Citation:
Lunn, D and Nicholson, G and Cooke, M and Crespo, R and Robinson, T and Price, R and Walker, J (2023) Discrete Hamstring-to-Quadriceps Strength Ratios Do Not Represent Angle-Specific Ratios in Premier League Soccer Players. Journal of Strength and Conditioning Research. pp. 1-6. ISSN 1064-8011 DOI: https://doi.org/10.1519/JSC.0000000000004574

Link to Leeds Beckett Repository record:
https://eprints.leedsbeckett.ac.uk/id/eprint/10071/

Document Version:
Article (Accepted Version)

Discrete hamstring:quadriceps strength ratios do not represent angle-specific ratios in Premier League soccer players

ABSTRACT

This study compared angle-specific hamstring:quadriceps (H:Q) ratios to their discrete counterparts during strength testing in professional male soccer players. Twenty-seven professional English Premier League players were recruited (age: 22 ± 4 y; stature: 1.81 ± 0.08 m; body mass: 74.7 ± 6.5 kg). Isokinetic testing of the knee flexors and extensors was conducted concentrically at two angular velocities (60°/s and 240°/s) and eccentrically (for the knee flexors only) at 30°/s. Conventional H:Q ratio was calculated as the ratio between peak joint moment in the flexors and extensors at 60°/s. Functional H:Q ratio was calculated as the peak joint moment in the flexors during the eccentric condition and the extensors at 240°/s. Discrete conventional and functional H:Q ratios were 0.56 ± 0.06% and 1.28 ± 0.22%, respectively. The residual differences between discrete values and angle specific residual values were 13.60 ± 6.56% when normalized to the magnitude of the discrete value. For the functional ratios, the normalized residual was 21.72 ± 5.61%. Therefore, neither discrete ratio was representative of angle-specific ratios, although the conventional ratio had lower error overall. Practitioners should therefore consider H:Q ratio throughout the full isokinetic range of motion, not just the discrete ratio calculated from peak joint moments, when designing and implementing training programs or monitoring injury risk, recovery from injury, and readiness to return to play.

Keywords: Isokinetic testing, injury risk, muscle imbalance, ACL, knee, football.

INTRODUCTION

The most common non-contact injuries in soccer include hamstring tears and anterior cruciate ligament (ACL) ruptures, with incidence rates of between 3 and 19 per 10000 hours (14) and 0.9 and 2 per 10000 hours (24), respectively. Whilst injury risk is multi-faceted and injuries are not often caused by a single risk factor, these injuries have been previously associated with strength imbalances between the hamstrings and quadriceps (27). During activities such as running and kicking, which are frequently performed in soccer, if the hamstrings are not able to generate sufficient forces to decelerate the tibia during knee extension tasks (e.g., the hamstring energy absorption phase of running, around late swing), hamstring strains or ACL injuries can occur (29). As a result, the routine assessment of the strength of these muscle groups in elite soccer players has previously been undertaken, both as a marker for recovery in return-to-play protocols (34), or as a screening tool when identifying injury risk (23).

Isokinetic dynamometry has been frequently used to assess joint mechanical function for several decades (5). The method assesses joint moments throughout the full range of movement (ROM) of a joint at a predetermined angular velocity. Joint moment measurements using isokinetic dynamometry typically assess strength attributes through variables such as peak joint moment and angle of peak joint moment (5). Calculated mechanical characteristics such as the peak joint moment ratio between the hamstrings and quadriceps, known as the H:Q ratio, are more commonplace when assessing athletes' muscle imbalances. Typically, H:Q ratios using the "conventional" or "functional" knee strength ratios, defined using peak joint moment of the flexors and extensors, are used in practice to estimate injury risk (6). Where conventional H:Q ratio is determined by measuring the peak joint moment of the hamstrings and quadriceps during concentric actions, the functional H:Q ratio is determined by measuring the peak moment of the quadriceps during concentric action and the hamstrings peak moment during eccentric action, as would be observed during running or kicking (1). Despite literature commonly reporting these values, there remains uncertainty regarding their relevance to human movement (20). In a recent systematic review, Baroni *et al.* (6) suggested that a value in the range of 0.52 to 0.67 is considered typical the sample population for conventional ratio (i.e., the peak joint moment of the hamstrings is 60% of the quadriceps) and 1.3 (or 130%) was the optimum functional H:Q ratio when comparing eccentric knee flexor moment at 30°/s with concentric extensor moment at 240°/s. However, these benchmarks depend on the angular velocities that the athletes are tested at, which has varied substantially in the literature (6). Therefore, it is apparent that these discrete benchmarks based on peak joint moments alone might be an oversimplification of knee joint strength imbalances, potentially rendering them inappropriate as screening tools for injury risk.

Furthermore, peak torque values for the knee extensors are typically observed between 60° and 70° and peak knee flexor torque values occurring at 25°–40° when this hip is flexed at 85° (8, 28). Therefore these discrete ratios provide a single value based on peak joint moments that occur at different joint angles (15). As such, discrete ratios do not make use of the benefit that isokinetic assessments have in comparison to other strength measures (e.g., isometric) in providing ROM specific information. It is therefore not surprising that a number of studies have suggested a time-series metric from angle-specific joint moments. Although these angle-specific ratios require additional analysis, they could be more useful for screening injury risk or identifying strength deficits following injury (28, 35) and in evaluating interventions aimed at promoting ROM specific adaptations (10). Research of this kind has focused on angle-specific strength ratios in healthy recreational athletes (8, 9, 32) and elite skiers (3) as well as other populations with previous injuries (28, 33). As a result, there is a lack of normative angle-specific information based on healthy, professional soccer players despite the high prevalence of hamstring injury in soccer (2) and the high demands of the modern game (11). Importantly, the existing research has revealed differences between discrete and angle-specific ratios that raise questions regarding the accuracy of prospective injury risk categorization in soccer if this is based on discrete H:Q ratios. It is notable, however, that no study is yet to compare angle-specific ratios with conventional and functional H:Q ratios despite the frequency of screening and return-to-play assessments that use the functional ratio (26).

Research that assesses angle-specific H:Q ratios in healthy elite professional soccer players is needed to understand whether these should be adopted in future screening and return-to-play protocols. Furthermore, research that compares angle-specific H:Q ratios with their conventional and functional (discrete) counterparts would inform the decision-making of practitioners when designing isokinetic protocols aimed at assessing an athlete's muscle balance. Therefore, the aim of this study was to compare the angle-specific ratios to their discrete counterparts during both conventional and functional testing protocols in professional male soccer players.

METHODS

Experimental Approach to the Problem

Professional, male soccer players from the same English Premier League club formed the sample population for this cross-sectional study design. Maximal knee flexor and knee extensor strength was obtained under specific concentric and eccentric isokinetic conditions. These were selected to allow for the computation of two commonly-reported H:Q ratios: a "conventional" H:Q ratio, and a "functional" H:Q ratio, which have been used in previous research (6, 13, 21). These ratios are typically calculated using peak joint moment but, by analysing joint moment data throughout the full isokinetic ROM, we were able to compare the discrete calculations of H:Q ratio to a range of angle-specific strength ratios as independent variables, thus allowing us to establish the ability of discrete ratios to represent strength ratios throughout the full joint ROM.

Subjects

Twenty-seven professional soccer players volunteered to participate this study (age: 22 ± 4 y; stature: 1.81 ± 0.08 m; body mass: 74.7 ± 6.5 kg). All subjects were recruited from the same soccer club who were competing in the English Premier League. Subjects gave informed written consent and were confirmed free of musculoskeletal injury at the time of testing. Testing took place during the off-season ahead of the 2021-2022 competitive season as part of a larger testing battery of each athlete's pre-season health and performance. This study gained ethical approval from the local university ethics committee (project number 91888) and testing was carried out in accordance with the Declaration of Helsinki.

Procedures

Following a standardized warm-up, strength testing of the knee joint in the dominant and non-dominant limb was conducted using an isokinetic dynamometer (System 4 Pro, Biodex Medical Systems, USA), where the dominant limb was defined as each subject's preferred kicking leg. To conduct the testing, subjects were seated in the dynamometer with straps fixed across the torso and the waist, as well the thigh of the involved limb. The hip joint was placed at ~85° flexion for every subject, and the center of rotation of the knee joint (approximated using the lateral femoral epicondyle) was aligned with the dynamometer's axis of rotation. Finally, the lever arm length of the dynamometer was adjusted to replicate the subject's lower leg length and was fixed proximal (~2 cm) to the ankle joint center. Once fixed in position, each subject's individual maximal ROM was registered by the dynamometer, and a gravity correction was applied to the dynamometer's joint moment signal by measuring passive joint moment at 30° knee flexion and registering this in the dynamometer software.

Isokinetic strength testing of the knee flexors and extensors was conducted in a concentric motion at two angular velocities (60°/s for flexors and extensors, and 240°/s for extensors only) and in an eccentric motion (for the knee flexors only) at one angular velocity (30°/s) (6, 13, 21). The order of limb testing was randomized for each subject, and the angular velocity tested was also randomised within each limb. For each testing condition, subjects were permitted five familiarization trials that were then followed by five maximal-effort repetitions where subjects were instructed to contract maximally throughout their entire ROM. Sets were separated by 120-s rest intervals. Signals for joint moment and joint position were recorded by the dynamometer's software at 100 Hz.

All data processing was conducted in MATLAB (R2022a, MathWorks, Inc., USA). Imported joint moment and positional data were initially filtered using a recursive, second-order, low-pass Butterworth filter with cut-off frequency of 10 Hz (28). Joint angular velocities were calculated as the first time derivative of joint angle, and the isokinetic range for all testing conditions was defined when calculated angular velocity was at least 95% of the target velocity (4). From the five maximal-effort repetitions, the “best trial” (determined using maximum joint moment generated) for both left and right legs was used for analysis, where the data from the best trial for the left and right limbs were then averaged for each subject. Peak joint moment was defined as the maximum joint moment achieved throughout the isokinetic range, whilst angle of peak joint moment described the joint angle at which peak joint moment was achieved. Additionally, average joint moment was calculated throughout the isokinetic range, and the total work done was calculated as the area under the joint moment-angle curve throughout the isokinetic range. To ensure inter-limb strength asymmetries would not affect our interpretations of the combined limb data, we conducted paired-samples *t*-tests on peak joint moment for dominant (kicking leg) and non-dominant limbs. No significant effect of limb was found for peak joint moment across any of the isokinetic conditions in this study ($p \geq 0.262$).

Conventional, discrete H:Q ratio (cHQR-D) was calculated as the ratio between peak joint moment in the flexors and extensors at 60°/s. Functional, discrete H:Q ratio (fHQR-D) was calculated as the ratio between peak joint moment in the flexors during the eccentric condition at 30°/s and the extensors at 240°/s. In addition to these discrete ratios, angle-specific H:Q ratios (cHQR-AS and fHQR-AS) were computed as the ratio between flexor and extensor joint moments for all joint angles where both muscle groups were in the isokinetic range for all subjects. This corresponded to 27-80° of flexion for cHQR-AS and 37-77° of flexion for fHQR-AS, where 0° = full extension.

The observed error between discrete and angle-specific ratios through the isokinetic ROM was quantified using the modulus residual ($|R|$) between the angle-specific curves and the discrete value superimposed over the isokinetic ROM (as a horizontal line on the ratio-angle curve); the higher the value of $|R|$, the greater the disagreement between discrete and angle-specific ratios. The mean value of $|R|$ ($|\bar{R}|$), is therefore the overall mean agreement between discrete and angle-specific ratios for each subject.

Statistical analyses

Statistical analyses were conducted in SPSS (version 27, IBM, USA). A one-sample *t*-test was used to assess the magnitude of $|\bar{R}|$, when calculated as an absolute, arbitrary value and when normalized to its respective discrete ratio. Testing the hypothesis that a variable is significantly different to zero, so a significant result here indicates that overall, the discrete ratios (cHQR-D and fHQR-D) are not representative of their angle-specific, time-series counterparts (cHQR-AS and fHQR-AS, respectively). In addition, a paired-samples *t*-test was also used to assess the differences between $|\bar{R}|$ values for the conventional and functional approaches. This was only conducted on the normalized values to account for absolute differences in ratios. Significance levels were set at $p < 0.05$. Cohen's *d* (12) effect sizes (ES) were also computed alongside all statistical tests using the in-built Cohen's *d* point estimate in version 27 of SPSS. ES magnitudes were interpreted using the guidelines of (17): 0.10-0.29 = small, 0.30-0.49 = moderate, 0.50-0.69 = large, 0.70-0.89 = very large, ≥0.90 = extremely large.

RESULTS

Descriptive, discrete isokinetic statistics can be seen in Table 1. Overall, cHQR-D and fHQR-D were 0.56 ± 0.06 and 1.28 ± 0.22, respectively. When calculated for the conventional ratios, $|\bar{R}|$ was 0.08 ± 0.04 across the isokinetic ROM that was 13.60 ± 6.56% when normalized to cHQR-D (Table 2). For the functional ratios, $|\bar{R}|$ was 0.27 ± 0.07 across the isokinetic ROM, which was 21.72 ± 5.61% when normalized to fHQR-D (Table 2). All $|\bar{R}|$ values were significantly different from zero (all $p < 0.001$, $d > 0.90$, Table 2).

[INSERT TABLE 1 HERE]

[INSERT TABLE 2 HERE]

[INSERT FIGURE 1 HERE]

When comparing $|\bar{R}|$ between functional and conventional ratios (normalized to their respectively discrete ratios), there was a significant difference between tests ($t = 5.35$, $p < 0.001$, $d > 0.70$, Table 2), indicating that errors between discrete and angle-specific ratios are lower for conventional than functional computations.

DISCUSSION

The aim of this study was to compare angle-specific H:Q ratios (cHQR-AS and fHQR-AS) to their discrete counterparts (cHQR-D and fHQR-D) during both conventional and functional isokinetic testing protocols in professional male soccer players. The findings demonstrate that the discrete H:Q ratios did not represent angle-specific ratios well, as substantial differences were observed between the discrete and angle-specific approaches across various parts of the isokinetic ROM. There was, however, a difference between the relative error of conventional and functional ratios with cHQR-D being more representative of the full ROM than its “functional” counterpart. These findings have important implications for practitioners during the design and analysis of testing protocols aimed at assessing hamstring and quadriceps strength ratios.

The finding that single-value strength ratios do not represent the strength ratio between muscle groups throughout the entire ROM is consistent with previous investigations (8) and suggests that where possible, angle-specific, or time-series analyses of H:Q strength should be conducted to accurately understand muscle balance through the ROM. Recent evidence exists that discrete H:Q strength ratios are not independent risk factors for either hamstring or anterior cruciate ligament injury (20). Although the cause of these types of injuries is known to be multifactorial (2, 27, 30), Kellis et al. (20) suggested that the low predictive capacity of the H:Q ratio could partly result from the fact that the conditions of measurement often have limited association with the mechanism of injury. Critically, the present findings confirm that angle-specific ratios more closely reflect the instantaneous relationship between knee flexor and extensor moments at different joint positions, that might more closely replicate the injury mechanisms of the anterior cruciate ligament (7, 9) and the hamstring muscles (22, 29). Although longitudinal research is needed to better understand the predictive capacity of angle-specific ratios for injury occurrence, the present study is the first to provide angle-specific data for healthy male professional soccer players. Although the cHQR-D reported in this investigation was lower than the mean values reported in the review by Baroni and co-authors (6), there was considerable inter-study variation reported, and the present results are similar to those reported in some studies (18, 31) for professional soccer players. As such, this study provides an indication of H:Q ratio values which can be expected in this cohort of professional soccer players, with potential use by practitioners working with similar athletes. Future research should consider investigating the effect of limb dominance on time-series interpretations of H:Q ratios. Although the current study showed no clear signs of asymmetry between dominant and non-dominant limbs, similar populations might show angle-specific differences between limbs when the role of a “dominant” or “non-dominant” limb is specialized.

Compared with previous studies (9, 28), where angle-specific and discrete values were compared for conventional H:Q ratio only, our study compared both conventional and functional ratios. Conventional ratios (i.e., cHQR-D) have been criticized for not being reflective of real-world muscle actions i.e., quadricep concentric action couple with hamstring concentric actions and instead, other research (1, 19) has favored more “functional” ratios (i.e., fHQR-D) which do reflect real-world muscle actions i.e., quadricep concentric action coupled with hamstring eccentric actions. The rationale for this is that the slow, eccentric knee flexor muscle action, coupled with the rapid, concentric knee extensor action, more accurately reflects the mechanisms/conditions where hamstring strain injuries occur (e.g., during the terminal swing phase of high-speed running) (16, 22). The mean fHQR-D in the current study was 1.28, which is similar to previously reported values for professional soccer players (25). However, similar to cHQR-D, fHQR-D did not represent angle-specific H:Q ratios and was found to have a mean difference of 21% across the full range of motion compared to fHQR-AS. This suggests that neither the functional nor conventional discrete H:Q ratio represents the H:Q ratio throughout the full isokinetic ROM and it is therefore not surprising that fHQR-D offers no greater injury predictive capacity than the cHQR-D at present (20).

Although our results suggest the use of fHQR-D might not represent the strength ratio between the hamstring and quadriceps during the full isokinetic ROM, it has become more common practice in isokinetic strength assessments (28). As previously stated, neither cHQR-D nor fHQR-D represent the H:Q ratio throughout the entire ROM, indicating one might not be regarded as more relevant than the other. However, there was a difference between the relative error of conventional and functional ratios (Conventional $|\bar{R}|$ and Functional $|\bar{R}|$; $p < 0.001$; Table 2; Figure 1), indicating that the conventional, concentric ratio is actually more representative (i.e., lower $|\bar{R}|$) of the full ROM than its functional counterpart, meaning the time-series data deviates from the discrete values less than in the functional data. Secondly, cHQR-D seems to under-represent the cHQR-AS, whereas fHQR-D substantially over-represents fHQR-AS (Figure 1). This means that cHQR-D is more likely to highlight a player as being at-risk of hamstring injury (based only on H:Q ratio) when in fact they are not (i.e., false positive). However, over-representing H:Q ratio (using fHQR-D) potentially means players could be regarded as being "well-balanced" when in fact they have relatively weak hamstrings and be more susceptible to injury (i.e., "false negative"). Therefore, based on the findings of this study, when there is limited time available for testing, and only discrete ratios based on peak joint moments are possible, then conventional H:Q ratios might be preferential over functional H:Q ratios in providing a more cautious estimation of the strength ratio throughout the full range of motion.

When interpreting the findings of this study, practitioners should be mindful of some limitations. Firstly, the investigation comprised players from one English professional soccer team and therefore further research is required to understand whether the reported angle-specific H:Q ratios are representative of other teams and leagues with alternative training regimens. Secondly, the testing in this study was conducted at the beginning of pre-season, as this was the most appropriate time to minimize the risk of chronic fatigue influencing our results. Although baseline strength data collected during pre-season can provide important information for return-to-play decisions following injury, research that uses more regular testing is needed to understand how this might change during the competitive season. Finally, only one conventional and one functional strength ratio was computed in the current study, despite various iterations being presented across the literature. It should be noted that this testing took place as part of a larger pre-season testing battery, where it was important that the isokinetic testing did not induce too much fatigue to influence the validity of other tests conducted. As a result, we chose testing conditions that were commonly reported in the literature (60°/s for conventional ratio testing) and adhered to the rationale behind the "functional" ratio (fast concentric knee extension coupled with slow eccentric knee flexion).

In conclusion, although neither the conventional nor functional discrete ratios were representative of angle-specific ratios, the conventional H:Q ratio represented a more cautious estimate of the angle-specific ratio. This suggests the conventional H:Q ratio testing could be the most appropriate protocol when working with professional soccer players, where time for data collection and analysis is limited or fatiguing protocols are not appropriate. Further still, we have demonstrated the discrete functional H:Q ratio can mask hamstring weakness in relation to H:Q ratio throughout the isokinetic range. Our study has clearly demonstrated the need for angle-specific measurements to become more common practice in isokinetic dynamometry testing and that discrete values do not represent H:Q ratios throughout the full joint ROM.

PRACTICAL APPLICATIONS

This study offers knee flexor and knee extensor strength values for professional soccer players, which are needed by coaches and applied sports scientists to enable meaningful comparisons within screening and return-to-play protocols. In addition, these findings also highlight the need to understand knee flexor and extensors strength, and in-turn H:Q ratios, throughout the full isokinetic ROM to fully understand the functional capacity for force production around the knee joint. Discrete H:Q ratios, that are commonplace in practice, can potentially lead to incorrect conclusions regarding injury risk and should only be considered in conjunction with their angle-specific counterparts. As such, this has implications when designing and implementing a training program to reduce injury risk or a return-to-play protocol after injuries such as an ACL tear or hamstring strain. Finally, monitoring seasonal variation in angle-specific strength data would be recommended, but does not have to be limited to isokinetic dynamometry; various field-based alternative methods of strength measurement (e.g., Nordic Hamstring Exercise devices) also offer a time-series signal, meaning ROM-specific performance can also be considered without access to an isokinetic dynamometer.

Declaration of interest statement

The authors confirm there are no conflicts of interest to declare.

Funding details

The data collection was supported by funding provided by Leeds United Football Club as part of a wider sport science support project; however, the nature of the data is purely descriptive and not associated with any governing body, commercial sector, or product. No funding was provided for the writing of this manuscript. The results of the present study do not constitute endorsement by Leeds United Football Club.

Disclosure Statement

None declared.

REFERENCES

1. Aagaard P, Simonsen EB, Magnusson SP, et al. A New Concept For Isokinetic Hamstring: Quadriceps Muscle Strength Ratio. *The American Journal of Sports Medicine* 26: 231-237, 1998.
2. Alentorn-Geli E, Myer GD, Silvers HJ, et al. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 1: Mechanisms of injury and underlying risk factors. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA* 17: 705-729, 2009.
3. Alhammoud M, Morel B, Hansen C, et al. Discipline and Sex Differences in Angle-specific Isokinetic Analysis in Elite Skiers. *Int J Sports Med* 40: 317-330, 2019.
4. Baltzopoulos V. Isokinetic dynamometry, in: *Biomechanical evaluation of movement in sport and exercise*. Routledge, 2017, pp 140-167.
5. Baltzopoulos V and Brodie DA. Isokinetic Dynamometry. *Sports Medicine* 8: 101-116, 1989.
6. Baroni BM, Ruas CV, Ribeiro-Alvares JB, et al. Hamstring-to-Quadriceps Torque Ratios of Professional Male Soccer Players: A Systematic Review. *J Strength Cond Res* 34: 281-293, 2020.

7. Bates NA and Hewett TE. Motion Analysis and the Anterior Cruciate Ligament: Classification of Injury Risk. *J Knee Surg* 29: 117-125, 2016.
8. Baumgart C, Kurz E, Freiwald J, et al. Effects of Hip Flexion on Knee Extension and Flexion Isokinetic Angle-Specific Torques and HQ-Ratios. *Sports Medicine - Open* 7: 41, 2021.
9. Baumgart C, Welling W, Hoppe MW, et al. Angle-specific analysis of isokinetic quadriceps and hamstring torques and ratios in patients after ACL-reconstruction. *BMC Sports Sci Med Rehabil* 10: 23, 2018.
10. Bourne MN, Duhig SJ, Timmins RG, et al. Impact of the Nordic hamstring and hip extension exercises on hamstring architecture and morphology: implications for injury prevention. *Br J Sports Med* 51: 469-477, 2017.
11. Bush M, Archer DT, Barnes C, et al. Longitudinal match performance characteristics of UK and non-UK players in the English Premier League. *Science and Medicine in Football* 1: 2-9, 2017.
12. Croisier J-L. Factors Associated with Recurrent Hamstring Injuries. *Sports Medicine* 34: 681-695, 2004.
13. Diemer WM, Winters M, Tol JL, et al. Incidence of Acute Hamstring Injuries in Soccer: A Systematic Review of 13 Studies Involving More Than 3800 Athletes With 2 Million Sport Exposure Hours. *J Orthop Sports Phys Ther* 51: 27-36, 2021.
14. Eustace SJ, Page RM, and Greig M. Contemporary approaches to isokinetic strength assessments in professional football players. *Science and Medicine in Football* 1: 251-257, 2017.
15. Havens KL, Cohen SC, Pratt KA, et al. Accelerations from wearable accelerometers reflect knee loading during running after anterior cruciate ligament reconstruction. *Clin Biomech (Bristol, Avon)* 58: 57-61, 2018.
16. Heiderscheit BC, Hoerth DM, Chumanov ES, et al. Identifying the time of occurrence of a hamstring strain injury during treadmill running: A case study. *Clinical Biomechanics* 20: 1072-1078, 2005.
17. Hopkins W, Marshall S, Batterham A, et al. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3-13, 2009.
18. Hoshikawa Y, Iida T, Muramatsu M, et al. Differences in thigh muscularity and dynamic torque between junior and senior soccer players. *J Sports Sci* 27: 129-138, 2009.
19. Kellis E and Baltzopoulos V. Isokinetic eccentric exercise. *Sports Med* 19: 202-222, 1995.
20. Kellis E, Sahinis C, and Baltzopoulos V. Is hamstrings-to-quadriceps torque ratio useful for predicting anterior cruciate ligament and hamstring injuries? A systematic and critical review. *Journal of Sport and Health Science*, 2022.
21. Lehance C, Binet J, Bury T, et al. Muscular strength, functional performances and injury risk in professional and junior elite soccer players. *Scandinavian Journal of Medicine & Science in Sports* 19: 243-251, 2009.
22. Liu H, Garrett WE, Moorman CT, et al. Injury rate, mechanism, and risk factors of hamstring strain injuries in sports: A review of the literature. *Journal of Sport and Health Science* 1: 92-101, 2012.
23. McCall A, Carling C, Nedelec M, et al. Risk factors, testing and preventative strategies for non-contact injuries in professional football: current perceptions and practices of 44 teams from various premier leagues. *Br J Sports Med* 48: 1352-1357, 2014.
24. Montalvo AM, Schneider DK, Silva PL, et al. 'What's my risk of sustaining an ACL injury while playing football (soccer)?' A systematic review with meta-analysis. *Br J Sports Med* 53: 1333-1340, 2019.
25. Moreno-Pérez V, Barbado-Murillo D, Juan-Recio C, et al. Aplicación de la dinamometría isocinética para establecer perfiles de riesgo de lesión isquiosural en futbolistas profesionales.[The use of isokinetic dynamometry to establish risk profiles

of hamstring injury in professional football players]. *RICYDE Revista Internacional de Ciencias del Deporte doi: 105232/ricyde* 9: 333-341, 2013.

26. Nicholson G, Bennett T, Thomas A, et al. Inter-limb asymmetries and kicking limb preference in English premier league soccer players. *Frontiers in Sports and Active Living*: 331, 2022.
27. Opar DA, Williams MD, and Shield AJ. Hamstring strain injuries. *Sports medicine* 42: 209-226, 2012.
28. Read PJ, Trama R, Racinais S, et al. Angle specific analysis of hamstrings and quadriceps isokinetic torque identify residual deficits in soccer players following ACL reconstruction: a longitudinal investigation. *Journal of Sports Sciences*: 1-7, 2022.
29. Ruas CV, Pinto MD, Brown LE, et al. The association between conventional and dynamic control knee strength ratios in elite soccer players. *Isokinetics and Exercise Science* 23: 1-12, 2015.
30. Shultz SJ, Schmitz RJ, Benjaminse A, et al. ACL Research Retreat VII: An Update on Anterior Cruciate Ligament Injury Risk Factor Identification, Screening, and Prevention. *J Athl Train* 50: 1076-1093, 2015.
31. Śliwowski R, Grygorowicz M, Hojszyk R, et al. The isokinetic strength profile of elite soccer players according to playing position. *PLoS One* 12: e0182177, 2017.
32. Sousa LA, Soares ALA, Lima AB, et al. Modeling the Angle-Specific Isokinetic Hamstring to Quadriceps Ratio Using Multilevel Generalized Additive Models. *Medicina (Kaunas)* 55, 2019.
33. Tengman E, Schelin L, and Häger CK. Angle-specific torque profiles of concentric and eccentric thigh muscle strength 20 years after anterior cruciate ligament injury. *Sports Biomech*: 1-17, 2022.
34. van der Horst N, van de Hoef S, Reurink G, et al. Return to Play After Hamstring Injuries: A Qualitative Systematic Review of Definitions and Criteria. *Sports Med* 46: 899-912, 2016.
35. Walker J, Nicholson G, Jongerius N, et al. Commonly reported isokinetic parameters do not reveal long-term strength deficits of the Triceps surae complex following operative treatment of Achilles tendon rupture. *J Biomech* 101: 109630, 2020.

Table 1. Descriptive isokinetic characteristics of the cohort (*n* = 27).

	Flexion, 60°/s	**Extension, 60°/s**	**Extension, 240°/s**	**Eccentric flexion, 30°/s**
Peak joint moment (N·m)	134.4 ± 21.9	243.6 ± 34.9	145.7 ± 18.5	185.1 ± 33.7
Angle of peak joint moment (°)	50 ± 14	69 ± 6	63 ± 5	27 ± 10
Average joint moment (N·m)	96.1 ± 17.9	186.9 ± 27.6	131.9 ± 16.6	137.5 ± 29.0
Total work done (J)	131.4 ± 27.5	233.4 ± 44.4	120.1 ± 26.1	(−)188.5 ± 44.7
cHQR-D (arb.)	0.56 ± 0.06			
fHQR-D (arb.)			1.28 ± 0.22	

Note: cHQR-D = discrete conventional hamstring:quadriceps ratio; fHQR-D = discrete functional hamstrings:quadriceps ratio.

Table 2. Data for $|\bar{R}|$ and associated statistical tests.

	Conventional $|\bar{R}|$ (arb.)	**Functional $|\bar{R}|$ (arb.)**	**Conventional $|\bar{R}|$ (% cHQR-D)**	**Functional $|\bar{R}|$ (% fHQR-D)**
Mean ± SD (CV)	0.08 ± 0.04 (50%)	0.27 ± 0.07 (26%)	13.60 ± 6.56 (48%)	21.72 ± 5.61 (26%)
One-sample *t*-value	10.60	19.68	10.57	19.73
One-sample *p*-value	< 0.001	< 0.001	< 0.001	< 0.001
One-sample ES	2.08^{EL}	3.86^{EL}	2.07^{EL}	3.87^{EL}
Paired samples *t*-value			5.35	
Paired samples *p*-value			< 0.001	
Paired samples ES			1.05^{EL}	

Note: SD = standard deviation. CV = coefficient of variation. EL = *extremely large* ES.

Figure 1.

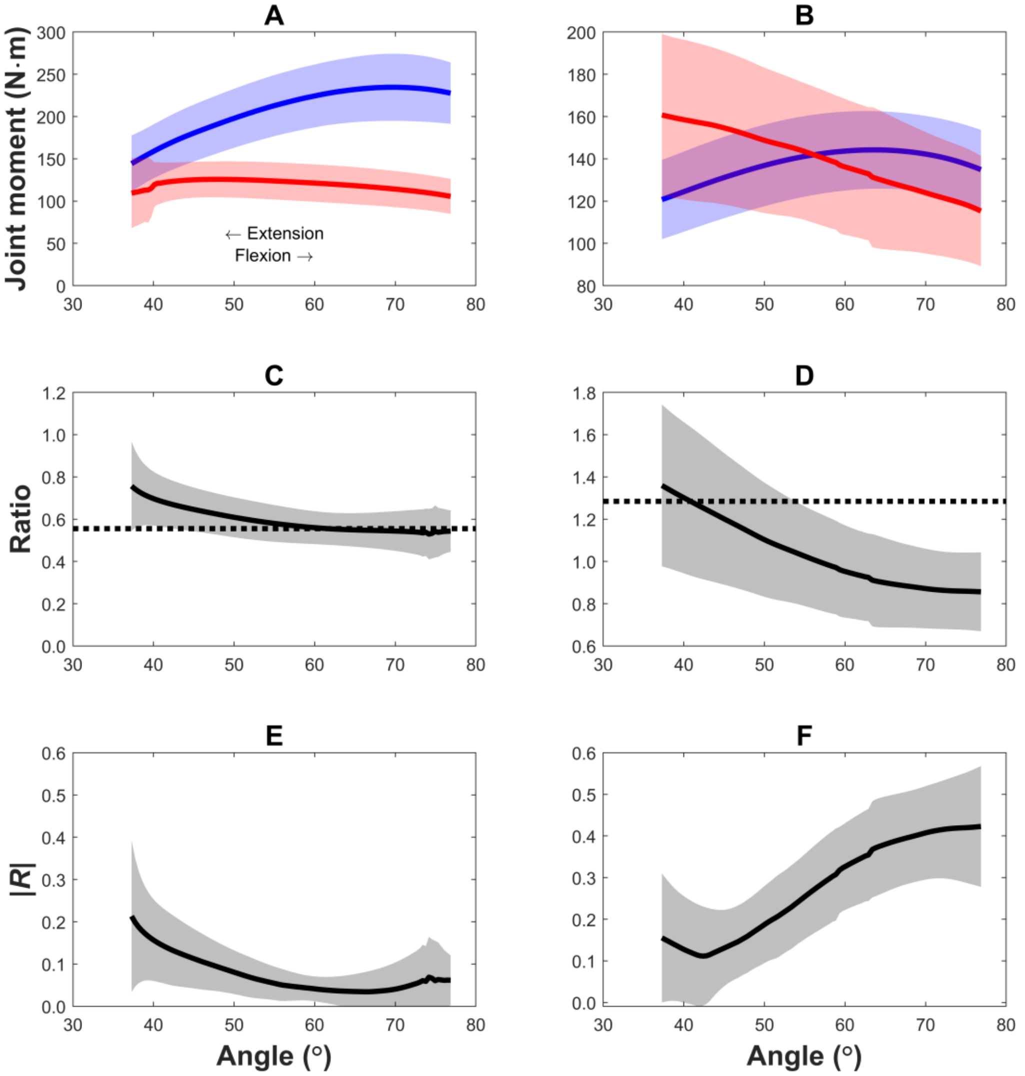
A
B
C
D
E
F
Joint moment (N·m)
Ratio
|R|
← Extension
Flexion →
Angle (°)
Angle (°)
300
250
200
150
100
50
0
200
180
160
140
120
100
80
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.6
0.5
0.4
0.3
0.2
0.1
0.0
30
40
50
60
70
80

TABLE AND FIGURE LEGENDS

Table 1. Descriptive isokinetic characteristics of the cohort (n = 27).

Table 2. Data for $|\bar{R}|$ and associated statistical tests.

Figure 1. Time-series joint moment, angle-specific strength ratio, and $|R|$ grouped data, all presented as a function of joint angle. (A) joint moments during concentric extension (blue) and flexion (red) at 60°/s. (B) joint moments during concentric extension at 240°/s (blue) and eccentric flexion at 30°/s (red). (C) cHQR-AS; horizontal dashed line denotes mean cHQR-D. (D) fHQR-AS; horizontal dashed line denotes fHQR-D. (E) and (F) $|R|$ data for conventional and functional ratios, respectively. All curves are presented as grouped means, with shaded areas depicting standard deviations. Angles defined as degrees of flexion (0° = full extension); therefore, reading the figures left-to-right denotes flexion, whereas reading the figures right-to-left denotes extension (as depicted in subplot A).