Correlation between quadriceps and hamstrings inter-limb strength asymmetry with change of direction and sprint in U21 elite soccer-players.

Giuseppe Coratella [1 2], Marco Beato [3], Federico Schena [2]

[1] Department of Biomedical Sciences for Health, University of Milano, Italy.

[2] Department of Neurological, Biomedical and Movement Sciences, University of Verona, Italy.

[3] Faculty of Health and Science, Department of Science and Technology, University of Suffolk, Ipswich, UK.

Corresponding author: Giuseppe Coratella, Department of Biomedical Sciences for Health, University of Milano, Italy.

Mail address: Via Giuseppe Colombo 71, 20133, Milano, Italy.

Email: giuseppe.coratella@univr.it

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Abstract

The aim of this study was to investigate the relationship between in quadriceps and hamstrings inter-limb strength asymmetry and change of direction, sprinting and jumping abilities in U21 elite soccer players. Twenty-seven soccer players volunteered for this study. Isokinetic quadriceps and hamstrings peak torque was measured at high and low angular velocities, both in concentric and eccentric modalities. Performance in agility T-test, 20+20 m shuttle-test, 10 m and 30 m sprint, squat jump (SJ) and counter-movement jump (CMJ), were measured. Overall, time on agility T-test and 20+20 m shuttle-test was moderately and positively correlated with the quadriceps and hamstrings inter-limb eccentric peak torque asymmetry, both at high and low angular velocities. In addition, time on 10 m and 30 m sprints was moderately and positively correlated with the hamstrings inter-limb high-velocity concentric peak torque asymmetry. SJ and CMJ showed trivial to small correlations with hamstrings and quadriceps inter-limb peak torque asymmetry. The present results provide further information insight the role of lower-limb muscle strength balance in COD, sprinting and jumping performance.

Keywords: Isokinetic peak-torque; squat jump; counter-movement jump; agility T-test; shuttle test

1. Introduction

With the increase in physiological demands shown in soccer matches in the last decade, the importance of players' physical abilities has also increased (Bush, Barnes, Archer, Hogg, & Bradley, 2015). It was recently shown that change of direction (COD) and sprinting affect the players' external and internal loads (Coratella, Beato, & Schena, 2016). In addition, players are also required to jump to contest the ball from the opponent player (e.g., from a cross or corner). COD, sprinting and jumping require lower-limb muscles to exert maximal strength to accelerate and decelerate body mass, both in horizontal and in vertical directions (Bobbert, Gerritsen, Litjens, & Van Soest, 1996; Morin et al., 2015). Hence, the interest in the relationship between lower-limb muscle strength and such abilities has arisen over time (Brooks, Clark, & Dawes, 2013; Comfort, Stewart, Bloom, & Clarkson, 2014; de Hoyo et al., 2015; Kellis & Katis, 2007; Newman, Tarpenning, & Marino, 2004; Ostenberg, Roos, Ekdahl, & Roos, 1998; Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004).

Among the several lower-limb muscle-groups, quadriceps and hamstrings are widely involved in COD, sprinting and jumping (Silva, Nassis, & Rebelo, 2015). Therefore, the studies that have investigated the correlation between lower-limb muscle strength and performance in COD, sprinting and jumping have mainly focused on quadriceps and hamstrings (Morin et al., 2015; Newman et al., 2004; Wisløff et al., 2004). Particularly, since during COD sprinting and jumping they act in both concentric and eccentric modalities, the use of an isokinetic dynamometer allows to separately measure the concentric or eccentric maximal strength of both quadriceps and hamstrings (Brooks et al., 2013; Chaouachi et al., 2012; Coratella, Bellin, Beato, & Schena, 2015; Coratella, Bellini, & Schena, 2016; Ostenberg et al., 1998). Specifically, peak torque is mostly used as a valid and reliable parameter to measure maximal strength (Brooks et al., 2013; Coratella & Bertinato, 2015; Impellizzeri, Rampinini, Maffiuletti, & Marcora, 2007;

Ostenberg et al., 1998). Screening the quadriceps and hamstrings peak torque allows the evaluation of inter-limb or anterior-posterior asymmetry in strength, which is used to monitor muscle strength asymmetries **that** are strongly correlated with high risk for hamstrings strain injury (Fousekis, Tsepis, Poulmedis, Athanasopoulos, & Vagenas, 2011). Indeed, several studies have investigated the hamstrings-to-quadriceps peak torque ratio (Coratella, Bellin, et al., 2015; Coratella, Bellini, et al., 2016; Delextrat, Gregory, & Cohen, 2010) or the inter-limb asymmetry in hamstrings peak torque (Fousekis et al., 2011) and their relationship with injury risk in soccer players.

In professional soccer players, inter-limb asymmetry in quadriceps and hamstrings maximal strength indicated a reduced muscle function and an increased risk of injury (Hägglund, Waldén, & Ekstrand, 2013). Particularly, it was shown that an hamstrings inter-limb eccentric strength asymmetry is a predictor of hamstrings strains (Fousekis et al., 2011). In addition, strength dominance was shown to account for a better drive kick performance with the stronger limb (McLean & Tumilty, 1993). Thus, inter-limb strength symmetry seems desirable for improving performance in soccer-related abilities (Rouissi et al., 2016). Notwithstanding, little is known about the relationship between quadriceps and hamstrings inter-limb strength asymmetry and COD, sprinting and jumping abilities in soccer players. Quadriceps inter-limb strength asymmetry accounted for a decrease in COD performance in young soccer players when required to side-step with the weaker vs stronger limb (Rouissi et al., 2016). In contrast, quadriceps inter-limb isokinetic peak torque asymmetry showed no correlation with the difference in single-limb jump height performed with the stronger or weaker lower-limb in physically active men (Kobayashi et al., 2013). Similarly, a computer-simulation study found negligible differences between inter-limb symmetry vs asymmetry bilateral jump height models, speculating that the stronger lower-limb could have compensated for the muscle deficit of the weaker limb in both squat jump (SJ) (Yoshioka, Nagano, Hay, & Fukashiro, 2011) and counter-movement jump (CMJ) (Yoshioka, Nagano, Hay, & Fukashiro, 2010).

Investigating the relationship between quadriceps and hamstrings inter-limb maximal isokinetic strength asymmetry and COD, sprinting and jumping performance could help to clarify the role of muscle strength imbalance and its impact on performance. Therefore, the aim of the current study was to investigate the correlation between the quadriceps and hamstrings inter-limb isokinetic concentric and eccentric peak torque asymmetry and COD, sprinting and jumping performance in U21 elite soccer players.

2. Methods

2.1. *Experimental design*

The present investigation was designed as a cross-sectional study. The sample size a priori was calculated using a sample size calculator (G-Power 2.0, Brunsbuttel, Germany). Assuming the effect size=0.5 (moderate), the α-error=0.05 and the power=0.8, the sample size resulted in 21 participants. Due to the higher number of participants recruited, an a-posteriori power analysis resulted as 1-β= 0.89.

2.2. Procedures

The present investigation was assessed in pre-season. The participants were involved in two testing sessions per week for two weeks, for a total of four testing sessions. In the first week, the participants were accustomed to the isokinetic testing procedures (first session) and to the COD, sprinting and jumping procedures (second session). In the second week, the participants were tested according to the same procedures of the first week. The isokinetic and the COD, sprint and jump testing-order were randomized over the two testing-sessions, i.e.: the participants performed either isokinetic or COD, sprint and jump measurements within the same session **(Chaouachi et al., 2012; Fousekis, Tsepis, & Vagenas, 2010).** Particularly, four different isokinetic testing-orders including hamstrings or quadriceps and right or left lower-limb were randomized among the participants (Fousekis et al., 2010). Similarly, four different testing-orders including COD, sprinting and jumping measurements were randomized among the participants. The randomization of the COD, sprinting and jumping measurements was done to avoid that the same testing-order may have resulted in a possible fatigue within the same task. Each testing-session was separated by at least two days.

Inter-limb asymmetry in quadriceps and hamstrings isokinetic peak torque was selected as the independent parameter. For a comprehensive evaluation, the knee-extension and knee flexion peak torque of both quadriceps and hamstrings was measured at both low and high knee angular velocities, both in concentric and in eccentric modalities. Therefore, a total of eight different testing modalities were carried out. The testing order consisted of first concentric, from low to high angular velocity and then eccentric, from low to high angular velocity, as previously used (Rahnama, Reilly, Lees, & Graham-Smith, 2003).

The dependent parameters were selected from the most used in literature that evaluate the physical abilities in soccer (Silva et al., 2015). Therefore, COD was evaluated using the 20m+20m shuttle-test and agility T-test; sprinting ability was assessed by the 10 m and 30 m sprint test and jumping ability was evaluated with SJ and CMJ. Although soccer players are not typically required to perform specific SJ or CMJ actions during a match, it is acknowledged that these types of jumps are largely used to evaluate the improvement in jumping ability in soccer players (Silva et al., 2015). In addition, due to the inter-limb symmetrical nature of both SJ and CMJ, it was decided to evaluate if an inter-limb asymmetry could affect the jumping ability in both jumps (Yoshioka et al., 2010). Finally, the procedures of both SJ and CMJ are simple and clearly related to lower-limb maximal strength (Yoshioka et al., 2010).

2.3. Participants

Twenty-seven male U21 elite soccer players (age ranging from 18 to 21 years; body-mass = 73.7 ± 7.0 Kg; height = 1.81 ± 0.05 m) volunteered to participate in the present investigation. The participants joined the AC Chievo U21 team, which competes in the Italian Serie A U21 soccer championship. All the participants were healthy, without cardiac or pulmonary diseases, as certified by the club's medical staff. Players with knee, ankle or hip injury in the previous six months were excluded from the present investigation. Therefore, three out of 30 players were excluded from the present investigation. The participants and the team staff were previously informed about the potential risks of this study, and they provided written informed consent. The procedures were assessed according to the Declaration of Helsinki (1975) and further updates concerning the studies involving human subjects. Finally, the local Ethical Committee of the University of Verona approved the study.

2.4. Strength measurements

The strength of the quadriceps and hamstrings was measured by an isokinetic dynamometer (Cybex Norm, Ronconcoma, USA). The device was calibrated and the gravity correction executed according to the manufacturer's procedures. All procedures were conducted according previous studies (Coratella, Milanese, & Schena, 2015a, 2015b). After a standardized warm up, consisting of a separate 10 sub-maximal concentric and 10 sub-maximal eccentric repetitions for quadriceps or hamstrings, peak torque was investigated at low (30 degrees $\cdot$ s^{-1}) and high (300 degrees $\cdot$ s^{-1}) angular-velocities, both in concentric and in eccentric modalities, in both quadriceps and hamstrings. Since the velocity at which the **limbs** act during COD, sprinting and jumping spans from null or very low to very high, measurements of low and high angular velocities were used. However, although the **limbs** usually reach higher angular velocities during sprinting or jumping (Nagahara, Matsubayashi, Matsuo, & Zushi, 2014), 300 degrees · s^{-1} was used according to previous studies (Coratella, Bellin, et al., 2015; Rahnama et al., 2003). Considering full knee extension = 0 degrees, the range of movement in all the conditions was from 90 to 10 degrees or from 10 to 90 degrees. The participants performed three repetitions for each modality. Both lower-limbs were tested, and the peak torque (the single highest value from the three repetitions, provided by the device by a sample frequency of 100 Hz) for each testing-modality was normalized for the individual's body-mass. Finally, the inter-limb asymmetry in peak torque was separately calculated according to the formula (Impellizzeri et al., 2007):

Asymmetry= (stronger limb – weaker limb) / stronger limb x 100,

which was recommended by the authors for healthy subjects, and inserted into the data analysis. Each set was separated by two minutes of passive rest. The operators provided standardized encouragements to the participants to maximally perform each repetition.

High test-retest reliability resulted for the peak torque measured in knee extension (respectively: slow concentric: α=0.961; slow eccentric: α=0.910; fast concentric: α=0.937 and fast eccentric: α=0.906) and knee flexion (respectively: slow concentric: α=0.942; slow eccentric: α=0.901; fast concentric: α=0.899 and fast eccentric: α=0.910).

2.5. Squat jump and counter-movement jump

The peak height of SJ and CMJ was investigated using an infrared device, with a sensitivity of 0.001 m (OptoJump, Microgate, Italy). In SJ, the participants were instructed to stand, flex the knees to approximately 90° and jump. The participants must avoid as much as possible any counter-movement and they were instructed to stop for

2s at each phase. In CMJ, the participants were instructed to stand, lower themselves to a self-selected knee flexion and immediately jump. Arms were placed on the hips for SJ and CMJ tests. In both SJ and CMJ the participants were instructed to avoid any knee-flexion before the landing, and the operator visually checked it (Figure 1). The participants were allowed to perform up to three trials to improve their technique in both SJ and CMJ. Once they felt ready for the task, three attempts were performed for each jump, and the peak-height was inserted into the data analysis. Two minutes of passive rest separated each jump. The test-retest reliability was for SJ: $\alpha = 0.894$ and for CMJ: $\alpha=0.875$.

Please insert figure 1 here

2.6. Sprinting and COD

The time-trials of 10 m and 30 m sprint, 20+20 m shuttle-test and agility T-test (Alemdaroğlu, 2012; Chaouachi et al., 2012) were separately investigated using an infrared device (Polifemo, Microgate, Italy).

20+20 m shuttle test was performed using two timing gates 20 m apart, and a cone was placed 1 m beyond the second gate. The participants stood behind the first gate and had to sprint towards the second gate, touch the cone and sprint back to the first gate. The trial was not considered if participants failed to touch the cone.

Agility T-test was performed turning right or left as first, and the sum of the two trials was inserted in the data analysis. The participants had to sprint forward 9.14 m from the start line to the first cone and touch the tip with their right hand, shuffle 4.57 m left to the second cone and touch it with their left hand, then shuffle 9.14 m right to the third cone and touch it with their right hand, and shuffle 4.57 m back left to the middle cone and touch it with their left hand before finally back pedalling to the start line. The participants had one trial to further familiarize with the task. The trials were not considered if participants failed to touch a designated cone or failed to face forward at all times. Only one timing gate placed on the start-finish line was used for timing the T-test.

The participants were allowed to perform two trials to improve their personal technique in both 20+20 m shuttle and agility T-test. Once they felt ready for the task, each test was repeated three times and the best performance was calculated and inserted into the data analysis. Two minutes of passive rest separated each trial.

High test-retest reliability was found for 10 m sprint: $\alpha = 0.903$, 30 m sprint: $\alpha = 0.909$, 20+20 m shuttle: $\alpha = 0.869$ and agility T-test: $\alpha = 0.857$.

2.7. Statistical analysis

The statistical analysis was performed using SPSS 20 (IBM, USA). The normality of the data was analysed using the Kolmogorov-Smirnov test. The test-retest reliability was analysed using the intra-class coefficient (Cronbach-α). The correlations between the asymmetries in peak torque for each testing-modality and the dependent parameters were calculated using Pearson's-r test. The effect size (ES) of the correlation was interpreted as follows: <0.1, trivial; 0.1 to 0.3, small; 0.3 to 0.5, moderate; 0.5 to 0.7, large; 0.7 to 0.9, very large; >0.9, nearly perfect (Hopkins, 2007). Descriptive statistics were shown as mean with standard deviation.

3. Results

The results of the independent parameters are shown in Table 1.

In the stronger lower-limb, concentric peak torque measured at low angular velocity was 3.46 ± 0.38 and 1.95 ± 0.25 N · m · kg^{-1} and the eccentric peak torque at low angular velocity was 4.12 ± 0.63 and 2.42 ± 0.43 N · m · kg^{-1} for quadriceps and hamstrings, respectively. The concentric peak torque measured at high angular velocity was 1.77 ± 0.18 and 1.06 ± 0.22 N · m · kg^{-1} and the eccentric peak torque measured at high angular velocity was 3.59 ± 0.57 and 2.26 ± 0.44 N · m · kg^{-1} for quadriceps and hamstrings, respectively.

In the weaker lower-limb, concentric peak torque measured at low angular velocity was 3.14 ± 0.35 and 1.75 ± 0.23 N · m · kg^{-1} and the eccentric peak torque at low angular velocity was 3.71 ± 0.73 and 2.17 ± 0.49 N · m · kg^{-1} for quadriceps and hamstrings, respectively. The concentric peak torque measured at high angular velocity was 1.63 ± 0.16 and 1.05 ± 0.22 N · m · kg^{-1} and the eccentric peak torque measured at high angular velocity was 3.46 ± 0.64 and 2.19 ± 0.46 N · m · kg^{-1} for quadriceps and hamstrings, respectively.

(Insert Table 1 here)

The results of the dependent parameters are shown in Table 2.

(Insert Table 2 here)

The correlations between the quadriceps and hamstrings inter-limb peak-torque asymmetry in and COD, sprinting and jumping performance are shown in Table 3. Overall, moderate correlations were found between the inter-limb peak torque asymmetry measured at high angular velocities (both for quadriceps and for hamstrings) and the dependent parameters. Inter-limb eccentric peak torque asymmetry in both quadriceps and hamstrings moderately to largely correlated with performance in COD. Hamstrings inter-limb concentric peak torque asymmetry moderately correlated with sprinting performance.

(Insert Table 3 here)

4. Discussion

To the best of the authors' knowledge, the present study was the first that has investigated if quadriceps and hamstrings inter-limb peak torque asymmetry was correlated with COD, sprinting and jumping abilities in U21 elite soccer players. Time on agility T-test was positively correlated with the quadriceps inter-limb eccentric peak torque asymmetry at high angular velocity (ES: moderate), with the hamstrings inter-limb concentric peak torque asymmetry at high angular velocity (ES: large) and with inter-limb eccentric peak torque asymmetry at both low (ES: moderate) and high angular velocity (ES: moderate). Time on 20+20m shuttle-test was moderately and positively correlated with the quadriceps inter-limb eccentric peak torque asymmetry at both low (ES: moderate) and high angular velocity (ES: moderate) and with the hamstrings inter-limb eccentric peak torque asymmetry at high angular velocity (ES: moderate). Time on 10 m and 30 m sprint was positively correlated with the hamstrings inter-limb concentric peak torque asymmetry (ES: moderate). Lastly, both SJ and CMJ showed trivial to small negative correlations with the quadriceps and hamstrings inter-limb peak torque asymmetry, whatever the contraction modality.

The importance of COD in soccer has recently been highlighted as a fundamental aspect in soccer physiological demands (Coratella, Beato, et al., 2016). The current results highlight the role of eccentric strength in both quadriceps and hamstrings within the 90 and 180 degrees turn. Indeed, COD requires both quadriceps and hamstrings to strongly decelerate the inertia of the body accumulated during a sprint (Neptune, Wright, & van den Bogert, 1999) and to stabilize both knees and hips to contribute to the propulsion phase (Rouissi et al., 2016). The inter-limb strength asymmetry accounts for the difference in COD performance when the stronger or the weaker lower-limb is used as the prime mover in side-stepping (Rouissi et al., 2016). The same authors argued that, although the predominant role of the hip-abductors and hip–adductors in side-stepping, quadriceps and hamstrings have a synergic role. During the T-test, the athletes are required to side-step in both stronger and weaker lower-limb directions. Hence, it can be argued that an inter-limb strength asymmetry may result in a greater effectiveness in side-stepping towards the stronger compared to the weaker lower-limb direction. In addition, the nature of the T-test, in which one has to change from the original forward run to a side-step run, requires both quadriceps and hamstrings to brake the inertia, control the body mass and adjust the strides (Rand & Ohtsuki, 2000). Consequently, such a change of movement pattern exerted by the stronger or the weaker lower-limb can explain the decrease in performance with the increasing of the inter-limb asymmetry in quadriceps eccentric peak torque (Neptune et al., 1999). Similarly during a 180 degrees turning action (i.e.: 20+20m shuttle), inter-limb asymmetry in eccentric peak torque correlated with performance. It can be speculated that the participants have turned using their preferred lower-limb to perform the only turn required in that task. Intriguingly, it was shown that the choice of the limb for both stabilization and mobilization was not dependent on the limb preference, but it seems to depend on the task (Grouios, Hatzitaki, Kollias, & Koidou, 2009). However, it would seem that the preferred limb is mostly used as the prime mover (Grouios et al., 2009). It may be speculated that the stabilization provided by the weaker lower-limb could have been affected by its lower strength, thus resulting in a slower turning. This may lead to confound the results further, since the stronger and the preferred limb to this specific task may not be the same. On the other hand, considering the fast braking action occurring during the task, the quadriceps and hamstrings inter-limb eccentric peak torque asymmetry moderately correlated with the 20+20m shuttle time. Since both lower-limbs are required to contribute to the deceleration action, an inter-limb strength asymmetry may affect the COD performance.

Moderate correlations resulted between 10 m and 30 m sprints performance and the inter-limb asymmetry in hamstrings concentric peak torque at high angular velocity.

The role of hamstrings in the development of the horizontal force during sprinting was recently highlighted (Morin et al., 2015). Indeed, hamstrings are required to accelerate the centre of mass throughout fast consecutive hips-extensions and to increase the step frequency and velocity throughout fast knee-flexions (Exell, Irwin, Gittoes, & Kerwin, 2017). The same authors have found both minimum knee-flexion and maximum hip-extension angle asymmetry and they have argued that it can reflect an inter-limb hamstrings strength asymmetry (Exell et al., 2017). However, given the complexity of the sprinting technique, the athletes may have compensated their inter-limb hamstrings strength asymmetry by enhancing other movements (e.g. plantar flexion) (Mero, Komi, & Gregor, 1992). As a result, top-level sprinters accelerate by increasing their stride length, which could be different in the right or left lower-limb depending on the maximal strength of each limb (Rabita et al., 2015). Therefore, although specific inter-limb muscle strength asymmetry, these additional compensatory movements may be used to reduce the sprint performance (Exell et al., 2017).

The current results did not report any correlation between asymmetry in strength (irrespective of the muscle, angular velocity, and contraction modality) and both SJ and CMJ. In line with the current results, a computer-simulation study showed that an intra-limb strength difference of 10% did not result in any significant change compared to the symmetric model, in either SJ (Yoshioka et al., 2011), or CMJ (Yoshioka et al., 2010). To achieve their goals, the authors set in both studies a 10% difference in strength in several muscle-groups (i.e.: quadriceps, hamstrings, glutei, gastrocnemii). Compared to the symmetrical model, the authors found a greater **performance** exerted by the stronger lower-limb and a lower **performance** exerted by the weaker lower-limb within the asymmetrical model in both SJ (Yoshioka et al., 2010) and CMJ (Yoshioka, et al., 2011). Hence, the same authors argued that the stronger limb might have compensated for the strength-deficit, thus resulting in a similar jump height in asymmetrical vs symmetrical model. Although the quadriceps and hamstrings inter-limb strength asymmetry presently reported, the lack of significant correlation with the SJ and CMJ height suggests a consistent compensation by the stronger limb.

The present study comes with some acknowledged limitations. Firstly, although the strength-evaluations provided by the isokinetic dynamometer are accurate, they can only refer to single-joint movements. The complexity of the COD, sprinting and jumping abilities depends on several additional factors (e.g., running kinematics and kinetics or different muscle roles) that must be taken into account for a more comprehensive evaluation. Additionally, both quadriceps and hamstrings have been evaluated as only knee-extensors and -flexors, respectively. Useful information might have been provided by further evaluations, considering quadriceps and hamstrings as hip-flexors or hip-extensors. Importantly, the present study was not designed to investigate the correlation between the hamstrings-to-quadriceps ratio and the performance in COD, sprinting and jumping. Indeed, the angular velocities considered here are different from the angular velocity suggested and mainly used in literature to evaluate and interpret both the conventional and the functional hamstrings-to-quadriceps ratio (60 degrees · s^{-1}) (Coratella, Bellin, et al., 2015; Delextrat et al., 2010; Rahnama et al., 2003). Finally, the present results are specific for U21 elite soccer-players. Different results may occur in different populations.

5. Conclusions

In conclusion, the current study highlighted that quadriceps and hamstrings inter-limb peak torque asymmetry is correlated with COD and sprinting ability, while no correlation was found with SJ and CMJ. The present results offer new insight into the specific role of the lower-limb muscle strength in COD, sprinting and jumping actions.

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Figure captions

Figure 1: a schematic representation of both squat jump and counter-movement jump is given.