Angle Specific Isokinetic Metrics Highlight Strength Training Needs of Elite Youth Soccer Players

ABSTRACT

The purpose of this study was to assess traditional and angle-specific isokinetic strength of eccentric knee flexors (eccKF) and concentric knee extensors (conKE) between senior professional and youth soccer players. 34 male soccer players (17 senior and 17 youth) were recruited for bilateral assessments at 180, 270 and 60°·s^{-1}. 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. EccKF and conKE PT (*P* = 0.782) and DCR (*P* = 0.508) were not different between groups across all angular velocities. Significant differences were identified for eccKF APT (*P* = 0.018) and FR (*P* = 0.006), DCR_{AST} at 270°·s^{-1} (*P* = 0.031) and in AST data recorded across angular velocities for eccKF and conKE (*P* = 0.003). Traditional strength measures were not sensitive to playing age, with implications for misinterpretation in training prescription. In contrast, AST data did differentiate between ages. Strength deficits which highlight the muscle contraction type, angular velocity and joint angle can be manipulated within an individualized training intervention. Given the relevance to injury aetiology, this study highlights potential implications for improved assessment strategies to inform training prescription for performance and injury prevention. Given the high number of injuries in adolescent soccer players, and in line with previous recommendations, practitioners should consider utilising more informed and specific strength and conditioning practices at younger ages.

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

INTRODUCTION

Epidemiology studies in professional soccer have reported thigh musculature strains to be prevalent in both male professional (13) and youth soccer players (26). When compared to their senior counterparts there exists a greater proportion of thigh musculature injuries in youth players (8) specifically between 16-18 years of age (33, 34) and particularly in players following adolescent growth (34). Given the specific injury epidemiology and potential influence of maturation, strength deficits in elite youth soccer players have implications for performance and injury (11, 19, 34). In support, it has been suggested that strength of the thigh musculature is a modifiable risk factor in preventing muscular strains in soccer (2, 10), thus identifying the strength training needs of elite youth soccer players would inform the development of effective strength and conditioning interventions. In support of these observations, previous studies have demonstrated that youth players possess reduced thigh musculature strength compared to senior aged players and may be associated with greater injury risks in youths (16, 23). As such, it appears that training history and training exposure may also influence thigh musculature strength and potential injury risk (8, 37). Considering that weekly training load increases in youth soccer players with playing age (37), practitioners therefore need to ensure that youth players possess sufficient muscular capabilities to cope with the increased training and match demands, which can lead to increased thigh musculature strain injury risk (31). In order to implement appropriate strength training strategies for youth players, practitioners are required to utilise relevant methods of assessing thigh musculature strength to for identifying potential injury risk and monitoring training progress.

In elite soccer, lower limb strength assessments are often completed using isokinetic dynamometry (18, 20, 25); however, recently literature has begun to question the ability of isokinetic strength assessments to predict injury risk in soccer (33, 34). The lack of efficacy in isokinetic profiling (14) could potentially be attributed to methodological limitations in quantifying strength. For example, a common methodological limitation of isokinetic assessments is the use of low angular testing velocities ($\leq 120°\cdot s^{-1}$), thus negating the high knee angular velocities associated with lower limb injury incidence and the performance demands of soccer. The use of more functionally relevant testing velocities are therefore advocated, both in relation to the demands of the sport and subsequent training interventions.

Further methodological concerns with isokinetic strength assessments in professional soccer players have influenced recent criticisms of the peak torque measure in isolation due to the failure to consider more than a single point on the strength curve (14). Such limitations lead to the development of the previously defined functional range (FR) metric that identifies the angular range over which a specific threshold of isokinetic strength (85% of peak torque) that can be maintained (14). The FR metric was based on previous literature that identified that a strength deficit of 15% is associated with an increased risk of thigh musculature injuries in professional male soccer players (10). Specifically, a larger FR indicates that the muscle is better able to maintain strength across an angular range, thereby demonstrating a superior torque-angle curve. Angle-specific measures of torque are also able to identify thigh muscular strength and co-contraction ability where injury is more likely to occur (5, 7) and, therefore, this may be useful for practitioners to prescribe exercise. For instance, conducting strength training at greater angular velocities have demonstrated significant increases in force-production at the specific training velocity for both concentric and eccentric actions (21, 22). Additionally, strength training at specific joint angles by limiting exercise range of motion has identified significant increases in strength at the specific training angle (3, 27). Although angle specific measures of isokinetic strength have been assessed in senior soccer players (9, 14, 15), this has not previously been utilized in elite youth male soccer players. The aforementioned isokinetic procedures and metrics may identify a more holistic profile of related factors that could inform the prescription of age specific strength and conditioning in an attempt to reduce injury risk (25).

The current study aims to assess and compare the strength characteristics of eccentric knee flexor (eccKF) and concentric knee extensors (conKE) musculature of youth and senior soccer players using both traditional (peak torque, angle of peak torque, and dynamic control ratios) and angle-specific isokinetic metrics (angle specific torque, FR, and angle specific dynamic control ratios). It was hypothesized that youth players would possess strength deficits and/or imbalances of the thigh musculature that are influenced by exposure and associated with greater injury risk. Highlighting strength deficits should subsequently inform opportunities for training interventions.

METHODS

Experimental approach to the problem

This experimental study comprised a repeated measures design to identify the effects of playing age on traditional and contemporary measures of eccKF and conKE musculature strength across a range of angular velocities. Although epidemiological studies of lower limb injury in senior and youth soccer report thigh musculature strains are most common (13, 26), such injuries appear to be further prevalent in youth players (8, 33, 34). After the completion of isokinetic strength assessments at 180, 270, and $60°\cdot s^{-1}$, both traditional and contemporary measures of isokinetic strength were calculated for additional analyses. The traditional measures included peak torque and dynamic control ratios at each angular velocity of both lower limbs. In addition, the contemporary measures included angle specific measures of torque, dynamic control ratios and the ability to maintain strength over an angular range were all considered at each respective angular velocity. The contemporary measures were utilized considering that injury to the thigh/knee region commonly occur during increased angular velocities and knee extension (5, 7). As such, the aforementioned measures were compared between senior and youth players to identify whether if such discrepancies support previous epidemiological observations.

Subjects

A priori power calculation from pilot study 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; $P \leq 0.05$). Therefore, seventeen senior professional soccer players (age 25.09 ± 3.83 years; height 182.46 ± 3.82cm; mass 83.23 ± 10.01kg) and seventeen elite youth soccer players (age 17.00 ± 0.6 years; height 179.69 ± 4.75cm; mass 70.18 ± 6.33kg) from the same club in the English Football League Division Two were recruited. To control for previous injury, all players were free from lower limb injury for >6 months prior to data collection. In addition to weekly matches, the two groups possessed similar weekly training volumes of $\sim 10hr\cdot week^{-1}$. Prior to each experimental condition, all participants were required to complete a health screening procedure comprising a health, physical activity and pre-exercise control questionnaire. The measurement of both resting heart rate and blood pressure was also measures, where resting heart rate >90 $beats\cdot min^{-1}$ and blood pressure >140/90 mmHg respectively were contraindications to exercise. All participants were informed of the associated risks associated with this study before providing written consent. Parent/guardian consent was also obtained for the youth players aged below 18 years. The current study was also approved by a local university ethics committee. All equipment was risk assessed and calibrated in accordance to the manufacturer's guidelines.

Experimental Procedures

Participants were required to attend the laboratory on two occasions to complete a familiarisation trial and a single experimental trial, interspersed by a minimum of 96 hours. The procedures of the familiarisation trial replicated the subsequent experimental condition. In accordance with the participant's regular training schedule and in an attempt to control for circadian variation (30), all testing was conducted between 1000-1200 hours. Participants attended the laboratory on each occasion in a 3hr post-absorptive state following a 48 hour abstinence of exercise and alcohol consumption. Prior to the start of each trial, participants were also required to complete a standardized 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 $60°\cdot s^{-1}$ (18). For each angular velocity and muscle group, participants were instructed to provide 3 maximal contractions with a 60 second rest period was provided between each angular velocity (10).The range of motion of the knee joint was set at 25–90° where each participant was secured in a seated position with approximately 90º hip flexion, with restraints applied proximal to the knee joint across the thigh, the waist and the participant's chest, with the cuff of the lever arm secured 3cm proximal to the malleoli. As per the manufacturer's guidelines, torque was gravity-corrected following the measurement of the participant's limb mass performed at end range.

The isokinetic phase was identified at the constant angular velocity by applying a 1% cut-off (14). The peak torque (PT) and corresponding angle of peak torque (APT) was identified. The functional range

(FR) was defined as the range over which 85% of PT was maintained (14). The PT values recorded from the eccKF and conKE assessments were used to calculate the dynamic control ratio (DCR). Angle specific torques (AST) and angle specific DCR (DCR_{AST}) were identified at 10° increments between 70 and 40°. The choice of angular range and 10° increments was based on the isokinetic data which was common across groups, contraction types, and angular velocities. In accordance with previous recommendations (4), where significant bilateral differences were observed between lower limbs, asymmetry angles were calculated and identified as percentages using the following equation (39):

$$(45° - \text{arctan}\ (\text{dominant limb}\ \div \text{nondominant limb})) \div 90° \text{ x } 100$$

Statistical Analyses

To establish whether statistically significant differences existed between the senior and youth playing ages, a mixed repeated measures general linear model (GLM) was performed. The assumptions associated with the GLM were assessed to ensure model adequacy, with none of the variables violating any of the assumptions. Where significant main effects or interactions were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied with 95% confidence intervals (CI) for differences were also reported. Partial eta squared (η2) values were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared was classified as small (0.01 to 0.059), moderate (0.06 to 0.137) and large (>0.138) (6). For all variables associated with the current study, intra-class correlation coefficients (ICC) 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 (24). 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 ± standard deviation unless otherwise stated.

RESULTS

No significant four-way interaction between limb, contraction, angular velocity, and age (*P* = 0.782; η^2= 0.008) was identified for PT. A significant three-way interaction for limb, contraction, and age (*P* = 0.047; η^2 = 0.118) was however identified, with the eccKF (Senior 198.9 ± 30.9N.m; Youth = 158.3 ± 30.1N.m; 95%CI: 21.6 to 59.6N.m; *P* < 0.001) and conKE (Senior = 208.7 ± 23.27N.m; Youth = 173.6 ± 27.4N.m; 95%CI: 15.5 to 46.4N.m; *P* < 0.001) data recorded for the dominant limb being significantly higher for senior players when compared to the youth players. A similar trend was observed for the eccKF (Senior = 178.8 ± 20.8N.m; Youth = 150.4 ± 25.8N.m; 95%CI: 13.8 to 43.0N.m; *P* < 0.001) and conKE (Senior = 204.5 ± 30.7N.m; Youth = 168.2 ± 29.8N.m; 95%CI: 21.3 to 59.7N.m; *P* < 0.001) data recorded for the non-dominant limb. The ICC values calculated for the Senior and Youth conKE PT data recorded at $60°\cdot s^{-1}$ (Senior: 0.91, Youth: 0.87), $180°\cdot s^{-1}$ (Senior: 0.87, Youth: 0.89), and $270°\cdot s^{-1}$ (Senior: 0.83, Youth: 0.84) were almost perfect. Likewise, the ICC values calculated for the Senior and Youth eccKF PT data recorded at $60°\cdot s^{-1}$ (Senior: 0.88, Youth: 0.84), $180°\cdot s^{-1}$ (Senior: 0.85, Youth: 0.89), and $270°\cdot s^{-1}$ (Senior: 0.83, Youth: 0.82) were almost perfect.

For the DCR data (Table 1), the GLM did not identify a significant three-way interaction for limb, angular velocity and age (*P* = 0.508, η^2 = 0.021), nor any two-way interactions for limb and angular velocity (*P* = 0.294; η^2 = 0.038), limb and age (*P* = 0.116; η2 = 0.076) and angular velocity and age (*P* = 0.115, η^2 = 0.067). There was a significant main effect for limb (*P* = 0.017; η^2=0.166), with higher values recorded for the dominant limb (0.98 ± 0.19) when compared to the non-dominant limb (0.91 ± 0.16; 95% CI: 0.01 to 0.13). A significant man effect for angular velocity (*P* < 0.001; η^2 = 0.809) was also identified with higher values recorded at $270°\cdot s^{-1}$ (1.13 ± 0.22) when compared to both $180°\cdot s^{-1}$ (0.96 ± 0.15; 95%CI: 0.12 to 0.24) and $60°\cdot s^{-1}$ (0.75 ± 0.16; 95%CI: 0.32 to 0.45) and significantly higher values recorded at $180°\cdot s^{-1}$ when compared to $60°\cdot s^{-1}$ (95%CI: 0.15 to 0.26). The ICC values calculated for the Senior and Youth DCR data recorded at $60°\cdot s^{-1}$ (Senior: 0.85, Youth: 0.83), $180°\cdot s^{-1}$ (Senior: 0.83, Youth: 0.80), and $270°\cdot s^{-1}$ (Senior: 0.79, Youth: 0.77) were substantial to almost perfect.

[Table 1 near here]

A significant four-way interaction for limb, contraction, angular velocity and age (P = 0.048; η^2 = 0.088) was identified for the APT data. Post-hoc pairwise comparisons identified the senior player's dominant limb eccKF PT recorded at 270°·s^{-1} (42 ± 12 º) occurred at significantly increased knee extension angles when compared to youth (57 ± 17 º; 95%CI: -25. to -5 º; P = 0.06). The ICC values calculated for the Senior and Youth conKE APT data recorded at 60°·s^{-1} (Senior: 0.73, Youth: 0.68), 180°·s^{-1} (Senior: 0.69, Youth: 0.67), and 270°·s^{-1} (Senior: 0.66, Youth: 0.70) were substantial. Likewise, the ICC values calculated for the Senior and Youth eccKF APT data recorded at 60°·s^{-1} (Senior: 0.74, Youth: 0.70), 180°·s^{-1} (Senior: 0.69, Youth: 0.70), and 270°·s^{-1} (Senior: 0.72, Youth: 0.65) were also substantial.

For the FR data, the GLM did not identify a significant four-way interaction for limb, contraction, angular velocity and age (P = 0.854; η^2 = 0.001), nor did it identify significant three-way interactions for limb, contraction and angular velocity (P = 0.218; η^2 =0.047), limb, angular velocity and age (P = 0.301; η^2=0.128), or limb, contraction and age (P = 0.926; η^2 < 0.001). As identified in Table 1, a significant contraction, angular velocity and age interaction (P = 0.006, η^2= 0.147) was identified, with senior player's eccKF FR being higher than the youth players. The ICC values calculated for the Senior and Youth conKE FR data recorded at 60°·s^{-1} (Senior: 0.83, Youth: 0.78), 180°·s^{-1} (Senior: 0.85, Youth: 0.77), and 270°·s^{-1} (Senior: 0.79, Youth: 0.78) were substantial. Likewise, the ICC values calculated for the Senior and Youth eccKF FR data recorded at 60°·s^{-1} (Senior: 0.84, Youth: 0.81), 180°·s^{-1} (Senior: 0.80, Youth: 0.76), and 270°·s^{-1} (Senior: 0.81, Youth: 0.73) were also substantial to almost perfect.

As identified in Table 2, a significant five-way interaction for angle, angular velocity, limb, age and contraction (P = 0.030, η^2 = 0.078) was identified for the AST data. It was identified the majority of the dominant limb AST data was higher in senior players. However, these differences were less pronounced in the eccKF AST data recorded for the non-dominant limb. Table 2 also identifies angle-specific bilateral strength differences, with senior players demonstrating significantly higher dominant eccKF strength across joint angles recorded at 60 and 270°·s^{-1}. This response was not however observed for the youth players. The ICC values calculated for Seniors and Youths between 70-40º for conKE AST ranged between 0.91-0.86, 0.92-0.83, and 0.86-0.82 for data recorded at 60°·s^{-1}, 180°·s^{-1} and 270°·s^{-1}, respectively, were almost perfect. Likewise, the ICC values calculated for Seniors and Youths between 70-40º for eccKF AST ranged between 0.90-0.81, 0.89-0.83, and 0.85-0.80 for data recorded at 60°·s^{-1}, 180°·s^{-1} and 270°·s^{-1}, respectively, were almost perfect

[Table 2 near here]

A significant four-way limb, angular velocity, angle and age interaction (P = 0.031; η^2 = 0.069) was identified for the DCR_{AST} data. No significant differences in DCR_{AST} data were identified between age groups in the dominant limb. However, for the data recorded from the non-dominant limb, significantly higher DCR_{AST} data was recorded at 270°·s^{-1} for the youth players when compared to senior players at both 70º (Youth = 1.20 ± 0.34; Senior = 0.99 ± 0.15; 95%CI: 0.02 to 0.39; P = 0.03) and 60º (Youth = 1.13 ± 0.28; Senior = 0.90 ± 0.20; 95%CI: 0.05 to 0.40; P = 0.01) of knee flexion. The ICC values calculated for Seniors and Youths between 70-40º for DCR_{AST} ranged between 0.88-0.82, 0.86-0.79, and 0.83-0.77 for data recorded at 60°·s^{-1}, 180°·s^{-1} and 270°·s^{-1}, respectively, were substantial to almost perfect.

DISCUSSION

The purpose of this study was to assess and compare the strength characteristics of eccKF and conKE musculature between youth and senior soccer players using both traditional and angle-specific isokinetic metrics. It was identified that there were no statistical differences in eccKF and conKE PT and DCR across the two groups across all angular velocities, suggesting equivalence and potentially misinforming strength training needs. There was however significantly higher AST values identified for the senior players compared to youths for eccKF and conKE at all angular velocities throughout the defined angular range in both lower limbs. Furthermore, senior players were also able to elicit a larger FR and APT closer to knee extension at 270°·s^{-1} for the eccKF musculature. Although DCR_{AST} was significantly higher in the youth players compared to seniors at 270°·s^{-1}, these findings were observed at 70 and 60º knee flexion and may not be meaningful since thigh musculature injuries occur at increased knee extension angles (5). The present data suggest strength and conditioning coaches should utilize angular velocity and angle specific measures of isokinetic strength to inform subsequent training interventions. Specific training interventions may then be implemented to increase force production at higher knee angular velocities during increased knee extension where players are most susceptible to muscular strains (5).These measures are able to inform angular velocity and angle specific exercise prescription for the development of lower limb musculature strength for the reduction of injury risk and benefit performance, particularly with youth players.

The non-significant differences observed in the current PT and DCR data is not in support of previous findings that identified differences in eccKF and conKE PT data recorded across different soccer playing ages (20, 23). It should be acknowledged these studies utilized more extreme differences in playing ages (5-18 years) when compared to the current study, suggesting these metrics may only be sensitive to more pronounced physical differences such as, but not limited to, age, maturation, training history, training exposure and injury status (8, 11, 37). As such, alternative isokinetic metrics are advocated to compare thigh musculature strength between players with more comparable characteristics and weekly training loads. The current PT and DCR data is therefore in support of recent research that has questioned the sensitivity of these metrics in identifying players who possess increased risk of injury (33).

The APT and FR of youth players have not been previously compared to senior players, limiting comparisons to previous studies. For example, the FR metric has only previously been assessed in professional male soccer players (14). The current data identified that the eccKF APT data recorded at 270°·s^{-1} in the senior players occurred at significantly increased knee extension angles when compared to the youth players; however, the APT data recorded in the current study was shown to elicit only substantial reliability, thus further advocating the use of additional isokinetic metrics. The observed response in the APT data was supported by the AST data, with large between group differences also being observed at high angular velocities and extended knee joint angles. Additionally, the senior players were also able to generate a significantly larger eccKF FR at 270°·s^{-1} in comparison to youth players. When considering the aetiology of thigh based muscular strains and knee ligamentous injuries (5), the observed differences in FR data suggests the youth players may be at an increased risk of thigh musculature injuries compared to senior players. It was recently stated that the identification of a player's FR depends on both the angular testing velocity and contraction type (14). Whilst this was also the case in this present study, eccKF FR in youth players reduced with increased angular velocity; however, this was not identified in senior players. With this in mind, youth players may be at further increased risk of knee flexor injury compared to senior players. These findings reinforce the importance of using increased angular velocities to help determine injury risk. Therefore, practitioners may need to consider the implications of velocity specific training for improving strength discrepancies at higher angular velocities. Similarly, it has been previously identified that training at higher velocities improves force production in high-speed movements through the use of Olympic lifting and manipulating contraction speed of traditional exercises (21, 22). Such exercises can also be considered at specific knee joint angles as previous research identified angle-specific strength increases relative to training angle (3, 27) and may also be used in conjunction with specific contraction velocities.

As previously mentioned, the current AST data was significantly higher in senior players when compared to youth players across limbs and angular velocities. It must be noted the differences between playing ages were less pronounced when comparisons were made to the non-dominant eccKF data. These findings demonstrate senior players displayed greater limb asymmetry, potentially predisposing the non-dominant limb to an increased risk of knee flexor injury (10). In further support, the calculation of asymmetry angles also identified bilateral eccKF strength differences of ~5%. The increased limb asymmetry in senior players may also be linked to frequent single leg movement patterns encountered during soccer specific exercises (30), developing a progressively increased limb dominance with playing age. These data suggest that limb asymmetries are developed as a result of prolonged soccer exposure and, as such, these asymmetries can be comparably reduced with a change in practice. The findings of the current study therefore suggest practitioners should consider bilateral asymmetries beyond the assessment of traditional isokinetic metrics and also include AST comparisons. Where notable differences in strength are identified between lower limbs, the calculation of asymmetry angle may more accurately determine discrepancies (4).

Although DCR_{AST} was unable to distinguish between youth and senior players at 60 and 180°·s^{-1}, it was sensitive to age at 270°·s^{-1}, with the youth players eliciting significantly higher DCR_{AST} values in the non-dominant limb at knee flexion angles of 70 and 60°. These data further emphasise the importance of utilising increased angular velocities during isokinetic strength assessments. The observed differences in the DCR_{AST} data can be accounted by higher conKE relative to eccKF values in senior players' non-dominant limb. Furthermore, these findings do not necessarily suggest the observed differences in the DCR_{AST} data may be associated with an increased injury risk, since the differences between playing ages were identified in flexed knee positions, where injury typically does not occur (5, 7). The present findings are in support of previous research identifying DCR_{AST} differences between different standards of players (15), but their ability to distinguish between injured and non-injured soccer players and ability to predict injury risk have yielded equivocal findings (25, 33, 34). Such criticisms have led to the development of DCR equilibrium point as a measure that determines the knee joint angle where the knee flexors and extensors produce the same muscular force at ~40º of knee flexion (17), and in agreement with the present study findings that identify increased DCR_{AST} with increased knee flexion. Therefore, further prospective studies may wish to analyse these metrics to identify their association with injury risk.

Although not directly assessed in this present study, torque was not normalized relative to body mass, where additional differences may also exist. However, normalization of isokinetic strength overcorrects for mass and strongly correlates with torque of the thigh musculatures (38). Irrespective of the aforementioned limitations, isokinetic dynamometry and muscular strength testing is a common practice in soccer. It is therefore important for sports scientists and fitness coaches alike to identify the limitations of equipment, but as identified in the current study, practitioners should attempt to develop methods to better utilise equipment to further inform practice.

PRACTICAL APPLICATIONS

Isokinetic assessment is often used to quantify thigh musculature strength, with interpretation of the data informing strength training interventions. However, the current study highlights that commonly used metrics such as peak torque, and the derived strength ratios, might lead to misinterpretation of an athlete's needs. It is therefore recommended that isokinetic evaluation be performed at specific joint angles, and with specific relevance to performance goals and/or injury risk. Furthermore, isokinetic assessments should be conducted across a range of velocities with greater functional specificity. In the current study, only when angle-specific measures of isokinetic strength were considered across testing velocities were youth players identified as possessing impaired strength when compared to their senior counterparts. The design of the isokinetic testing battery and the choice of analysis metrics therefore need careful consideration, and specificity to sports demands and/or injury mechanism and aetiology should inform this design. Although APT data yielded the lowest reliability, all other parameters exhibited substantial reliability and may help inform the design of an isokinetic testing procedures.

Interpretation of the isokinetic data should subsequently inform strength training interventions, based on a needs analysis. Given the discrepancies in isokinetic thigh musculature strength in youth soccer players and the associated injury risk practitioners may wish to develop muscular strength at younger ages (27). To aid the development of strength in soccer players, and particularly in youths, practitioners may wish to implement training at specific joint angles and contraction velocities to correct for strength discrepancies. For example, youth players may benefit from the use of low velocity exercises such as, but not limited to, Romanian deadlifts and Nordic hamstring curls which have been shown to be effective in reducing KF injuries in senior soccer players (1). Likewise, more high velocity eccentric activities could also be utilised such as eccentric box jumps or weightlifting exercises with manipulations to achieve increased eccentric KF loading. The lower angle specific concentric knee extensor strength in the youth players also highlights an additional need for matched concentric knee extension training, so that plyometric and power variants of strength training exercises might be advocated.

DISCLOSURE OF INTEREST

The authors report no conflict of interest.

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Table 1. The influence of angular velocity on PT and DCR in senior and youth players. 95% confidence intervals for differences are also presented.

Metric	Angular Velocity (°·s^{-1})	Senior Dominant	Senior Non-dominant	Youth Dominant	Youth Non-dominant
EccKF PT (N.m)	60	204.7 ± 38.9	180.2 ± 24.2	154.1 ± 28.6	143.9 ± 26.4
	180	195.3 ± 34.4	178.5 ± 19.9	161.5 ± 29.1	153.0 ± 28.6
	270	195.9 ± 19.5	177.7 ± 18.2	159.5 ± 32.6	154.3 ± 26.4
ConKE PT (N.m)	60	246.8 ± 26.1	242.3 ± 37.1	215.9 ± 34.4	205.9 ± 35.2
	180	196.9 ± 19.6	206.0 ± 29.4	166.8 ± 21.7	162.6 ± 26.3
	270	170.8 ± 25.4	177.9 ± 25.7	138.3 ± 26.1	136.1 ± 27.8
DCR	60	0.81 ± 0.16	0.76 ± 0.15	0.73 ± 0.17	0.72 ± 0.17
	180	1.02 ± 0.14	0.88 ± 0.14	0.98 ± 0.19	0.95 ± 0.16
	270	1.18 ± 0.17	1.02 ± 0.14	1.19 ± 0.32	1.16 ± 0.21
EccKF FR (º)	60	31 ± 10	28 ± 11	28 ± 11	25 ± 9
	180	22 ± 7	22 ± 9	20 ± 12	24 ± 11
	270	24 ± 11* (2 to 13º)	21 ± 8* (1 to 15º)	17 ± 10	14 ± 9
ConKE FR (º)	60	20 ± 8	21 ± 8	16 ± 6	19 ± 7
	180	20 ± 9	19 ± 10	15 ± 6	19 ± 8
	270	10 ± 4	13 ± 7	12 ± 5	13 ± 3

The Asterisk symbol (*) denotes a significant difference between playing age

Table 2. The influence of angular velocity, angle, and limb on isokinetic torque in senior and youth players. 95% confidence intervals for difference are also presented.

Angle (°)		70		60		50		40	
Group		Senior	Youth	Senior	Youth	Senior	Youth	Senior	Youth
270°·s^{-1}	Dominant eccKF (N.m)	154.3 ± 19.0 *(2.2 to 29.7)	138.3 ± 20.3	164.9 ± 31.2 *(17.7 to 59.4) ~(8.1 to 39.9)	126.3 ± 28.3	180.2 ± 34.4 *(23.2 to 70.0) ~(9.7 to 41.3)	133.5 ± 32.5	192.5 ± 35.6 *(30.9 to 79.4) ~(5.7 to 45.0)	137.3 ± 33.8
	Non-dominant eccKF (N.m)	147.9 ± 12.0	136.8 ± 20.7	140.9 ± 21.0	132.4 ± 27.5	154.7 ± 21.0	135.5 ± 40.5	167.1 ± 23.7 *(3.1 to 50.4)	140.4 ± 41.5
	Asymmetry Angle (%)	1.35	0.35	4.99	1.50	4.84	0.48	4.48	0.70
	Dominant conKE (N.m)	155.9 ± 36.9 *(3.1 to 47.2)	130.7 ± 25.0	147.1 ± 21.4 *(2.4 to 30.3)	130.7 ± 18.4	125.5 ± 22.0 *(10.1 to 40.3)	100.4 ± 20.9	111.6 ± 18.5 *(7.7 to 32.0)	91.7 ± 16.2
	Non-dominant conKE (N.m)	152.6 ± 25.6 *(9.0 to 52.9)	121.6 ± 36.2	160.1 ± 25.0 *(25.9 to 56.0)	119.2 ± 17.5	127.6 ± 23.5 *(7.4 to 42.1)	102.8 ± 26.3	121.7 ± 21.2 *(20.5 to 56.2)	83.4 ± 29.1
	Asymmetry Angle (%)	0.74	2.30	3.97	2.93	2.06	0.77	4.15	3.03
180°·s^{-1}	Dominant eccKF (N.m)	140.7 ± 28.8 *(7.4 to 40.8)	117.0 ± 16.2	154.6 ± 29.50 *(8.7 to 44.0)	128.3 ± 20.1	169.3 ± 32.6 *(11.7 to 51.2)	137.8 ± 23.3	185.7 ± 34.2 *(18.4 to 63.0)	144.9 ± 29.7
	Non-dominant eccKF (N.m)	132.1 ± 24.4	121.6 ± 27.2	142.2 ± 28.4	135.9 ± 28.9	155.7 ± 29.1	142.2 ± 35.0	170.2 ± 27.2	153.2 ± 36.6
	Asymmetry Angle (%)	2.00	1.25	2.66	1.84	2.66	1.12	2.77	1.75
	Dominant conKE (N.m)	173.6 ± 15.3 *(12.1 to 37.1)	149.0 ± 20.2	169.3 ± 30.1 *(8.9 to 42.2)	143.7 ± 15.3	147.6 ± 27.4 *(6.7 to 41.5)	123.4 ± 21.8	127.7 ± 32.4 *(14.6 to 53.4)	93.7 ± 22.2
	Non-dominant conKE (N.m)	183.0 ± 31.4 *(18.7 to 55.4)	146.0 ± 20.0	177.8 ± 28.3 *(8.2 to 47.6)	149.9 ± 28.2	163.1 ± 25.3 *(13.7 to 48.4)	131.8 ± 25.0	136.2 ± 24.6 *(18.2 to 53.6)	100.2 ± 26.0

	Asymmetry Angle (%)	2.50	0.66	1.70	1.34	3.58	2.09	2.13	2.14
	Dominant eccKF (N.m)	152.0 ± 27.4 *(19.2 to 54.8) ~(9.1 to 30.0)	115.0 ± 23.5	167.2 ± 30.2 *(21.1 to 62.9) ~(9.4 to 31.0)	125.2 ± 29.6	181.1 ± 34.6 *(19.5 to 63.8) ~(7.7 to 35.0)	139.4 ± 28.5	188.6 ± 39.6 *(21.9 to 70.3)	142.5 ± 28.9
	Non-dominant eccKF (N.m)	132.7 ± 26.6 *(1.2 to 39.3)	112.4 ± 26.9	146.8 ± 29.6 *(2.5 to 43.9)	123.5 ± 29.7	159.9 ± 28.7 *(7.6 to 49.0)	131.5 ± 30.4	172.6 ± 25.7 *(20.7 to 62.7)	130.9 ± 33.8
60°·s^{-1}	Asymmetry Angle (%)	5.33	0.72	4.13	1.57	3.95	1.87	2.81	2.69
	Dominant conKE (N.m)	233.2 ± 35.1 *(13.7 to 70.9)	190.9 ± 46.1	202.4 ± 34.0 *(24.2 to 68.9)	155.8 ± 29.9	172.7 ± 27.3 *(23.7 to 59.1)	131.3 ± 23.2	142.8 ± 20.0 *(24.4 to 53.0)	104.2 ± 20.8
	Non-dominant conKE (N.m)	230.7 ± 34.1 *(14.5 to 70.9)	188.0 ± 45.7	204.4 ± 36.6 *(11.8 to 69.7)	163.6 ± 45.8	178.6 ± 38.0 *(19.5 to 71.4)	133.1 ± 36.2	146.4 ± 31.7 *(16.3 to 58.5)	109.0 ± 28.6
	Asymmetry Angle (%)	0.41	0.72	0.03	0.43	1.08	1.87	0.80 ± 2.59	2.69

(*) denotes a significant difference between playing age, (~) demotes a significant difference between lower limbs.