint angles, contraction mode, and lower limbs. It was also identified that the non-dominant limb's eccKF AST were significantly lower when compared to the dominant side, irrespective of playing age. These observed bilateral differences were greatest at increased knee extension angles, and illustrated by Table 4. Where significant differences between dominant and non-dominant limbs are presented in Table 4, larger 95%CI are identified with increased knee extension. In addition, Pearson's correlation identified positive and significant correlations between PT and playing age across contraction modes, angles, angular velocities and between dominant and non-dominant limbs for all variables (R = 0.338-0.630; $P < 0.05$). When body mass was entered as a covariate, no significant main effect was identified for all independent variables ($P = 0.891$; η2 = 0.012).

[Table 4 here]

The GLM identified a significant limb, angular velocity, and age ($P = 0.026$; $\eta^2 = 0.122$) interaction, with the youth athletes (1.84 ± 0.73) eliciting higher values at 270°·s^{-1} when compared to the senior athletes (1.46 ± 0.24; 95%CI: 0.20 to 0.73; $P = 0.040$). However, the GLM identified no four-way interaction for age, angular velocity, limb, and angle ($P = 0.053$; $\eta^2 = 0.076$), nor three-way interactions for age, angular velocity, and angle ($P = 0.086$; η^2= 0.092), or limb, angle and age ($P = 0.389$; η^2 = 0.028).

DISCUSSION

The purpose of this study was to assess isokinetic strength of eccKF and conKE musculature between elite senior and youth female soccer players. It was hypothesised that youth female soccer players would demonstrate significantly different isokinetic strength characterises when compared to their senior peers. The findings of this study demonstrate that the eccKF and conKE PT and AST values recorded for the youth female soccer players were significantly lower when compared to senior aged players. Irrespective of playing age, further observations identified that the non-dominant eccKF PT and AST data were significantly lower when compared to the dominant side across different testing velocities and joint angles. In support of the original hypotheses, the current study has identified that youth female soccer players are unable to elicit the same magnitude of torque across an angular range when compared to their senior counterparts. Although the reductions of thigh musculature strength values in youth female soccer may be relative to the demands of soccer match-play, youths may still benefit from specific training interventions that target strength developments of the eccKF and conKE, musculature across an angular range. In turn, this may help better prepare youth players who begin to compete against senior aged players during a period when injury risk is reportedly greatest (Söderman et al. 2002).

The observed differences in strength capacity of the eccKF and conKE musculature between the two groups is in support with previous observations across elite female soccer playing ages (Manson et al. 2014). These present findings are however not entirely in agreement with a similar study conducted in male players that identified that eccKF and conKE PT were not significantly different between seniors and youths, whereas eccKF and conKE AST yielded significant differences between these populations (Eustace et al. 2018). These observations may be attributed to male players having increasingly similar weekly training demands when compared to females. As a result, the significantly higher PT and AST values observed in the senior female soccer players are likely a result of increased training exposure (Kellis et al. 2001; Fousekis et al. 2011), with these data also supporting higher sprint and high intensity running distances observed in senior female players when compared to youths (Taylor et al. 2017). Since injury risk in youths is also further influenced in those who possess significant thigh musculature strength deficits when compared to their youth counterparts (Ryman Augustsson and Ageberg, 2017), the coupling of reduced strength capacities and increased match-play demands may increase injury risk in youth female soccer players who begin to compete against senior aged players (Söderman et al. 2002). Therefore, practitioners need to determine if youths are sufficiently conditioned to compete at increased match demands to avoid additional injury risk. Although the present procedures and analytical approaches may not be able to identify those at increased injury risk due to the complex interaction of many factors (Verhagen et al. 2018), these approaches may help identify if youth female soccer players possess sufficiently developed thigh musculature strength to compete in senior match-play.

The current data also advocates the assessment of thigh muscular strength across a range of knee joint angles and velocities to better identify additional strength training needs with increased functional relevance (Nedergaard et al. 2014; De Ste Croix et al. 2017; Eustace et al. 2017, 2018). The AST data demonstrates significant strength differences for the eccKF and conKE across all angular velocities and joint angles between senior and youth female soccer players. When considering that thigh musculature and knee ligament injuries commonly occur at increased knee extension angles (Boden and Dean, 2000; Chumanov et al. 2012), the observed strength differences between playing age may have implications for injury risk. The role of eccKF for injury risk reduction is primarily for shank deceleration during the terminal swing-phase of functional movements, and to act as agonists for the ACL by reducing strain (Shimokochi et al. 2009; Hewett et al. 2010). In relation to the conKE, these musculature are responsible for aiding dissipation of large impact forces during functional tasks and providing dynamic knee stability (Hughes and Watkins, 2006; Norcross et al. 2013). However, as the conKE were unable to elicit sufficient force during knee extension based on the present data and previous observations (Podraza and White, 2010), this places an increased importance of the eccKF to provide dynamic knee stability. To aid development of thigh musculature strength at increased knee extension angles, and lower the strength differences between female soccer playing ages, angle-specific strength training may be an appropriate intervention since strength developments have suggested to be greatest when training at the coincident joint angle (Barak et al. 2004). Therefore, functional (variants of deadlifts, squats and lunges) and isolated strengthening exercises for the knee flexors and knee extensors may be adapted to target strength developments at specific joint angles. Performing the aforementioned exercises at higher training velocities should consequently also be considered to improve force production during high-speed movements (Kawamori and Newton, 2006), and can also be adapted to target specific joint angles.

The findings of the present study also support the use of AST data for identifying bilateral strength differences between playing ages. With potential implications for injury risk, significant bilateral strength differences were identified for eccKF PT and AST for both age groups, with lower values recorded in the non-dominant limbs. The inclusion of AST data identified a trend where additional bilateral eccKF strength differences were observed at increased knee extension angles, with significantly lower values for the non-dominant limb. Similar findings were also observed by a study comparing male players, where it was demonstrated that AST identified significantly lower eccKF strength for the non-dominant limb when compared to the dominant side (Eustace et al. 2018). As the present data appears to suggest that the eccKF are the primary dynamic knee stabilisers at increased knee extension due to an inability of the conKE to elicit a large magnitude of force, this may result in a reduced capacity for the non-dominant eccKF to provide dynamic knee stability. In turn, these increased demands may place the eccKF at increased injury risk due to an inability of the musculature to elicit a sufficient amount of force to quickly decelerate the shank during the late-swing phase of functional tasks (Morgan and Proske, 2004). The inclusion of AST measures may therefore be appropriate for assessing bilateral strength differences in female soccer players and further inform exercise prescription to practitioners.

When considering the DCR and DCR_{AST} are derived from PT and AST data, respectively, it could also be expected that differences between female soccer playing ages for these measures for these measures may also exist. Although youths displayed significantly higher DCR_{AST} values at $270°\cdot s^{-1}$, no further differences were identified between playing age in relation to ratio data, despite the significant differences in PT and AST, and in agreement with previous observations identified between different male soccer playing ages (Eustace et al. 2018). These lower DCR_{AST} values at $270°\cdot s^{-1}$ could be indicative of a reduced injury risk when compared to their senior counterparts, but these conclusions are contrary to previous epidemiological observation (LeGall et al. 2008; Hägglund and Waldén, 2016) and may misinform player injury risk for youth female soccer players. Consequently, considering ratio data without corresponding strength values may incorrectly identify or disregard training needs. For example, an acceptable ratio can be achieved through equally impaired eccKF and conKE values and, as such, DCR and DCR_{AST} should be used with caution. The DCR metrics may have limited use in comparing between female playing age, supporting recent research that has questioned the usefulness of ratios in determining injury risk (Van Dyk et al 2016, 2017; Green et al. 2018).

Care should be taken when generalising beyond the specific population and experimental paradigm used. In relating the observations to injury management, it should be noted that the isokinetic phase did not include a full ROM, with data not meeting analysis criterion at full knee extension. When considering the aetiology of lower limb injuries in soccer (Boden and Dean, 2000; Chumanov et al. 2012) the use of increased knee angular velocities could be advocated; however, due to restrictions imposed by the equipment, and the reduced isokinetic phases which are observed at additional angular velocities, it was not possible to collect data at increased knee angular velocities. The current procedures and analytical approaches advance current practice, thus characterising thigh musculature strength with enhanced functional relevance.

CONCLUSION

The present study is the first to assess angle-specific measures of isokinetic strength of eccKF and conKE between professional female senior and youth soccer players across different angular velocities. The data presented in this study suggests that PT and AST are able to differentiate between players, suggesting that youth female soccer players have a reduced absolute muscular strength capacity that persists across an angular range. It is however advocated that the use of DCR and DCR_{AST} is used in conjunction with the corresponding torque values to avoid misinterpretation of player training needs. In turn, these approaches may be used to help practitioners identify if youth female soccer players possess sufficiently developed strength of the thigh musculature when beginning to compete against senior aged players during a period of increased injury risk. The approaches identified in this study may also inform the development of appropriate training strategies to aid athletic development and strength development of the thigh musculature in female soccer players.

Highlights

- Thigh musculature strength of female soccer players influenced by playing age
- No differences in strength ratios across female soccer playing age
- These metrics can inform training and better prepare youths for senior match-play

Declarations of interest: none.

REFERENCES

Barak, Y., Ayalon, M. and Dvir, Z. (2004) ‘Transferability of strength gains from limited to full range of motion’, *Medicine and Science in Sports and Exercise*. doi: 10.1249/01.MSS.0000135777.01093.21.

Boden, B. P. *et al.* (2000) ‘Mechanisms of Anterior Cruciate Ligament Injury’, *Orthopedics*. doi: 10.1016/j.ptsp.2008.01.002.

Brophy, R. *et al.* (2010) ‘Gender influences: The role of leg dominance in ACL injury among soccer players’, *British Journal of Sports Medicine*. doi: 10.1136/bjsm.2008.051243.

Campenella, B., Mattacola, C. G. and Kimura, I. F. (2000) ‘Effect of visual feedback and verbal encouragement on concentric quadriceps and hamstrings peak torque of males and females’, *Isokinetics and Exercise Science*. doi: 10.3233/IES-2000-0033.

Chumanov, E. S. *et al.* (2012) ‘Hamstrings are most susceptible to injury during the late swing phase of sprinting’, *British Journal of Sports Medicine*. doi: 10.1136/bjsports-2011-090176.

Cohen, J. Statistical Power Analysis for the Behavioral Sciences. (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates, 1988.

Croisier, J. L. *et al.* (2008) ‘Strength imbalances and prevention of hamstring injury in professional soccer players: A prospective study’, *American Journal of Sports Medicine*. doi: 10.1177/0363546508316764.

De Ste Croix, M.B.A., Elnagar, Y.O., Iga, J., Ayala, F., James, D. (2017). ‘The impact of joint angle and movement velocity on sex differences in the functional hamstring/quadriceps ratio’. *The Knee*. Doi: 10.1016/j.knee.2017.03.012.

Eustace, S. J., Page, R. M. and Greig, M. (2017) ‘Contemporary approaches to isokinetic strength assessments in professional football players’, *Science and Medicine in Football*. doi: 10.1080/24733938.2017.1371851.

Eustace, S., Page, R. and Greig, M. (2018). 'Angle Specific Isokinetic Metrics Highlight Strength Training Needs of Elite Youth Soccer Players'. *Journal of Strength and Conditioning Research*. doi: 10.1519/JSC.0000000000002612. [Epub ahead of print].

Faude, O. *et al.* (2006) 'Risk factors for injuries in elite female soccer players', *British Journal of Sports Medicine*. doi: 10.1136/bjsm.2006.027540.

Gordon, D. *et al.* (2013) 'The effects of menstrual cycle phase on the development of peak torque under isokinetic conditions', *Isokinetics and Exercise Science*. doi: 10.3233/IES-130499.

Greig, M. (2008) 'The influence of soccer-specific fatigue on peak isokinetic torque production of the knee flexors and extensors', *American Journal of Sports Medicine*. doi: 10.1177/0363546508314413.

Gür, H. (1997) 'Concentric and eccentric isokinetic measurements in knee muscles during the menstrual cycle: A special reference to reciprocal moment ratios', *Archives of Physical Medicine and Rehabilitation*. doi: 10.1016/S0003-9993(97)90164-7.

Gur, H. *et al.* (1999) 'Effects of age on the reciprocal peak torque ratios during knee muscle contractions in elite soccer players', *Scandinavian Journal of Medicine & Science in Sports*. doi: 10.1111/j.1600-0838.1999.tb00213.x.

Hägglund, M. and Waldén, M. (2016) 'Risk factors for acute knee injury in female youth football', *Knee Surgery, Sports Traumatology, Arthroscopy*. doi: 10.1007/s00167-015-3922-z.

Hewett, T. E., Myer, G. D. and Ford, K. R. (2004) 'Decrease in neuromuscular control about the knee with maturation in female athletes', *Journal of Bone and Joint Surgery - Series A*. doi: 10.2106/00004623-200408000-00001.

Hewett, T. E. *et al.* (2006) 'Preparticipation physical examination using a box drop vertical jump test in young athletes: The effects of puberty and sex', *Clinical Journal of Sport Medicine*. doi: 10.1097/00042752-200607000-00003.

Hewett, T. E., Myer, G. D. and Zazulak, B. T. (2008) ‘Hamstrings to quadriceps peak torque ratios diverge between sexes with increasing isokinetic angular velocity’, *Journal of Science and Medicine in Sport*. doi: 10.1016/j.jsams.2007.04.009.

Hewett, T. E. and Myer, G. D. (2011) ‘The mechanistic connection between the trunk, hip, knee, and anterior cruciate ligament injury’, *Exercise and Sport Sciences Reviews*. doi: 10.1097/JES.0b013e3182297439.

Hughes, G. and Watkins, J. (2006). ‘A risk-factor model for anterior cruciate ligament injury’, *Sports Medicine*. 36 (5), pp. 411–428. Doi: 10.2165/00007256-200636050-00004.

Kawamori, N. and Newton, R. U. (2006) ‘Velocity specificity of resistance training: Actual movement velocity versus intention to move explosively’, *Strength and Conditioning Journal*. doi: 10.1519/1533-4295(2006)028[0086:VSORTA]2.0.CO;2.

Fousekis, K., Tsepis, E. and Vagenas, G. (2010) ‘Lower limb strength in professional soccer players: Profile, asymmetry, and training age’, *Journal of Sports Science and Medicine*.

Lee, J. W. Y. *et al.* (2017) ‘Eccentric hamstring strength deficit and poor hamstring-to-quadriceps ratio are risk factors for hamstring strain injury in football: A prospective study of 146 professional players’, *Journal of Science and Medicine in Sport*. doi: 10.1016/j.jsams.2017.11.017.

Le Gall, F., Carling, C. and Reilly, T. (2008) ‘Injuries in young elite female soccer players: An 8-season prospective study’, *American Journal of Sports Medicine*. doi: 10.1177/0363546507307866.

Manson, S. A., Brughelli, M. and Harris, N. K. (2014) ‘Physiological characteristics of international female soccer players’, *Journal of Strength and Conditioning Research*. doi: 10.1519/JSC.0b013e31829b56b1.

Marchant, D. C. and Greig, M. (2017) ‘Attentional focusing instructions influence quadriceps activity characteristics but not force production during isokinetic knee extensions’, *Human Movement Science*. doi: 10.1016/j.humov.2017.01.007.’

Morgan, D.L. and Proske, U. (2004). Popping sarcomere hypothesis explains stretch-induced muscle damage', *Clinical and Experimental Pharmacology and Physiology*. doi: 10.1111/j.1440-1681.2004.04029.x

Myer, G. D. *et al.* (2011) 'When to initiate integrative neuromuscular training to reduce sports-related injuries and enhance health in youth?', *Current Sports Medicine Reports*. doi: 10.1249/JSR.0b013e31821b1442.

Nedergaard, N. J., Kersting, U. and Lake, M. (2014) 'Using accelerometry to quantify deceleration during a high-intensity soccer turning manoeuvre', *Journal of Sports Sciences*. doi: 10.1080/02640414.2014.965190.

Rae, D. E., Stephenson, K. J. and Roden, L. C. (2015) 'Factors to consider when assessing diurnal variation in sports performance: the influence of chronotype and habitual training time-of-day', *European Journal of Applied Physiology*. doi: 10.1007/s00421-015-3109-9.

Ryman Augustsson, S. and Ageberg, E. (2017) 'Weaker lower extremity muscle strength predicts traumatic knee injury in youth female but not male athletes', *BMJ Open Sport and Exercise Medicine*. doi: 10.1136/bmjsem-2017-000222.

Söderman, K. *et al.* (2002) 'Anterior cruciate ligament injuries in young females playing soccer at senior levels', *Scandinavian Journal of Medicine and Science in Sports*. doi: 10.1034/j.1600-0838.2002.120201.x.

Taylor, J. B. *et al.* (2017) 'Activity Demands During Multi-Directional Team Sports: A Systematic Review', *Sports Medicine*. doi: 10.1007/s40279-017-0772-5.

Toonstra, J. and Mattacola, C.G. (2013) 'Test–Retest Reliability and Validity of Isometric Knee-Flexion and -Extension Measurement Using 3 Methods of Assessing Muscle Strength', *Journal of Sport Rehabilitation*. doi:10.1590/S1413-35552012005000149.

Van Dyk, N. *et al.* (2017) 'A comprehensive strength testing protocol offers no clinical value in predicting risk of hamstring injury: A prospective cohort study of 413 professional football players', *British Journal of Sports Medicine*. doi: 10.1136/bjsports-2017-097754.

Van Dyk, N. *et al.* (2016) 'Hamstring and Quadriceps Isokinetic Strength Deficits Are Weak Risk Factors for Hamstring Strain Injuries', *American Journal of Sports Medicine*. doi: 10.1177/0363546516632526.

Verhagen, E. *et al.* (2018) 'Do not throw the baby out with the bathwater; screening can identify meaningful risk factors for sports injuries', *British Journal of Sports Medicine*. doi: 10.1136/bjsports-2017-098547.

Table 1
Interclass Correlation Coefficients of Outcomes Measures for Senior and Youth Female Soccer Players

Group	Senior	Youth
ConKE PT 60-270°·s^{-1}	0.87-0.93	0.81-0.89
EccKF PT 60-270°·s^{-1}	0.80-0.86	0.78-0.87
ConKE FR 60-270°·s^{-1}	0.81-0.86	0.82-0.77
EccKF FR 60-270°·s^{-1}	0.75-0.84	0.73-0.81
ConKE APT 60-270°·s^{-1}	0.65-0.76	0.67-0.72
EccKF APT 60-270°·s^{-1}	0.64-0.71	0.61-0.68
DCR 60-270°·s^{-1}	0.78-0.88	0.75-0.84
ConKE AST 60-270°·s^{-1}	0.86-0.95	0.84-0.89
EccKF AST 60-270°·s^{-1}	0..80-0.91	0.78-0.85
DCR_{AST} 60-270°·s^{-1}	0.79-0.83	0.77-83

Table 2.
The influence of angular velocity on knee flexor and extensor PT and FR in senior and youth players

Group		Senior PT (Nm)	Youth PT (Nm)	Senior FR (º)	Youth FR (º)
270°·s^{-1}	Dominant eccKF	150.4 ± 24.9 *(3.2 to 34.3)	131.6 ± 19.2 ~(8.5 to 33.1)	28 ± 9	25 ± 10
	Non-dominant eccKF	143.8 ± 29.8 *(15.8 to 50.0)	110.9 ± 17.5	29 ± 10	29 ± 10
	Dominant conKE	112.3 ± 16.4 *(6.5 to 34.7)	91.7 ± 23.4	22 ± 7	18 ± 6
	Non-dominant conKE	115.0 ± 17.0 *(9.9 to 35.4)	92.4 ± 18.6	22 ± 9	19 ± 8
180°·s^{-1}	Dominant eccKF	155.9 ± 20.6 *(7.2 to 37.06)	133.8 ± 22.05 ~(11.4 to 38.6)	24 ± 7	28 ± 10
	Non-dominant eccKF	145.6 ± 31.9 *(18.7 to 54.8)	108.8 ± 17.9	29 ± 12	30 ± 10
	Dominant conKE	131.4 ± 15.6 *(6.4 to 31.0)	112.7 ± 19.4	28 ± 8	25 ± 6
	Non-dominant conKE	131.1 ± 17.8 *(13.5 to 41.1)	103.8 ± 21.6	30 ± 5	29 ± 5
60°·s^{-1}	Dominant eccKF	147.2 ± 27.6 *(8.9 to 40.8) ~(3.5 to 24.9)	122.3 ± 16.7 ~(6 to 27.4)	31 ± 8	34 ± 9
	Non-dominant eccKF	132.9 ± 20.2 *(14.1 to 40.5)	105.6 ± 17.6	33 ± 8	31 ± 9
	Dominant conKE	176.4 ± 24.2 *(6.8 to 41.3)	152.3 ± 25.1	31 ± 8	34 ± 9
	Non-dominant conKE	180.8 ± 28.9 *(17.9 to 55.1)	144.2 ± 24.2	23 ± 6	31 ± 9

(*) denotes a significant difference (with 95 CI intervals) between playing age, (~) denotes a significant difference (with 95%CI intervals) between limbs.

Table 3.
The influence of angular velocity on DCR calculated by eccKF: conKE in senior and youth players

Group		Senior	Youth
270°·s^{-1}	Dominant	1.36 ± 0.22	1.55 ± 0.48
	Non-dominant	1.26 ± 0.24	1.23 ± 0.27
180°·s^{-1}	Dominant	1.21 ± 0.14	1.21 ± 0.21
	Non-dominant	1.10 ± 0.19	1.07 ± 0.25
60°·s^{-1}	Dominant	0.84 ± 0.16	0.92 ± 0.31
	Non-dominant	0.74 ± 0.08	0.73 ± 0.14

Table 4. The influence of angular velocity on knee flexor and extensor AST in senior and youth players. (*) denotes a significant difference between playing age, (~) denotes a significant difference (with 95%CI intervals) between lower limbs

Angle (°)		70		60		50		40	
Group		Senior	Youth	Senior	Youth	Senior	Youth	Senior	Youth
270°·s^{-1}	Dominant eccKF (N.m)	127.6 ±12.1 *(6.6 to 22.9)	112.9 ±11.2 *(1.1 to 14.5)	135.5 ± 22.3 *(4.4 to 33.2) ~(0.5 to 20.1)	116.6 ± 18.6 ~(7.3 to 27.5)	145.6 ± 24.0 *(7.5 to 37.1) ~(4.3 to 27.1)	123.4 ± 18.0 ~(8.8 to 31.6)	148.2 ± 25.0 *(7.3 to 38.2) ~(3.4 to 30.4)	125.5 ± 18.8 ~(7.4 to 34.5)
	Non-dominant eccKF (N.m)	121.1 ± 17.0 *(4.3 to 27.8)	105.6 ± 16.6	124.9 ± 22.2 *(12.6 to 38.7)	99.2 ± 14.4	130.0 ± 27.9 *(10.3 to 43.4)	103.2 ± 18.4	131.3 ± 31.2 *(8.4 to 45.2)	104.6 ± 20.4
	Dominant conKE (N.m)	108.0 ± 21.7 *(4.6 to 38.1)	86.7 ± 26.1	103.6 ± 15.0 *(9.7 to 34.3)	81.6 ± 19.9	96.3 ± 15.7 *(10.2 to 36.2)	73.0 ± 21.2	83.4 ± 13.3 *(11.07 to 36.7)	59.5 ± 22.3
	Non-dominant conKE (N.m)	107.1 ± 19.0 *(9.5 to 37.0)	83.9 ± 20.4	101.7 ± 13.4 *(5.5 to 28.1)	84.9 ± 18.5	95.9 ± 15.1 *(9.4 to 30.5)	76.0 ± 15.1	82.5 ± 16.1 *(6 to 30.3)	64.3 ± 18.8
180°·s^{-1}	Dominant eccKF (N.m)	112.8 ± 20.2 *(1.3 to 27.6)	98.4 ± 17.3	127.1 ± 17.5 *(2.5 to 26.7)	112.5 ± 17.1 ~(6.0 to 26.3)	139.5 ± 21.4 *(7.1 to 35.5)	118.2 ± 22.7 ~(6.6 to 28.9)	148.2 ± 21.1 *(6.8 to 35.8)	126.9 ± 20.4 ~(11.5 to 37.4)
	Non-dominant eccKF (N.m)	111.9 ± 21.0 *(10.5 to 36.4)	88.4 ± 15.8	120.6 ± 22.7 *(10.5 to 38.0)	96.3 ± 16.0	125.9 ± 27.7 *(8.8 to 42.1) ~(2.5 to 24.8)	100.4 ± 19.0	128.4 ± 32.8 *(6.5 to 45.3) ~(6.8 to 32.7)	102.5 ± 21.6
	Dominant conKE (N.m)	119.7 ± 16.7 *(5.6 to 29.1)	102.4 ± 17.0	124.4 ± 17.0 *(5.6 to 31.4)	105.9 ± 19.8	115.0 ± 14.9 *(8.9 to 34.0)	93.4 ± 20.4	98.7 ± 17.6 *(9.7 to 36.1)	75.8 ± 20.0
	Non-dominant conKE (N.m)	120.5 ± 15 *(11.4 to 38.4)	95.6 ± 22.8	127.2 ± 16.7 *(18.2 to 43.9)	96.2 ± 19.8	115.2 ± 13.5 *(13. 2to 36.3)	90.4 ± 19.2	99.4 ± 15.9 *(10.4 to 35.4)	76.4 ± 19.7
60°·s^{-1}	Dominant eccKF (N.m)	112.5 ± 17.7 *(2.7 to 28.7) ~(3.6 to 18.5)	96.8 ± 19.4 ~(4.8 to 19.8)	125.2 ± 19.0 *(5.0 to 31.3) ~(4.0 to 18.7)	107.0 ± 18.7 ~(7.8 to 22.5)	136.2 ± 20.7 *(10.1 to 37.9) ~(5.6 to 23.1)	112.5 ± 18.2 ~(7.6 to 24.9)	143 ± 23.7 *(15.5 to 50.2) ~(8.6 to 31.5)	110.9 ± 25.7 ~(5.3 to 28.1)
	Non-dominant eccKF (N.m)	101.4 ± 18.6 *(5.3 to 28.5)	84.5 ± 14.3	113.8 ± 18.9 *(10.2 to 33.9)	91.8 ± 14.9	121.9 ± 19.6 *(8.8 to 42.0)	96.3 ± 16.3	123.7 to 19.6 *(14.6 to 44.4)	94.3 to 22.9
	Dominant conKE (N.m)	167.5 ± 32.7 *(2.8 to 44.1)	144.1 ± 26.1	153.1 ± 31.8 *(8.4 to 49.0)	124.4 ± 26.0	129.0 ± 29.7 *(4.4 to 38.8)	107.4 ± 18.2	106.0 ± 23.0 *(2.9 to 30.9)	89.1 ± 16.4
	Non-dominant conKE (N.m)	166.9 ± 23.6 *(10.2 to 43.6)	139.9 ± 24.3	151.4 ± 23.9 *(9.5 o 43.5)	124.9 ± 24.8	128.2 ± 23.9 *(10.9 to 43.0)	101.3 ± 22.0	106.0 ± 22.6 *(8.8 to 38.3)	82.4 ± 19.5