



Relationship between vastus lateralis muscle ultrasound echography, knee extensors rate of torque development, and jump height in professional soccer athletes

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Abstract

Purpose This study aimed to investigate the relationship between knee extensors maximum voluntary contraction (MVC) torque and rate of torque development (RTD) with jump performance and with echography intensity (EI) from the vastus lateralis muscle (VL).

Methods We assessed the MVC torque and RTD from knee extensors by a standard isokinetic device from 16 male professional soccer players (25.5 ± 3.9 years). Counter-movement jump (CMJ) and squat jump (SJ) height were calculated from their flight times. EI was determined from VL ultrasound images' grayscale histogram acquired in the middle of the thigh. Correlation between variables was investigated by the Pearson correlation coefficient.

Results We observed a VL EI of 26.4 ± 7.8 a.u., and the SJ and CMJ heights were 36.0 ± 3.0 and 36.2 ± 4.1 cm, respectively. There was a significant correlation between the MVC torque and absolute late-phase RTD ($r = 0.67$ and 0.76 —RTD₂₀₀ and RTD₂₅₀, respectively), between the CMJ height and absolute RTD₅₀ ($r = 0.50$), and between the normalized early-phase RTD and SJ height ($r = 0.53$ – 0.60 —RTD₅₀ and RTD₁₅₀). Additionally, normalized RTD₂₀₀ ($r = -0.51$) and RTD₂₅₀ ($r = -0.56$) were negatively correlated with EI.

Conclusions Such results suggest that athletes with the ability to produce torque explosively in the very beginning (between 50 and 150 ms) of knee extension can jump higher. Also, the muscle quality assessed by the VL IE seems to be more important to maximum strength and later periods of torque rise (> 200 ms).

Keywords Squat jump · Counter-movement jump · Echo intensity · Ultrasound · Muscle quality · Rate of force development

Introduction

Muscle strength is a critical skill to sports performance and injury risk reduction. In sports tasks such as sprinting, jumping, and kicking, the ability to generate strength explosively

seems to be more important than the maximum force itself [1]. In fact, the time available to produce muscle strength in those tasks is considerably restricted (i.e., < 300 ms) [1]. The explosive strength can be measured using the rate of torque development (RTD), which evaluates the rate of torque rise at the beginning of a muscle contraction [1]. It is widely accepted that the early RTD (≤ 150 ms) relies on neural factors such as the number of active muscle units and their firing frequency [2], while the late RTD (≥ 200 ms) seems to be influenced by architectural properties and maximum strength [3, 4].

The maximum muscle strength relies majorly on the anatomical structure [5]. Indeed, muscle anatomical and physiological cross-sectional areas are highly associated with joint torque production [6, 7], and muscle thickness increase is frequently associated with improvements in muscle strength

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[8, 9]. However, not just the muscle structure but also the muscle belly permeation by non-contractile elements, such as fat and fibrous tissue, seems to influence the strength production [9]. Muscle ultrasound images have been used to access the proportion of contractile and non-contractile tissues by the echography intensity (EI) [9–12]. The EI is an objective measure of the tissue echogenic responses defined by the mean value of the image grayscale histogram [13, 14]. Once contractile and non-contractile elements demonstrate different echogenic responses, the EI analysis can be used to evaluate the so-called muscle quality [9, 11, 12]. Different studies observed a relationship between EI with muscle maximum and explosive strengths [9, 11, 12]. Furthermore, aging [13] and muscle illness [15] have shown to negatively affect EI.

The maximum muscle strength has been extensively assessed using isokinetic dynamometers due to its data precision and reliability. However, although such an instrument allows accurate strength measurements, functional tests are more useful to assess the ability to use such strength during sports tasks. For instance, vertical jump tests are commonly applied in athletes as strength and power functional assessments for lower limbs [16]. While the squat jump (SJ) is employed to assess the strength from a static position with a low level of muscle contraction, the countermovement jump (CMJ) involves the elastic energy utilization in the stretch-shortening cycle mechanism to enhance the jump height [16]. Therefore, the use of both jump test modalities can provide complementary information, since the SJ and CMJ have different patterns of movement and correlate with distinct physical tests [17]. The knee extensor explosive strength production seems more relevant than the MVC torque to both SJ and CMJ jump performances [18–20]. In addition, the quadriceps EI has shown to be correlated with CMJ height in middle school athletes and CMJ peak power in the healthy older men [9, 11, 12]. However, the relationship between muscle quality and jump performance in professional soccer athletes remains unknown.

Both maximum and explosive strength capacities of knee extensors are of interest to soccer players, coaches, and physiotherapists, because these variables have shown to be correlated to both the performance obtained during the field tests and reduction of injury risk [21, 22]. A better understanding of the association between maximum and explosive strengths, and muscle tissue composition with functional outcomes will help to design training programs for the soccer players. Although knee extensor maximum strength and vertical jump height are usually assessed in physical screening batteries of soccer athletes, to the best of our knowledge, there is no previous study reporting RTD, vertical jump, and muscle quality together from professional soccer players. Therefore, this study aimed to investigate the relationship between knee extensor maximum and explosive

strength of knee extensors with (1) the jump performance, (2) the vastus lateralis (VL) muscle quality, and (3) the relationship between muscle quality and jump performance in soccer players. We hypothesized that the RTD should be better correlated with the jump height than MVC torque, and the EI should be significantly associated with both explosive and maximum strength.

Materials and methods

Subjects

Sixteen professional soccer players (mean $\pm$ SD; age: 25.5 ± 3.9 years; body weight: 81.2 ± 10.3 kg; height: 180.1 ± 8.9 cm) volunteered for the current investigation. All participants self-reported the right leg as dominant. None of them had a history of neuromuscular disorders and/or orthopedic surgery previously to the study for up to 2 years, and all of them gave written informed consent. The local Ethical Committee previously approved the research.

Knee extensors strength measurements

The muscle strength was assessed by means of an isokinetic dynamometer (HUMAC NORM II, CSMI, USA) in which the participants were positioned according to the manufacturer's recommendations, remaining seated with hips flexed about 85° with non-elastic straps placed over the chest and thigh. The knee joint was aligned with the dynamometer axis of rotation. The participants were previously familiarized with a warm-up procedure comprising five progressive sub-maximal repetitions at the velocity of $30^\circ/\text{s}$. After that, a concentric isokinetic protocol of five maximum exertions at $30^\circ/\text{s}$ was accomplished to obtain the highest peak torque (PT) and its corresponding PT angle (PTA). The PTA was considered as the optimal angle and its value was employed to perform the subsequent explosive isometric exertions. Such an approach aimed at equalizing the subjects upon their angle–torque relationship capacity, allowing similar muscular mechanical conditions to the subjects. After a 5-min rest, a familiarization set was provided comprising three progressive sub-maximal isometric efforts. After resting for 30 s, participants carried out three attempts of maximum isometric effort lasting 3 s (pilot testing confirmed this recovery time was sufficient) when they were instructed to perform the contraction “as fast and hard as possible” and to keep the maximum strength until the end of the trial. A minimum of 30 s interval was provided between attempts. The one which presented the highest maximum voluntary contraction (MVC) torque was used for further analyses. The same evaluator conducted all the measurements and they were applied only to the dominant limb.

Rate of torque development

The torque signals were registered by a computer after sampled at 1 kHz using an A/D converter (EMGLAB™EMG System do Brasil, Brazil), and were further processed using a custom-built routine developed in Matlab (Mathworks Inc., USA). The signal was thus filtered using a fourth-order low-pass Butterworth bidirectionally filter with a 50 Hz cut-off frequency [23]. The torque onset was defined as the point where the signal rose above three standard deviations from the baseline signal [3]. The RTD was calculated as the slope of the torque signal for the firsts 50, 100, 150, 200, and 250 ms (RTD_{50} , RTD_{100} , RTD_{150} , RTD_{200} , and RTD_{250} , respectively) after the torque onset [9, 24]. Additionally, the peak RTD was obtained from the maximal value of the discrete derivate function of the torque–time signal [25]. All RTD values were expressed in absolute and normalized values, the latter obtained by dividing the torque signal by its corresponding MVC torque value.

Squat jump and counter-movement jump

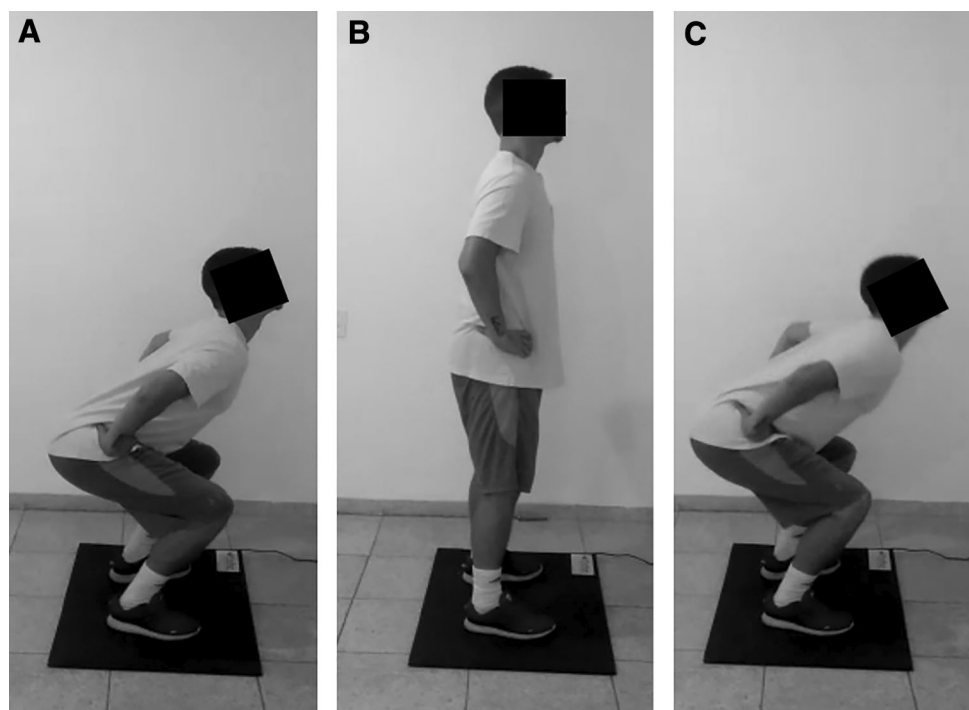
The vertical jump test comprised an SJ and a CMJ on a jump carpet (Jump System Pro, Cefise, Brazil) (Fig. 1) as described previously [9, 17]. For the SJ, subjects maintained a stable static squat position with the knee at approximately 90° of flexion and jumped as high as possible by extending the hips, knees, and ankles after the evaluator command. To perform the CMJ, athletes started from a standing posture and quickly flexed the ankles, knees, and hips as much as

desired and then jumped upwards as high as possible with arms akimbo. Three trials were recorded for each jump modality with a between jump interval of 60 s. The jump height (cm) was calculated from the flight time, and only the highest value was computed.

Muscle echography

A B-mode ultrasound device (SD900, ALOKA, Japan) was used to obtain ultrasound images from VL. The ultrasound images captured using a linear array probe of 40 mm, scanning depth of 80 mm, frequency of 7.5 MHz, and gain of 70 dB, with maximum brightness and contrast. A light-weight foam fixation, similar to that previously reported in other studies [26–28], was used to prevent the gel to spread and avoid direct contact between the probe and the volunteer's skin. An ultrasound experienced researcher applied a generous amount of water-soluble transmission gel in the apparatus and took care to avoid tissue deformation. Participants remained laid supine for 10–15 min before image acquisition to allow fluid to balance along with body compartments [29, 30]. The images from VL were acquired with the probe oriented longitudinally, about one-half of the distance between the major trochanter and the superior edge of the patella. Longitudinal images allow the visualization of the entire VL thickness without the need of an extended field of view, ensuring that all individual had the same muscle region analyzed, and the echography intensity assessment from longitudinal ultrasound images was validated [14] and used in other studies [9, 30–32]. The largest

Fig. 1 Jump height assessment. **a** Starting position for the squat jump. The athlete stands still with knees flexed at 90° (anatomical position is 0°) and then jumps as high as possible. **b** Starting position for the counter-movement jump. **c** Counter-movement before the jump. To perform the counter-movement jump, the athlete lowers the center of mass and then jumps as high as possible



visible area of VL was marked by the polygon tool and the EI was determined by the standard histogram function in Image-J (National Institute of Health, USA, version 1.51) as the mean value of the grayscale histogram [13, 14]. The EI (Fig. 2) was reported in arbitrary units (a.u.) ranging from 0 to 255.

Statistical analyses

The Shapiro–Wilk test revealed that all data could be assumed to be normally distributed ($p > 0.05$), so the Pearson r coefficient was calculated to investigate the relationship between the variables. The coefficient value was classified as very high ($0.91 \leq r \leq 1.00$), high ($0.71 \leq r \leq 0.9$), moderate ($0.51 \leq r \leq 0.70$), low ($0.31 \leq r \leq 0.50$), or negligible ($0.0 \leq r \leq 0.30$). All the statistical procedures were performed in SPSS 19 (IBM SPSS Inc., Chicago, IL, EUA). The statistical significance level adopted was $p \leq 0.05$.

Results

PT, PTA, and MVC torque values (mean $\pm$ SD) were 270.0 ± 57.8 Nm, $73.1 \pm 8.4^\circ$, and 320.3 ± 68.0 Nm, respectively, and the values of absolute and normalized RTD are displayed in Table 1. The EI of VL was 26.4 ± 7.8 a.u.. The SJ and CMJ heights were 36.0 ± 3.0 and 36.2 ± 4.1 cm, respectively. Among all correlation coefficients obtained, there were only found significant values between the MVC torque and absolute RTD_{200} and RTD_{250} (Table 2), between the CMJ height and absolute RTD_{50} (Table 3), and the normalized early RTD (RTD_{50} , RTD_{100} , and RTD_{150}) and

Table 1 Absolute and normalized rate of torque development of knee extensors

	Absolute (Nm/s)	Normalized (%MVC torque)
RTD_{50}	1167.0 ± 288.0	3.8 ± 1.2
RTD_{100}	1347.7 ± 283.9	4.3 ± 1.1
RTD_{150}	1355.8 ± 289.6	4.4 ± 1.5
RTD_{200}	1209.5 ± 261.4	3.8 ± 0.6
RTD_{250}	1066.2 ± 247.4	3.4 ± 0.5
Peak RTD	1624.0 ± 318.4	5.2 ± 1.3

RTD rate of torque development, *peak RTD* peak rate of torque development. The subscripts numbers represent the time interval employed for RTD calculations from the torque signal onset

SJ height (Table 3). Additionally, normalized RTD_{200} and RTD_{250} were negatively correlated with EI (Table 3), and no significant correlation between EI and the other variables was found (Table 4). All significant correlation values were classified as moderate.

Discussion

The present study aimed to investigate the relationship between knee extensors maximum and explosive torque capacity with both SJ and CMJ performance and the VL IE. We also investigated the relationship between muscle quality and jump performance in professional soccer players. The main findings of this study were that both normalized early RTD and peak RTD were positively correlated with the SJ

Fig. 2 Ultrasound image from vastus lateralis. **a** Selection of the vastus lateralis area (delimited by the lines and dots) by the polygon tool from ImageJ software. **b** Histogram of the gray scale from the vastus lateralis area used to measure the echography intensity. **c** Example of probe position during image acquisition

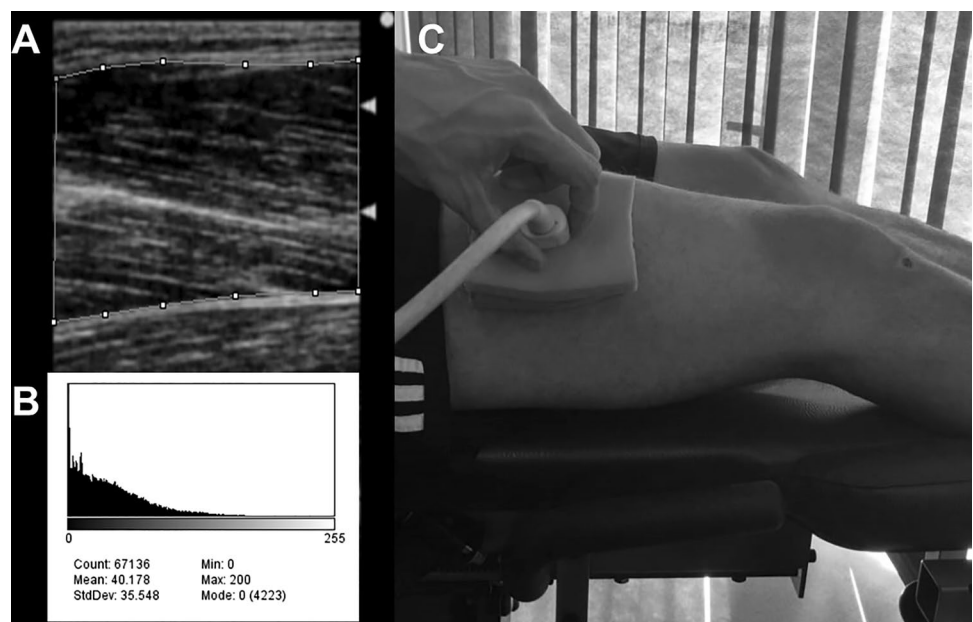


Table 2 Pearson correlation coefficient values calculated between maximum voluntary isometric torque and extensors rate of torque development in absolute values (Nm/s), and vertical jumps maximum height (cm)

	RTD ₅₀	RTD ₁₀₀	RTD ₁₅₀	RTD ₂₀₀	RTD ₂₅₀	Peak RTD	SJ	CMJ
MVC torque	0.27 (<i>p</i> =0.31)	0.44 (<i>p</i> =0.09)	0.27 (<i>p</i> =0.31)	0.67* (<i>p</i> <0.05)	0.76** (<i>p</i> <0.001)	0.46 (<i>p</i> =0.69)	− 0.20 (<i>p</i> =0.46)	− 0.00 (<i>p</i> =0.98)

RTD rate of torque development, *peak RTD* peak rate of torque development, *SJ* squat jump, *CMJ* countermovement jump, and *MVC* maximal voluntary contraction. The subscripts numbers represent the time interval for RTD calculations from the torque signal onset

p*<0.05 and *p*<0.001

Table 3 Pearson correlation coefficient values calculated between absolute (Nm/s) and normalized (%MVC torque) rate of torque development, vertical jumps maximum height (cm), and echography index (a.u.)

Absolute RTD						
	RTD ₅₀	RTD ₁₀₀	RTD ₁₅₀	RTD ₂₀₀	RTD ₂₅₀	Peak RTD
SJ	0.49 (<i>p</i> =0.13)	0.26 (<i>p</i> =0.34)	0.35 (<i>p</i> =0.19)	− 0.12 (<i>p</i> =0.66)	− 0.24 (<i>p</i> =0.36)	0.28 (<i>p</i> =0.30)
CMJ	0.50* (<i>p</i> =0.04)	0.40 (<i>p</i> =0.13)	0.43 (<i>p</i> =0.09)	0.06 (<i>p</i> =0.81)	− 0.61 (<i>p</i> =0.82)	0.44 (<i>p</i> =0.09)
EI	0.16 (<i>p</i> =0.56)	0.14 (<i>p</i> =0.60)	− 0.10 (<i>p</i> =0.70)	0.04 (<i>p</i> =0.87)	0.06 (<i>p</i> =0.84)	0.14 (<i>p</i> =0.61)
Normalized RTD						
	RTD ₅₀	RTD ₁₀₀	RTD ₁₅₀	RTD ₂₀₀	RTD ₂₅₀	Peak RTD
SJ	0.60* (<i>p</i> =0.02)	0.53* (<i>p</i> =0.04)	0.53* (<i>p</i> =0.04)	0.19 (<i>p</i> =0.47)	− 0.03 (<i>p</i> =0.92)	0.54* (<i>p</i> =0.03)
CMJ	0.47 (<i>p</i> =0.07)	0.40 (<i>p</i> =0.12)	0.38 (<i>p</i> =0.14)	0.11 (<i>p</i> =0.70)	− 0.09 (<i>p</i> =0.74)	0.42 (<i>p</i> =0.10)
EI	− 0.25 (<i>p</i> =0.36)	− 0.33 (<i>p</i> =0.21)	− 0.44 (<i>p</i> =0.09)	− 0.51* (<i>p</i> =0.04)	− 0.56* (<i>p</i> =0.02)	− 0.35 (<i>p</i> =0.18)

RTD rate of torque development, *peak RTD* peak rate of torque development, *SJ* squat jump, *CMJ* countermovement jump, *MVC* maximal voluntary contraction, and *EI* echography intensity. The subscripts numbers represent the time interval for RTD calculations from the torque signal onset

p*<0.05 and *p*<0.001

Table 4 Pearson correlation coefficient values calculated between echography index (au) and maximum voluntary isometric torque (Nm) and vertical jumps maximum height (cm)

	MVC torque	SJ	CMJ
EI	0.50 (<i>p</i> =0.07)	− 0.14 (<i>p</i> =0.61)	0.24 (<i>p</i> =0.38)

EI echography intensity, *MVC* maximal voluntary contraction, *SJ* squat jump, and *CMJ* countermovement jump

height. However, the EI was negatively correlated with the late RTD.

The early phase explosive capacity was better correlated with the SJ and then with the CMJ performance. This corroborates with the previous studies that found no correlations between knee extensors RTD and CMJ height in soccer athletes and that RTD was a poor predictor of CMJ height in physically active adult males [33, 34]. Additionally, Chang et al. [35] observed positive correlations between

knee extensors and the SJ in recreationally active individuals. Otherwise, Thompson et al. [18] reported significant correlation values between arms swinging CMJ and knee extensors RTD when assessed at 0–30 to 0–200 ms and peak RTD, in collegiate American football players. Interestingly, we just observed significant correlations between explosive strength and SJ only after RTD data scaling. Although we observed a significant correlation between CMJ height and RTD₅₀, after the normalization by MVC torque, the correlation coefficient did not reach statistical significance (*p*=0.07). Indeed, normalization of the RTD by MVC torque was already pointed out as a necessary approach to access further information of explosive muscle capacity besides maximum strength [1]. A better association with the SJ performance could be explained by the technique used to jump. In an SJ, the subject tries to reach the highest jump starting from the rest, while during a CMJ, the performance depends on the use of stretch-shortening cycle and the elastic energy buffered in the tendon-muscle unit [17]. Since the RTD was

measured from an isometric contraction starting from the muscle relaxed, it seems reasonable to consider there is a motor pattern similarity between both tasks.

Another important aspect to be addressed regarding the association between RTD of knee extensors and jump height is that such association seems to depend on jump technique. We observed that the SJ and CMJ heights values were very similar to the previous reports from professional male soccer athletes [33, 34]. It is expected that the jump height obtained in a CMJ be greater than during the SJ because of the use of the stored elastic energy. However, our results were very similar in both jumps (0.5% mean difference). Since this similitude reflects a low capacity to use the elastic energy storage mechanism to enhance jump height, we account for the fact that the athletes in this present investigation were tested during the pre-season, returning from vacations. An improvement in CMJ performance should likely be expected along the season.

Regarding the RTD, this study adds new data to the few reports of knee extensors RTD in male professional soccer players [33, 36, 37]. Wilhelm et al. [33] measured the knee extensors RTD with the knee at 70° (0° = full extension) and reported values from 15 to 20% lower than the results of the present study. Grazioli et al. [36] reported a greater difference from a similar group of soccer athletes, while the RTD₅₀ and RTD₂₀₀ measured with the knee at 30° was almost half of the value found in the present study. Another study found similar RTD₅₀ and RTD₁₀₀ values to the present study, in a group of 26 athletes (including 10 soccer players) with the knee at 60° of flexion [37]. The discrepant results can be partly explained by the adoption of PTA to run the isometric exertions, whereas others employed the same absolute knee angles for all participants. The approach applied by the other studies demands the participants to make their maximum effort at different positions of their torque–angle relationship. Given that high correlations between MVC torque and RTD have been described elsewhere [3] and also observed here, it is expected that the RTD values are influenced by the joint–angle relationship [38–40]; therefore, the joint angle should be taken into account when comparing results from different studies.

It has been suggested that late RTD relies more on muscle structural factors, like muscle cross-sectional area and maximum strength [1]. Since the strength production is affected by the content of non-contractile elements in the muscle belly [9], it is reasonable to assume that muscle quality also plays a role in the RTD. To the best of our knowledge, this was the first study that revealed a significant negative correlation between EI VL and later RTD in adult soccer athletes, although such relationships have already been reported for older adults [11] and trained teenagers males [9, 11, 12]. As EI is correlated to the maximum strength [9, 11, 12], which in turn is highly correlated with late RTD, one might expect

that a worse muscle quality impairs later periods of torque rise. Therefore, the high correlation among early RTD with neural factors can partly explain the lack of correlation with EI in this period [2]. Although Stock et al. [9] observed a correlation between VL and rectus femoris EI with CMJ height in middle school athletes, we did not observe significant correlations between VL EI and jump performance. This is in line with the lack of correlation between jump performance and MVC torque in the present investigation.

The EI of soccer players was only previously reported for female young adult athletes who found the EI of VL of starters and non-starters along the season [10]. They respectively revealed 64.6 and 66.5 a.u. at the beginning, and 59.9 and 62.6 a.u. at the end of the season, whereas only time showed a significant effect on EI. The values reported by Jajtner et al. [10] were higher than our results which might be in part due to the sex, a factor which was already shown to influence EI in highly trained athletes [30]. Despite the EI from VL found here to be similar to the data reported from healthy adults [13], it was lower than those reported from track and field athletes [30], football [41], and cross-country runners [29]. However, as there is no standardization available for image acquisition settings, such as gain, contrast, and brightness; and EI values are highly dependent on them, caution should be taken when comparing EI from different sources, as warned previously [42].

Other studies have investigated the relationship between multi-joint tasks with jump ability, using isometric and dynamic exertions. In the present study, we focused on measurements from a standard isokinetic device, because it is commonly available in soccer training centers. Considering the use of RTD as a criterion for returning to sports activity after knee surgery [43], it is not difficult to include the RTD in assessment routines due to its greater safety in relation to dynamic explosive tests such as vertical or broad jumps. One of the limitations of the present study was the small sample size (16 subjects), since marginal significant values (8 out of 30) could become significant in a larger group of the same population. Moreover, we just evaluated the EI from the VL. Although the VL alone represents ~33% of the total quadriceps volume [7], a recent study reported that the vastus intermedius muscle thickness was the only quadriceps muscle significantly associated with the knee extensors late RTD [4]. Thus, future studies should include more muscles to improve the observations in the same athlete population.

In summary, the most relevant findings of the present study were the positive moderate correlation between the early-phase normalized RTDs (RTD₅₀, RTD₁₀₀, and RTD₁₅₀) and peak RTD with SJ height, and the negative moderate correlation between the late-phase normalized RTD (RTD₂₀₀ and RTD₂₅₀) and the EI. Such results suggest that athletes with the ability to produce torque quickly at the very

beginning of knee extension can jump higher. Additionally, the muscle quality seems to be important to produce strength at later periods of torque rise and MVC torque. Since significant correlations were observed with normalized but not with absolute RTD values and the other variables, we suggest including both of them in athletes' physical screening and future studies.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest regarding the data presented in this paper.

Ethical approval The whole protocol was approved by the ethical committee of the Instituto Nacional de Traumatologia e Ortopedia for experiments with humans, in accordance with the Brazilian national committee and with the 1964 Helsinki declaration and the latter amendments or comparable ethical standards.

Informed consent All volunteers who participated in the study were instructed about the procedures and gave a signed written consent.

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