Lower-limb muscle strength, anterior-posterior and inter-limb asymmetry in professional, elite academy and amateur soccer players

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Conflict of interest statement: no conflict of interest.

Abstract

Given the importance of the lower-limb strength and strength balance in soccer players and its relationship with injury prevention and performance, the present study compared quadriceps and hamstrings strength, the conventional (H_{conc}:Q_{conc}), functional (H_{ecc}:Q_{conc}) hamstrings-to-quadriceps ratio and inter-limb strength asymmetry in professional, elite academy and amateur male soccer players. In this cross-sectional study, two hundred-six soccer players (professional = 75, elite academy = 68, amateurs = 63) volunteered to participate. Quadriceps and hamstrings isokinetic peak torque was investigated at $60°\cdot s^{-1}$ in both the concentric and eccentric modality and at $300°\cdot s^{-1}$ in the concentric modality. The conventional H_{conc}:Q_{conc}, functional H_{ecc}:Q_{conc} ratio and quadriceps and hamstrings inter-limb strength asymmetry were then calculated. Professional players presented greater quadriceps and hamstrings strength than elite academy (effect size from *small* to *moderate*) and amateur players (*moderate* to *very large*). Both the conventional H_{conc}:Q_{conc} and functional H_{ecc}:Q_{conc} ratio were greater in professional than elite academy and amateur players (*small* to *moderate*). Overall, quadriceps and hamstrings inter-limb strength asymmetry was greater in amateurs than professional (*small* to *very large*) and elite academy (*trivial* to *large*) players. The present findings provide coaches and medical staffs with normative lower-limb muscle strength data on professional, academy and amateur soccer players. Overall lower-limb muscle strength and inter-limb strength asymmetry could be used to evaluate possible inference on injury prevention and performance. The hamstrings-to-quadriceps ratio poorly differentiates between the soccer players background and offers limited prediction for injury prevention and performance.

Keywords: isokinetic, knee flexors, hamstrings-to-quadriceps ratio, injury prevention.

Introduction

Soccer players perform specific activities such as jumps, sprints, changes of direction (COD) and technical actions (e.g.: shots, passes, etc.), which demand fast and powerful movements, involving lower-limb muscles in maximal and rapid actions (Rodriguez-Rosell et al., 2017). Among the lower-limb muscles, quadriceps and hamstrings have a crucial anatomical and biomechanical role in the knee and hip joint and are mostly involved during jumps, sprints, COD and kicks (Comfort et al., 2014). Since previous studies have found a positive correlation between quadriceps and hamstrings strength and soccer-related abilities (Chaouachi et al., 2012; Comfort et al., 2014; Morin et al., 2015; Wisløff et al., 2004), a periodic quadriceps and hamstrings strength screening may provide coaches and conditioners with useful information about the soccer players' fitness level.

In addition to quadriceps and hamstrings strength, soccer players may benefit from a balance in anterior/posterior muscle strength, usually defined as a hamstrings-to-quadriceps ratio (Baroni et al., 2018). Particularly, the relative hamstrings strength weakness might have repercussion on the anterior cruciate ligament safety (Weiss and Whatman, 2015) and represents a co-factor for the hamstrings strain injury occurrence (Green et al., 2018). The hamstrings-to-quadriceps ratio is commonly assessed with an isokinetic dynamometer, considered as the "gold standard" for such an evaluation since it provides a controlled environment in which the neuromuscular performance of the joint system can be stressed maximally (Impellizzeri et al., 2008). To monitor the strength balance between hamstrings and quadriceps, the conventional H_{conc}:Q_{conc} ratio was first established, in which concentric strength of both hamstrings and quadriceps was evaluated (Heiser et al., 1984). However, since hamstrings and quadriceps do not act simultaneously in a concentric modality, the functional H_{ecc}:Q_{conc} ratio has been proposed later, in which hamstrings strength is measured eccentrically (Orchard et al., 1997). It was suggested that a conventional H_{conc}:Q_{conc} ratio lower than 0.55 (Croisier et al., 2008) and a functional H_{ecc}:Q_{conc} ratio lower than 0.7 (Rahnama et al., 2003) may theoretically result in an increased risk of a hamstrings strain injury. Notwithstanding, this was not further supported, since a recent meta-analysis showed that low conventional H_{conc}:Q_{conc} and functional H_{ecc}:Q_{conc} ratios were not predictors of the hamstrings strain injury (Green et al., 2018). However, hamstrings injury is a multi-factorial event accounted for several factors (e.g. injury history, age, poor eccentric strength, training load) (Ekstrand et al., 2016; Hägglund et al., 2013; Malone et al., 2019), thus lower-limb muscle strength could be useful to monitor possible risk factors.

The inter-limb muscle strength asymmetry is defined as the relative strength difference between limbs (Thomas et al., 2017). An inter-limb strength screening may provide useful information about the injury risk and performance. Indeed, it was reported that injury frequency increased in athletes with quadriceps inter-limb asymmetry of 10% or more (Jeon et al., 2016). Similarly, in professional soccer players, an inter-limb asymmetry in quadriceps and hamstrings maximal strength indicated a reduced muscle function and an increased risk of injury (Hägglund et al., 2013). Additionally, quadriceps and hamstrings inter-limb strength asymmetry was negatively correlated with COD and sprinting ability (Coratella et al., 2018b).

The players' playing level and age were proposed to affect lower-limb muscle strength and asymmetry, suggesting monitoring it over the players' career evolution (Carvalho et al., 2016). Generally, amateur players reported lower quadriceps and hamstrings concentric and eccentric peak torque, as well as lower strength ratios in both lower-limbs compared to professional players (Carvalho et al., 2016). The authors also reported greater hamstrings inter-limb asymmetry in concentric and eccentric strength in amateur players (Carvalho et al., 2016). Currently, limited evidence exists about the difference in muscle strength imbalances in soccer players of different performance levels or age (Carvalho et al., 2016; Croisier et al., 2008). Therefore, the aim of the present study was to compare quadriceps and hamstrings strength, the hamstrings-to-quadriceps ratio and inter-limb muscle asymmetry in professional, elite academy and amateur soccer players.

Methods

Participants

Two hundred-six soccer players (professional = 75, elite academy = 68, amateur = 63) volunteered for the present investigation. The anthropometrics for each group are reported in Table 1. Goalkeepers were excluded *a priori* from this study, as well as players who reported knee joint/muscle injuries in the previous year. The procedures were previously approved by the Ethics Committee of the University of Suffolk (Ipswich, UK) and conducted according to the Declaration of Helsinki (1975) for studies involving human subjects and in line with the ethical standards in sports and exercise science. No economic incentives were provided. Participants and the clubs' medical staffs were informed about the potential risks of the current procedures and provided written informed consent. Parental written consent was obtained from the minor participants.

Table-1 here

Study design

The present investigation was designed as a cross-sectional study. Since no study has used a similar design with similar populations, an accurate *a priori* power calculation was not possible. However, using statistical software for power calculation (G-Power, Stuttgart, Germany), given the study design, the number of participants, a *moderate* effect size (ES) of the main factor, the number of groups and $\alpha = 0.05$, an *a posteriori* power calculation resulted in $1\text{-}\beta = 0.91$.

Each participant was involved in two different testing sessions, separated by at least two days. During the first one, participants were familiarized with the isokinetic dynamometer and experienced each testing modality. During the second session, they were tested according to the same procedures used in the first session. Participants and the clubs were instructed to avoid any vigorous training session for the two days preceding the second testing session.

Isokinetic measurements

The quadriceps and hamstrings peak torque was measured using an isokinetic dynamometer (Cybex Norm, Ronkonkoma, USA). The device was calibrated and the gravity correction executed according to the manufacturer's procedures. The current procedures were conducted in line with previous research (Coratella et al., 2015). Briefly, participants were secured to the seat (inclination: 85°) by a seatbelt and the knee was aligned to the centre of rotation. An additional seatbelt secured the tested limb, while the untested limb was immobilized by a lever. The upper limbs were crossed against the chest. After a standardized warm up consisting of separate 10 sub-maximal concentric and 10 sub-maximal eccentric repetitions for both quadriceps and hamstrings, peak torque was investigated at $60°\cdot s^{-1}$ in both concentric and eccentric modalities and at $300°\cdot s^{-1}$ in the concentric modality (van Dyk et al., 2016). Hamstrings and quadriceps were randomly tested at first, but the sets were performed from the slowest to the quickest velocity, first in the concentric and then in the eccentric modality (Rahnama et al., 2003). Three maximal repetitions for each modality were performed and the peak torque was measured and inserted into the data analysis. Two minutes of passive recovery separated each set. The operators provided strong verbal encouragement to the participants to maximally perform during each trial. Both preferred and non-preferred limbs were tested in randomized order, with the preferred limb defined as the one preferred to kick a ball.

The conventional H_{conc}:Q_{conc} and the functional H_{ecc}:Q_{conc} ratio were then calculated and inserted into the data analysis (Coratella et al., 2015a, 2018a). In addition, the inter-limb asymmetry was calculated as follows (Coratella et al., 2018)

Asymmetry = (stronger / weaker) / stronger * 100.

Statistical analysis

Statistical analyses were performed using SPSS software version 20 for Windows 7, Chicago, USA. The Shapiro-Wilk test was used to check the normality assumption. Data were presented as mean ± standard deviation (SD). Separate one-way analysis of variance (ANOVA) was employed to detect possible between-group differences in hamstrings and quadriceps peak torque, conventional H_{conc}:Q_{conc} and functional H_{ecc}:Q_{conc} ratios in either a preferred or a non-preferred limb and inter-limb hamstrings and quadriceps peak torque asymmetry (Hopkins et al., 2009). Post-hoc analysis was conducted using Bonferroni's adjustment. Significance was set at $p < 0.05$. Outcomes were expressed as a value with a 90% confidence interval (CI). Robust estimates of the CI (bias corrected and accelerated) and data distribution (heteroskedasticity assumption) were evaluated using the bootstrapping technique (randomly 1000 bootstrap samples). Effect size (ES) was calculated and interpreted as: *trivial:* < 0.20, *small*: 0.20-0.59, *moderate*: 0.60-1.19, *large*: 1.20-1.99, and *very large* ≥ 2.00 (Hopkins et al., 2009).

Results

Table 2 summarises the strength variables of professional, elite academy and amateur players. In the preferred limb, the main effect for the factor group was found in quadriceps concentric peak torque at $60°·s^{-1}$ and $300°·s^{-1}$ ($F = 40.8$, $p < 0.001$, and $F = 36.5$, $p < 0.001$, respectively), hamstrings concentric peak torque at $60°·s^{-1}$ and $300°·s^{-1}$ ($F = 37.6$, $p < 0.001$, and $F = 61.8$, $p < 0.001$) and hamstrings eccentric peak torque at $60°·s^{-1}$ ($F = 29.8$, $p < 0.001$). In the non-preferred limb, the main effect for the factor group was found in the quadriceps concentric peak torque at $60°·s^{-1}$ and $300°·s^{-1}$ ($F = 60.7$, $p < 0.001$ and $F = 67.1$, $p < 0.001$, respectively), hamstrings concentric peak torque at $60°·s^{-1}$ and $300°·s^{-1}$ ($F = 61.8$, $p < 0.001$ and $F = 34.4$, $p < 0.001$) and hamstrings eccentric peak torque at $60°·s^{-1}$ ($F = 35.8$, $p < 0.001$).

Table-2 here

Table 3 summarises the strength ratio variables of professional, elite academy and amateur players. In the preferred limb, the main effect for the factor group was found in the conventional H_{conc}:Q_{conc} ratio at $60°·s^{-1}$ ($F = 4.1$, $p = 0.017$), but not at $300°·s^{-1}$ ($F = 2.08$, $p = 0.271$). The main effect for the factor group was in the functional H_{ecc}:Q_{conc} ratio in the preferred leg at $60°·s^{-1}$ ($F = 3.1$, $p = 0.047$). In the non-preferred limb, the main effect for the factor group was found in the conventional H_{conc}:Q_{conc} ratio at $60°·s^{-1}$ ($F = 5.2$, $p = 0.006$) and $300°·s^{-1}$($F = 7.04$, $p < 0.001$), but not in the functional H_{ecc}:Q_{conc} ratio at $60°·s^{-1}$ ($F = 0.003$, $p = 0.991$).

Table-3 here

Table 4 summarises the inter-limb strength asymmetry in professional, elite academy and amateur players. The main effect for the factor group was found in the quadriceps inter-limb concentric peak torque asymmetry in quadriceps at $60°{\cdot}s^{-1}$ and $300°{\cdot}s^{-1}$ (F = 8.1, $p < 0.001$, and F = 14.7, $p < 0.001$, respectively), in hamstrings inter-limb concentric peak torque asymmetry at $60°{\cdot}s^{-1}$ and $300°{\cdot}s^{-1}$ (F = 4.47, $p = 0.013$, and F = 10.7, $p < 0.001$, respectively) and in hamstrings inter-limb eccentric peak torque asymmetry at $60°{\cdot}s^{-1}$ (F = 3.2, $p = 0.040$).

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Discussion

The present study was the first to compare lower-limb muscle strength, anterior-posterior and inter-limb asymmetry in professional, elite academy and amateur soccer players. Greater (ES: *moderate*) quadriceps and hamstrings strength was found in professional compared to elite academy players; greater (ES: *moderate* to *very large*) quadriceps and hamstrings strength was found in professional compared to amateur players, while such a difference decreased between the elite academy and amateur players (ES *trivial* to *moderate*). A slightly higher (ES *small*) conventional H_{conc}:Q_{conc} ratio was found in professional compared to elite academy players; such a difference was not observed in professional compared to amateur players (ES *small* in both directions), while amateur athletes had a higher (ES *small* to *moderate*) conventional H_{conc}:Q_{conc} ratio than elite academy players. Overall, only a *moderately* higher functional H_{ecc}:Q_{conc} ratio was found in professional compared to elite academy players. Finally, while no difference in hamstrings and quadriceps inter-limb strength asymmetry was found in professional compared to elite academy players, greater quadriceps, but not hamstrings asymmetry was found in amateur compared to professional (ES *small* to *large*) and elite academy players (ES *small* to *large*).

Professional players have higher hamstrings and quadriceps strength compared to elite academy and amateur players. This difference in strength occurred in both quadriceps and hamstrings, at both $60°{\cdot}s^{-1}$ and $300°{\cdot}s^{-1}$ as well as in both the concentric and eccentric modality. The present results agree with previous evidence, which reported higher quadriceps concentric and hamstrings concentric and eccentric peak torque in first-division (258, 156 and 181 N·m, respectively) compared to second-division players (234, 138 and 164 N·m, respectively) (Carvalho et al., 2016). A recent study reported quadriceps and hamstrings concentric peak torque ($60°{\cdot}s^{-1}$) equal to 227 and 122 N·m in semi-professional players, which were lower values than those found in professional and elite academy players enrolled in the current study (Lee et al., 2017). Moreover, strength variables reported here for elite academy and amateur players are higher and equivalent, respectively, to young amateur players' quadriceps concentric (217 N·m) and hamstrings concentric and eccentric peak torque (136 and 150 N·m, respectively) (Thomas et al., 2017). Similar lower-limb muscle strength was reported in amateur soccer players (quadriceps and hamstring concentric peak torque of 215 and 152 N·m, respectively) (Ali and Williams, 2013). Previous studies have reported that lower-limb muscle strength is correlated with several soccer-related abilities. For example, lower COD performance time was negatively correlated to greater quadriceps and hamstrings strength (Jones et al., 2009). Similarly, quadriceps and hamstrings strength was positively correlated with COD performance, since the ability to accelerate and decelerate the body mass requires both quadriceps and hamstrings to exert maximal strength continuously (Chaouachi et al., 2012). Moreover, lower-limb muscle strength was correlated with jumping or sprinting ability (Comfort et al., 2014; Wisløff et al., 2004), with hamstrings playing a key role in the horizontal propulsion action during sprinting (Morin et al., 2015). On the other hand, hamstring weakness increases its susceptibility to tears and strains (Timmins et al., 2016). Coupled with muscle weakness, age was shown to increase the hamstrings injury risk, given the lower incidence in 17-22 year olds than in older players (Freckleton and Pizzari, 2013). Thus, increasing hamstrings strength may help counteract the negative effects of muscle weakness and age on the hamstrings injury risk.

Both the conventional H_{conc}:Q_{conc} and functional H_{ecc}:Q_{conc} (Orchard et al., 1997) ratios have been created to monitor the hamstrings strain injury risk. Their rationale is that hamstrings should counteract the force exerted by quadriceps to avoid occurring of over-elongation. Moreover, hamstrings assist the anterior cruciate ligament in preventing anterior drawer forces, as well as decelerate the leg prior to full extension and thus limiting the knee overextension (Croisier et al., 2008; Carvalho et al., 2016). However, a recent meta-analysis questioned the hamstrings injury prediction from low hamstrings-to-quadriceps values (Green et al., 2018). Indeed, while an association in the functional H_{ecc}:Q_{conc} ratio was found in sprinters (Yeung et al., 2009), no such an association was reported in Australian soccer players (Bennell et al., 1998). With the exception of the *moderately* greater functional H_{ecc}:Q_{conc} ratio in the preferred limb in professional *vs*. amateur soccer players, no other difference was observed here. This may be due to the larger difference in quadriceps than in hamstrings strength between the two populations. It could be argued that the preferred quadriceps are used to kick the ball and to perform COD effectively (Rouissi et al., 2016), although the tasks are not forcibly correlated with each other. However, the longer training experience might have led professional players to such a specific adaptation. The present data agree with values of the conventional H_{conc}:Q_{conc} ratio reported previously in the literature, which ranges between 0.53 and 0.82 for professional soccer players (Baroni et al., 2018). Additionally, conventional H_{conc}:Q_{conc} and functional H_{ecc}:Q_{conc} ratios equal to 0.62 and 0.69, respectively, were observed in amateur team sports players (Thomas et al., 2017) and equal to 0.62 and 0.71, respectively, in first-division soccer players, as well as equal to 0.59 and 0.71, respectively, in second-division soccer players (Carvalho et al., 2016). In contrast, a recent study has reported no difference in the conventional H_{conc}:Q_{conc} ratio in professional, amateur and university soccer players (0.64, 0.64 and 0.60, respectively) (Jeon et al., 2016). Given the hamstrings-injury multifactorial origin, factors like age, previous injuries history and strength should be included (Ekstrand et al., 2016). Age has consistently been identified as a risk factor for a hamstring injury, and a recent study has observed a 7% increased risk of a hamstring injury with each additional year (van Dyk et al., 2017). However, such a parameter is classified as a non-modifiable risk factor. Therefore, more attention should be dedicated to the modifiable risk factors that have previously shown relationships with injuries, such as previous injuries or training loads (Ekstrand et al., 2016; Hägglund et al., 2013; Malone et al., 2019). Lower-limb muscle strength and strength imbalances could have a key role in the development of preventive strategies in soccer (Croisier et al., 2008). It was suggested that a functional H_{ecc}:Q_{conc} ratio lower than 0.7 might result in an increased risk of hamstrings becoming over-elongated due to the greater strength in the quadriceps (Rahnama et al., 2003). Notwithstanding, in light of previous outcomes, caution should be used when correlating the functional H_{ecc}:Q_{conc} ratio and the hamstrings strain injury risk (van Dyk et al., 2016). The present findings also suggest that the hamstrings-to-quadriceps ratio offers limited possibility to differentiate between the soccer players' level and performance.

The present outcomes showed that the overall inter-limb strength asymmetry was lower in professional compared to elite academy and amateur players. The role of inter-limb strength asymmetry in the lower limb injury prevention is not clear. In a recent meta-analysis (Green et al., 2018) and a cohort study (Jeon et al., 2016), the hamstrings inter-limb asymmetry was shown to play a reduced role in predicting hamstrings injury risk. Nevertheless, it was reported previously that the inter-limb hamstrings eccentric strength asymmetry was predictive of the hamstrings strain-type injury risk (Freckleton and Pizzari, 2013). Additionally, a reduced quadriceps inter-limb strength asymmetry is essential for a safe return to the sport after injury (Ithurburn et al., 2015; Schmitt et al., 2015). Interestingly, hamstrings and quadriceps inter-limb strength asymmetry was recently shown to be negatively correlated with COD and sprinting ability (Coratella et al., 2018). Those authors reported that increasing the inter-limb asymmetry decreased the COD and sprint performance, with no impact on jumping ability. This could be due to the key role of both hamstrings and quadriceps in stabilizing, braking and accelerating the body during COD and a sprint (Morin et al., 2015; Rouissi et al., 2016), while the stronger limb seems to compensate for the work of the weaker limb in jumping ability (Yoshioka et al., 2011). In the literature, an inter-limb hamstrings strength deficit threshold less than 10-15% is recommended (Thomas et al., 2017; Ruas et al., 2015). The findings presented in the current study agree with the differences (range 9-12%) found in quadriceps and hamstrings inter-limb strength in collegiate athletes (Jones and Bampouras, 2010). Additionally, a previous investigation found hamstrings bilateral asymmetry equal to 9% in professional soccer players, 8% in physically active men and 7% in amateur team sports players (Impellizzeri et al., 2008). These results are of interest because players with inter-limb strength imbalance are 4 to 5 times more likely to sustain a hamstring injury when compared with a balanced inter-limb strength group (Croisier et al., 2008). Thus, monitoring hamstrings and quadriceps isokinetic strength asymmetry over time might be of help to check eventual repercussion on performance or injury risk.

Some limitations accompany the present investigation. This study provides normative data about soccer-specific populations but it does not provide evidence of the capacity of the isokinetic lower-limb muscle strength assessment to predict soccer players' injuries. It is acknowledged that the cost and availability of an isokinetic dynamometer constitutes a major limitation considering the feasibility and the reproducibility of the present procedures and consequences of their interpretation. Additionally, the isokinetic dynamometer allows a single-joint movement only to be assessed, limiting the inference on the complex multi-joint activities performed in soccer.

Conclusions

The present findings provide coaches and medical staff with normative data about the specific populations involved. A periodic screening could be useful to evaluate both the total lower-limb muscle strength and the inter-limb strength asymmetry, which showed possible usefulness to monitor the injury risk and soccer players' performance in the COD and sprints. Additionally, athletes returning to sport after injury should include an inter-limb strength evaluation to check the status of the injured limb. The hamstrings-to-quadriceps ratio offers limited capacity to differentiate between the soccer players' level and performance. Lastly, since the present investigation included professional players, normative strength data might indicate to the sub-elite population the desired quadriceps and hamstrings strength level.

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Table 1. Summary of the demographics and anthropometrics for each group (players = 206; Professional = 75; Elite academy = 68; Amateur = 63) is reported. Data are presented as mean ± SD.

Group	Age (years)	Body mass (kg)	Height (m)
Professional	24 ± 5	79.5 ± 7.9	1.83 ± 0.05
Elite academy	18 ± 2	74.4 ± 8.0	1.77 ± 0.06
Amateur	20 ± 3	79.1 ± 8.3	1.79 ± 0.06

Table 2. Summary of the quadriceps and hamstrings strength (players = 206: Professional = 75, Elite academy = 68, Amateur = 63) measures is reported. Data are presented as mean ± SD and differences in mean with 90% CI. Effect size and its interpretation are provided.

	Professional (N·m)	Elite academy (N·m)	Amateur (N·m)	Difference P-E (90% CI) ES (*interpretation*)	Difference P-A (90% CI) ES (*interpretation*)	Difference E-A (90% CI) ES (*interpretation*)
Concentric quadriceps (N·m)						
Pr (60°·s^{-1})	283.2 ± 47.3	241.9 ± 38.2	219.6 ± 39.5	41.2 (27.3; 55.1)* 1.08 (*moderate*)	63.5 (49.3; 77.5)* 1.66 (*large*)	22.3 (7.8; 36.9)* 0.58 (*small*)
NPr (60°·s^{-1})	282.5 ± 49.8	243.1 ± 39.7	198.3 ± 43.1	39.3 (24.5; 54.1)* 1.04 (*moderate*)	84.1 (69.1; 99.1)* 2.21 (*very large*)	44.8 (29.4; 60.3)* 1.18 (*moderate*)
Pr (300°·s^{-1})	145.5 ± 22.1	125.4 ± 18.9	118.1 ± 17.4	20.19 (13.7; 26.7)* 0.97 (*moderate*)	27.4 (20.7; 34.1)* 1.30 (*large*)	7.2 (0.4; 14)* 0.35 (*small*)
NPr (300°·s^{-1})	143.1 ± 22.6	125.6 ± 17.7	103.7 ± 18.6	17.5 (10.9; 24.1)* 0.84 (*moderate*)	39.4 (32.7; 46.1)* 2.04 (*very large*)	21.9 (15.0; 28.7)* 1.09 (*moderate*)
Concentric hamstrings (N·m)						
Pr (60°·s^{-1})	174.4 ± 41.1	136.3 ± 27.3	129.2 ± 26.1	37.6 (26.7; 48.3)* 1.10 (*moderate*)	44.7 (33.5; 55.8)* 1.18 (*moderate*)	7.0 (-4.3; 18.4) 0.21 (*small*)
NPr (60°·s^{-1})	168.2 ± 36.4	132.6 ± 24.3	113.4 ± 25.2	35.6 (25.8; 45.4)* 1.16 (*moderate*)	54.8 (44.5; 64.8)* 1.52 (*large*)	19.2 (9.9; 24.3)* 0.64 (*moderate*)
Pr (300°·s^{-1})	97.8 ± 18.4	81.9 ± 14.4	82.2 ± 18.5	15.8 (10.2; 21.5)* 1.06 (*moderate*)	15.5 (9.7; 21.4)* 1.04 (*moderate*)	-0.3 (-6.3; 5.6) 0.01 (*trivial*)
NPr (300°·s^{-1})	96.2 ± 16.98	78.5 ± 13.2	72.9 ± 18.7	17.7 (12.2; 23.1)* 1.18 (moderate)	23.3 (17.7; 28.8)* 1.55 (*large*)	5.5 (-0.1; 11.3) 0.37 (*small*)
Eccentric hamstrings (N·m)						
Pr (60°·s^{-1})	218.1 ± 66.4	177.8 ± 35.4	150.7 ± 32.7	40.2 (17.7; 63.3)* 0.76 (*small*)	67.3 (49.9; 84.6)* 1.57 (*large*)	27.0 (3.4; 50.7)* 0.79 (*small*)
NPr (60°·s^{-1})	208.8 ± 57.9	176.5 ± 39.1	142.6 ± 28.3	32.4 (11.8; 52.4)* 0.80 (*moderate*)	66.4 (50.7; 81.5)* 1.75 (*large*)	33.8 (12.8; 54.9)* 0.90 (*moderate*)

Pr = Preferred; NPr = Non-preferred; SD = Standard deviation CI = Confidence intervals; P = Professional; E = Elite academy; A = Amateur; ES = Effect size; * = $p < 0.05$.

Table 3. Summary of the conventional H_{conc}:Q_{conc} and functional H_{ecc}:Q_{conc} ratio is shown (players = 206: Professional = 75; Elite academy = 68; Amateurs = 63). Data are presented as mean ± SD, and differences in 90% CI. Effect size and its interpretation are provided.

	Pro (A.U.)	Elite young (A.U.)	Amateur (A.U.)	Difference P-E (90% CI) ES (*interpretation*)	Difference P-A (90% CI) ES (*interpretation*)	Difference E-A (90% CI) ES (*interpretation*)
Conventional ratio						
Pr (60°·s^{-1})	0.61 ± 0.10	0.56 ± 0.10	0.58 ± 0.06	0.04 (0.01; 0.07)* 0.52 (*small*)	0.02 (-0.01; 0.05) 0.34 (*small*)	-0.02 (-0.05; 0.01) 0.25 (*small*)
NPr (60°·s^{-1})	0.59 ± 0.07	0.55 ± 0.09	0.57 ± 0.07	0.04 (0.01; 0.06)* 0.44 (*small*)	0.02 (-0.01; 0.04) 0.22 (*small*)	-0.02 (-0.05; 0.01) 0.22 (*small*)
Pr (300°·s^{-1})	0.67 ± 0.10	0.65 ± 0.10	0.69 ± 0.11	0.01 (-0.05; 0.18) 0.20 (*small*)	-0.02 (-0.05; 0.01) 0.20 (*small*)	-0.04 (-0.07; -0.01)* 0.40 (*small*)
NPr (300°·s^{-1})	0.66 ± 0.12	0.62 ± 0.09	0.70 ± 0.14	0.04 (0.01; 0.08)* 0.40 (*small*)	-0.04 (-0.01; 0.01) 0.40 (*small*)	-0.07 (-0.11; -0.04)* 0.80 (*moderate*)
Functional ratio						
Pr (60°·s^{-1})	0.72 ± 0.10	0.76 ± 0.16	0.70 ± 0.15	0.04 (-0.03; -0.1) 0.44 (*small*)	0.06 (0.01; 0.11)* 0.66 (*moderate*)	0.03 (-0.04; 0.09) 0.22 (*small*)
NPr (60°·s^{-1})	0.73 ± 0.10	0.73 ± 0.12	0.73 ± 0.13	0.01 (0.06; 0.06) 0.01 (*trivial*)	0.01 (-0.04; 0.04) 0.01 (*trivial*)	0.01 (-0.06; 0.06) 0.01 (*trivial*)

Pr = Preferred; NPr = Non-preferred; SD = Standard deviation; CI = Confidence intervals; P = Professional; E = Elite academy; A = Amateur; ES = Effect size; * = $p < 0.05$.

Table 4. Summary of the inter-limb asymmetry (players = 206: Professional = 75, Elite academy = 68, Amateurs = 63), shown as the difference between the stronger and the weaker lower-limb. Data are presented as mean ± SD, and differences in mean with 90% CI. Effect size and its interpretation are provided.

Variable	Pro (%)	Elite young (%)	Amateur (%)	Difference P-E (90% CI) ES (*interpretation*)	Difference P-A (90% CI) ES (*interpretation*)	Difference E-A (90% CI) ES (*interpretation*)
Concentric quadriceps						
(60°·s^{-1})	6.4 ± 6.2	9.9 ± 7.7	11.5 ± 8.7	-3.5 (-6.4; 0.9) 0.43 (*small*)	-5.1 (-7.4; -2.6)* 0.67 (*large*)	-1.5 (-4.6; 1.6) 0.20 (*small*)
(300°·s^{-1})	6.3 ± 4.7	7.8 ± 5.4	12.1± 8.1	-1.4 (-3.5; 0.43) 0.29 (*small*)	-5.8 (-7.6; -4.0)* 0.87 (*large*)	-4.3 (-6.7; -1.9)* 0.62 (*large*)
Concentric hamstrings						
(60°·s^{-1})	9.7 ± 7.9	9.8 ± 10.3	14.1 ± 9.2	-0.1 (-4.2; 3.4) 0.01 (*trivial*)	-4.2 (-7.9; -0.6)* 0.50 (*small*)	-4.2 (-7.2; -0.54)* 0.44 (*small*)
(300°·s^{-1})	8.8 ± 8.5	10.1 ± 5.6	16.6 ± 12.9	-1.2 (-3.2; 0.9) 0.18 (*trivial*)	-7.8 (-11.1; -4.6)* 0.71 (*large*)	-6.5 (-10.1; -3.3)* 0.65 (*large*)
Eccentric hamstrings						
(60°·s^{-1})	9.9 ± 9.8	6.9 ± 6.4	6.6 ± 6.5	2.9 (-1.4; 7.2) 0.36 (*small*)	3.2 (-0.01; 6.5) 0.39 (*small*)	0.3 (-2.0; 2.8) 0.04 (*trivial*)

SD = Standard deviation; CI = Confidence intervals; P = Professional; E = Elite academy; A = Amateur; ES = Effect size; * = $p < 0.05$.