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RESEARCH NOTE

Quadriceps and Gastrocnemii Anatomical Cross-Sectional Area and Vastus Lateralis Fascicle Length Predict Peak-Power and Time-To-Peak-Power

Giuseppe Coratella, Stefano Longo, Susanna Rampichini, Eloisa Limonta, Sheida Shokohyar, Angela Valentina Bisconti, Emiliano Cè, and Fabio Esposito

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RESEARCH NOTE

Quadriceps and Gastrocnemii Anatomical Cross-Sectional Area and Vastus Lateralis Fascicle Length Predict Peak-Power and Time-To-Peak-Power

Giuseppe Coratella [a], Stefano Longo [a], Susanna Rampichini [a], Eloisa Limonta [a,b], Sheida Shokohyar[a], Angela Valentina Bisconti[a], Emiliano Cè [a,b], and Fabio Esposito [a,b]

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ABSTRACT

Purpose: The current study investigated the role of quadriceps and gastrocnemii size and *vastus lateralis* and *gastrocnemius medialis* muscle architecture in peak-power and time-to-peak-power exerted in an all-out Wingate test. Twenty-one amateur cyclists were recruited. **Methods**: Quadriceps and gastrocnemii anatomical cross-sectional area (ACSA), and *vastus lateralis* and *gastrocnemius medialis* pennation angle and fascicle length were measured using ultrasound. Relative peak-power (normalized per body mass) and time-to-peak-power were measured during a 30s all-out test. **Results**: Relative peak-power was correlated with quadriceps ACSA (r = 0.896, $p < .001$), gastrocnemii ACSA (r = 0.811, $p < .001$), *vastus lateralis* ($r = 0.787$, $p < .001$) and *gastrocnemius medialis* pennation angle ($r = 0.638$, $p < .003$). Multiple regression revealed that quadriceps and gastrocnemii ACSA accounted for 85% ($R^2 = 0.85$) of peak-power variance. ~~Muscle size and architecture seem specifically involved in peak-power and time-to-peak-power exertion.~~ Time-to-peak-power showed *very large* ($r = -0.866$, $p < .001$) and *large* correlation ($r = -0.637$, $p = .001$) with VL and GM fascicle length, respectively. Multiple regression analysis revealed that VL fascicle length explained 75% ($R^2 = 0.75$) of the time-to-peak-power variance. **Conclusions**: Quadriceps and gastrocnemii ACSA largely explained relative peak-power in an all-out Wingate test. *Vastus lateralis* fascicle length was the main predictor of the time-to-peak-power. Muscle architecture characteristics seem to be involved in the power generating capacity.

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Muscle size and its geometrical arrangement are strongly related to muscle function and can be investigated using ultrasounds (Blazevich, Gill, & Zhou, 2006; Franchi et al., 2018). The anatomical cross-sectional area (ACSA), i.e., the muscle area detected on the transversal plane, provides information about the muscle size and is used to estimate muscle hypertrophy or atrophy (Franchi et al., 2018), factors influencing the muscle force production (Erskine, Jones, Williams, Stewart, & Degens, 2010). Additionally, the muscle spatial geometry arrangement (i.e., muscle architecture) could provide further information about the relationship between muscle and performance (Blazevich et al., 2006). Particularly, in pinnate muscles, pennation angle is the angle between the muscle fascicles and the tendon aponeurosis and is representative of the amount of in-parallel sarcomeres (Blazevich et al., 2006). Fascicle length is measured from the superficial to the deep aponeurosis and depends on the amount of in-series sarcomeres (Blazevich et al., 2006). Both pennation angle and fascicle length are associated with specific muscle function. Larger pennation angle decreases the force transmission to the tendon aponeurosis, while it increases the amount of contractile material through an increment of the in-parallel sarcomeres (Blazevich et al., 2006). As a whole, this results in increased muscle strength. Longer fascicle allows faster contraction speed, larger range of movement and shifts rightward the torque/angle relationship (Blazevich et al., 2006). Such an association was shown previously, since longer fascicles were correlated with better sprint performance in running (Kumagai et al., 2000) and swimming (Nasirzade et al., 2014).

Power is the product of force and velocity and, because force decreases with increasing velocity, maximum power is an optimum along with the force-velocity profile. The Wingate test is used to measure peak-power throughout a 30-s all-out biking exercise (Akima, Kinugasa, & Kuno, 2005; Martin, Davidson, & Pardyjak, 2007; van der Zwaard et al., 2017, 2018). The maximal power production depends on several factors, such as pedaling rate, crank length, muscle shortening velocity, muscle volume, and type-II fiber's distribution, as previously reviewed (Martin et al., 2007). The lower-limb muscles play a non-uniform role in the peak-power production, with a predominance of the quadriceps' muscles (Akima et al., 2005), although peak-

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power was also predicted by leg muscles mass (Perez-Gomez et al., 2008). Notwithstanding, the role of muscle architecture in the peak-power production is less clear. Recently, it was shown that *vastus lateralis* (VL) muscle volume might affect the peak-power production in Olympic rowers (van der Zwaard et al., 2018) or high-level cyclists (van der Zwaard et al., 2017), with likely contribution of fascicle length. This might reinforce the rationale that the maximal power output could be accounted for the muscle structural characteristics that influence force and velocity. However, both refer to elite athlete, so it is not clear if such a relationship might be extendable to other populations.

The time-to-peak-power is the time needed to develop the maximal power. The ability to generate the maximal power rapidly is crucial when sprinting in cycling competitions (Rylands, Roberts, & Hurst, 2017). Thus, understanding the muscle structural factors that might contribute to its improvement could be beneficial for both athletes and trainers. More in detail, it would be relevant to understand whether or not larger muscle size or pennation angle and/or longer fascicles could somehow be associated with the time-to-peak-power. Given the role of fascicle length in increasing the muscle contraction speed (Blazevich et al., 2006), its relationship with high- but not slow-velocity peak torque (Coratella, Rinaldo, & Schena, 2018), and with the early-force production (Zaras et al., 2016), one might hypothesize that fascicle length could play a role in the time-to-peak-power. However, to date, this has not been yet shown. Given the specific contribution of both quadriceps (Akima et al., 2005) and calf muscles (Perez-Gomez et al., 2008) in cycling, the present study aimed to investigate whether or not quadriceps and gastrocnemii ACSA, and VL and *gastrocnemius medialis* (GM) muscle architecture could account for the peak-power production and the time-to-peak-power in an all-out cycling test. It was hypothesized that ACSA might influence the maximal power production. Additionally, given the specific role in increasing muscle force and speed by pennation angle and fascicle length, respectively (Blazevich et al., 2006), it was further hypothesized that the former might be related positively to peak-power, while the latter negatively to time-to-peak-power.

Methods

Experimental approach to the research question

The current investigation was designed as a cross-sectional study. The sample size was calculated using a statistical software (GPower 3.1, Stuttgart, Germany) based on previously reported results (Kumagai et al., 2000; Nasirzade et al., 2014; van der Zwaard et al., 2018). Given the study design, a two-tail possible correlation, a warranted power 1-β = 0.8, a = 0.05 and a *large* effect size (ρ = 0.6), a total of 17 participants was sufficient to ensure adequate statistical power. To prevent the effects of any possible dropout on the statistical power, 21 participants were recruited.

The participants were involved in two different sessions. In the first session, the ultrasound data were collected and the participants were familiarized with the Wingate protocol. In the second session, the Wingate test was performed. To check that the test was maximally performed, blood lactate concentration was measured at the end of the test. The participants were instructed to ingest a tailored meal 2 hours before the Wingate test. To avoid any circadian variability, the second session took place from 11 am to 1 pm. The sessions were interspersed by two-to-four days, during which the participants were explained to refrain from any further form of strenuous physical activity.

Participants

Twenty-one amateur male cyclists (age 24 ± 4 yrs, body mass 74.3 ± 5.5 kg, height 1.77 ± 0.06 m) volunteered for the present investigation. For reasons unrelated to the procedures, two participants did not complete the protocol. The participants were included if they self-reported a total training volume ranging from 200 to 250 km per week, corresponding to 10 to 12 hours weekly. Any cardiorespiratory, lower-limb muscle and joint disease recorded in the previous year, smoking and a systematic use of any drug were listed as exclusion criteria. The participants received explanations of all procedures and signed an informed consent and were free to withdraw at any time. The Ethical Committee of the local University approved the procedures, which were in line with the Declaration of Helsinki (1975 and further updates) concerning studies involving human subjects.

Muscle architecture

Muscle architecture was assessed *in vivo* at rest in VL and GM by B-mode ultrasound (LOGIQS7, GE©, Fairfield, Connecticut, USA) with a 5-cm linear-array probe (mod. 9L, 3.1–10.0 MHz) in extended-field-of-view (EFOV) mode (LOGIQview). This technique was previously validated for the ACSA and fascicle length acquisition (Noorkoiv, Nosaka, & Blazevich, 2010; Noorkoiv, Stavnsbo, Aagaard, & Blazevich, 2010). The participants lay supine on the examination bed with the hip joint extended and the knee joint almost fully extended (170° extension, with 180° full extension) for VL assessment,

whereas GM was assessed with the participants in prone position and the ankle fixed at 90° (perpendicularity of the tibia relative to the sole). The probe was held perpendicular to the skin surface by an expert operator, which ensured minimal pressure was applied to the muscle belly examined. No visually identifiable muscle compression was detected on the scan, as checked real time during the scan acquisition (Noorkoiv et al., 2010). A transmission gel was applied to improve acoustic coupling. Images were obtained along the mid-sagittal plane of each muscle, which included both superficial and deep aponeuroses, and the probe was oriented so that a number of clearly visible fascicles were captured. Careful manipulation was provided to align the transducer to the muscle fascicle plane and optimize the echogenicity of muscle fascicles (Franchi et al., 2018). The 50% of the muscle length and width were used as scanning sites for VL (Erskine et al., 2010) and GM (Stenroth, Peltonen, Cronin, Sipilä, & Finni, 2012). All muscles were inspected before EFOV acquisition and a line was marked on the skin following the fascicular path, i.e., the line of orientation of the muscle fascicles so that during EFOV the correct fascicle plane, i.e., the probe angle giving the largest continuous fascicle visualization could be followed (Noorkoiv et al., 2010). To obtain the muscle image, a continuous single view was taken by moving the probe along the drawn line for about 15 cm in 3–4 s. At 50% femur length and at 50% of the GM length, a line was drawn across the thigh and the leg, respectively. After three trials allowing the identification of acceptable images (i.e., visible muscle borders), a continuous single view was taken by moving the probe transversely on the marked lines on the thigh and the leg in approximately 7 s for capturing quadriceps and gastrocnemii ACSAs, respectively. For all EFOV images (para-sagittal and transverse planes), the operator ensured that the probe was kept perpendicular to the skin. Each site was scanned twice. The images were analyzed offline using an open source computer program (ImageJ 1.44b, National Institutes of Health, USA). Muscle fascicle length was measured by drawing a line along three clearly visible muscle fascicles between the deep and superficial aponeurosis. Any fascicle curvature was taken into account when present by drawing a curved line following the fascicle path. The VL and GM average fascicle length were normalized for the thigh and shank length, respectively (Abe, Kumagai, & Brechue, 2000) and used for the analysis. On the same highlighted fascicles, their insertion angle into the deep aponeurosis was measured as pennation angle. The three measured angles were averaged and used for the analysis. For the ACSAs, a polygon selection tool was used to define the contour of the muscles manually. The two measured images were averaged and considered for the analysis.

Wingate test

The procedures were in line with a previous study (van der Zwaard et al., 2018). The participants performed a 30-s Wingate test on a bicycle ergometer (Monark 894 E Peak Bike, Monark Exercise AB, Vansbro, Sweden). The test was preceded by a 10-min warm-up (brake weight 1–1.5 kg) with five 10-s maximal accelerations interspersed by 2-min. Three minutes after the end of the warm-up, the participants performed the Wingate test. The workload was set at 7.5% of the body mass and was automatically applied to the flywheel when the cadence exceeded 90 revolutions per minute. The participants were carefully instructed to remain seated and received strong verbal encouragement throughout the test. Peak-power output, relative peak-power output normalized per body mass ($W \cdot kg^{-1}$) and time-to-peak-power were obtained and inserted into the data analysis.

Blood lactate concentration

The lactate blood concentration was assessed by a spectrophotometric system (Lactate Pro LT-1710, Arkray, Kyoto, Japan). The procedures were in line with a previous investigation (Coratella, Beato, & Schena, 2016). The lactate samples were collected at baseline and two, four, six, eight and 10 min after the end of the Wingate test. The lactate analyzer was calibrated before each protocol to guarantee consistent data. The samples were collected using capillary blood from an ear lobe, at the end of each stage, while the participants were standing before the following stage. For each single blood sampling, the lobe was deterged with alcohol before and after the prick to avoid any contamination with external liquids (i.e., sweat). To ensure consistency, the same prick was used to collect the blood samples for each session within each participant. Thereafter, the blood samples were immediately placed onto a sample strip and inserted into the hand-held lactate analyzer for an immediate analysis. The same experienced operator collected the samples.

Statistical analysis

Statistical analysis was performed using a statistical software (SPSS 22.0, IBM, Armonk NY, USA). The normality of data was checked using test Shapiro-Wilk's test. The test–retest reliability for the ultrasound parameters was calculated using an intra-class coefficient (Cronbach's α) and interpreted as follows: $\alpha \geq 0.9$ = *excellent*; $0.9 > \alpha \geq 0.8$ = *good*; $0.8 > \alpha \geq 0.7$ = *acceptable*; $0.7 > \alpha \geq 0.6$ = *questionable*; $0.6 > \alpha \geq 0.5$ = *poor* (Tavakol & Dennick, 2011).

Standard error of the measurement (SEM) was also calculated and reported. Descriptive statistics are reported as mean ± SD. The correlation between quadriceps and gastrocnemii ACSA, and VL and GM pennation angle with relative peak-power and time-to-peak-power was calculated using Pearson's product and interpreted as follows: 0.00 to 0.09 = *trivial*; 0.10 to 0.29 = *small*; 0.30 to 0.49 = *moderate*; 0.50 to 0.69 = *large*; 0.70 to 0.89 = *very large*; 0.90 to 0.99 = *nearly perfect*; 1.00 = *perfect* (Hopkins, Marshall, Batterham, & Hanin, 2009). When a correlation was significant, the independent parameter was inserted into a step-wise multiple linear regression. Predictors were included in the model if a significant R^2 change ($p < .05$) was reported. Results are reported if assumptions for multiple regression analysis were met, demonstrating independent errors (indicated by a Durbin–Watson score between 1 and 3), no multicollinearity between predictors (reflected by a variance inflation factor <10 and tolerance >0.2), and homoscedasticity of residuals (normal distribution of standardized residuals). The figures show the regressions with the 95% confidence interval bands. The linear regression equations and R^2 are also shown.

Results

For ACSA, ICC ranges from α = 0.920 to α = 0.938 and SEM from 2.1% to 3.7%. For pennation angle, ICC ranges from α = 0.935 to α = 0.951 and SEM from 1.5% to 1.8%. For fascicle length, ICC ranges from α = 0.898 to α = 0.933 and SEM from 2.2% to 4.3%.

The descriptive statistics of the muscle architecture parameters are shown in Table 1. During the Wingate test, the average peak-power was 887 ± 118 W, the relative peak-power was 12.2 ± 1.4 W · kg^{-1} and the time-to-peak-power was 1.534 ± 0.700 s. The average blood lactate concentration at baseline was 1.9 ± 0.6 ml · L^{-1}, raised to 8.1 ± 2.0 ml · L^{-1} after 2 min the end of the Wingate test and remained higher than baseline after 4 min (9.9 ± 2.2 ml · L^{-1}), 6 min (10.7 ± 1.5 ml · L^{-1}), 8 min (11.8 ± 2.0 ml · L^{-1}) and 10 min (10.6 ± 1.8 ml · L^{-1}).

Peak-power showed *very large* correlation with quadriceps ACSA (r = 0.896, $p < .001$), gastrocnemii ACSA (r = 0.811, $p < .001$), VL pennation angle ($r = 0.787$, $p < .001$) and *large* correlation with GM pennation angle ($r = 0.638$, $p < .003$) (Figure 1). *Small* non-signifcant correlations were found between VL ($r = 0.267$, $p = .304$) and GM ($r = 0.195$, $p = .403$) fascicle length with peak-power. Multiple regression analysis revealed that quadriceps and gastrocnemii ACSA explained the 85% ($R^2 = 0.85$) of the peak-power variance.

Time-to-peak-power showed *very large* ($r = -0.868$, $p < .001$) and *large* correlation ($r = -0.680$, $p < .001$) with VL and GM fascicle length, respectively (Figure 2). *Small* non-significant correlations were found between ACSA and time-to-peak-power in quadriceps ($r = -0.244$, $p = .139$) and gastrocnemii ($r = -0.160$, $p = .289$). S*mall* correlations were found between pennation angle and time-to-peak-power for VL ($r = -0.231$, $p = .348$) and GM ($r = -0.128$, $p = .448$). Multiple regression analysis revealed that VL fascicle length explained 75% ($R^2 = 0.75$) of the time-to-peak-power variance.

Discussion

The present cross-sectional study was designed to investigate whether quadriceps and gastrocnemii size and architecture were related to peak-power and time-to-peak-power in an all-out cycling exercise. The current results highlighted that quadriceps and gastrocnemii ACSA predicted 85% of the relative peak-power variance, although VL and GM pennation angle showed *very large* and *large* positive pairwise correlations with relative peak-power. Normalized VL and GM fascicle length were not significantly correlated with relative peak-power. In contrast, normalized VL fascicle length explained 75% of the time-to-peak-power variance, although normalized GM fascicle length showed a large correlation with time-to-peak-power. Lastly, quadriceps and gastrocnemii ACSA and VL and GM pennation angle were not significantly correlated with time-to-peak-power.

The present findings highlight that larger muscles might contribute to the peak-power production. In the literature, recent studies have reported that VL muscle volume was a sprint-performance determinant in elite cyclists (van der Zwaard et al., 2017). Similarly, relative peak-power obtained in an all-out Wingate test was largely explained by VL muscle volume in Olympic rowers (van der Zwaard et al., 2018). Additionally, VL ACSA showed *moderate* correlation with absolute peak-power recorded during a squat jump (Suchomel & Stone, 2017). This was also reported in another study that showed *moderate* correlation between quadriceps volume and relative peak-power exerted in a unilateral jump (Murtagh et al., 2018). Both quadriceps and

Table 1. Descriptive statistics of the muscle architecture parameters measured. The data are reported as mean(SD).

	ACSA(mm^2)		FA(deg)	FL(mm)	FL_{norm}(mm·m^{-1})
Quadriceps	7833(1638)	*Vastus lateralis*	20(2)	74(9)	0.17(0.03)
Gastrocnemii	2109(460)	*Gastrocnemius medialis*	22(4)	48(10)	0.12(0.03)

ACSA: anatomical cross-sectional area; PA: pennation angle; FL: fascicle length; FL_{norm}: fascicle length normalized per lower-limb length.

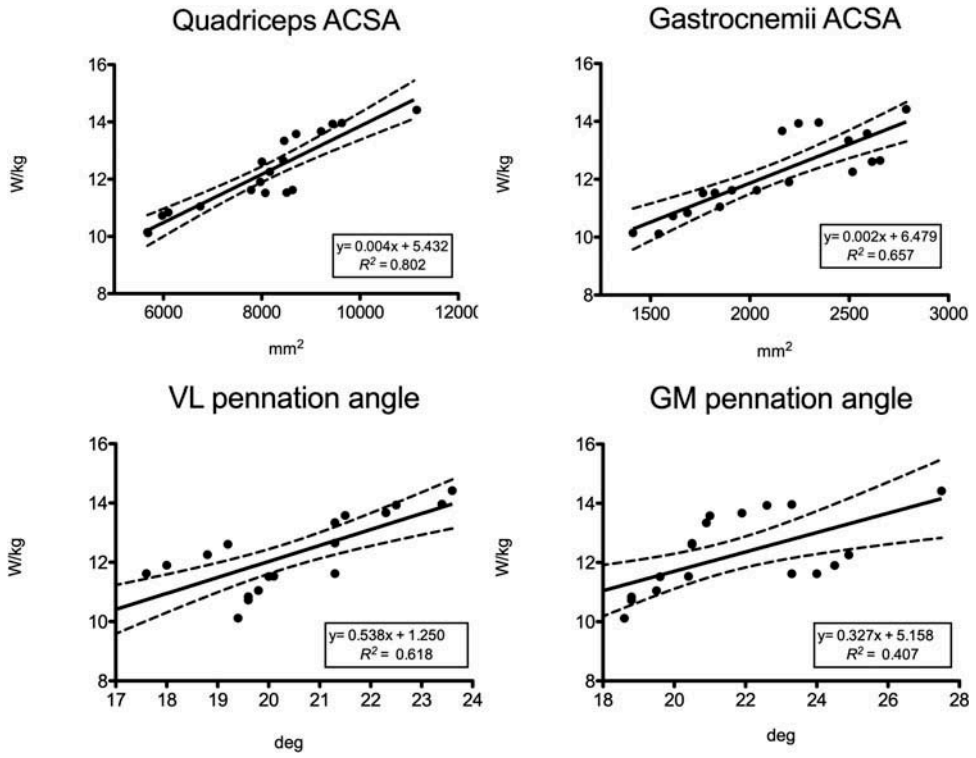

Figure 1. The linear regressions between quadriceps and gastrocnemius ACSA (anatomical cross-sectional area) and VL (*vastus lateralis*) and GM (*gastrocnemius medialis*) pennation angle with relative peak-power are shown with 95% confidence interval bands. The regression equation and R^2 have been calculated and reported for each dataset.

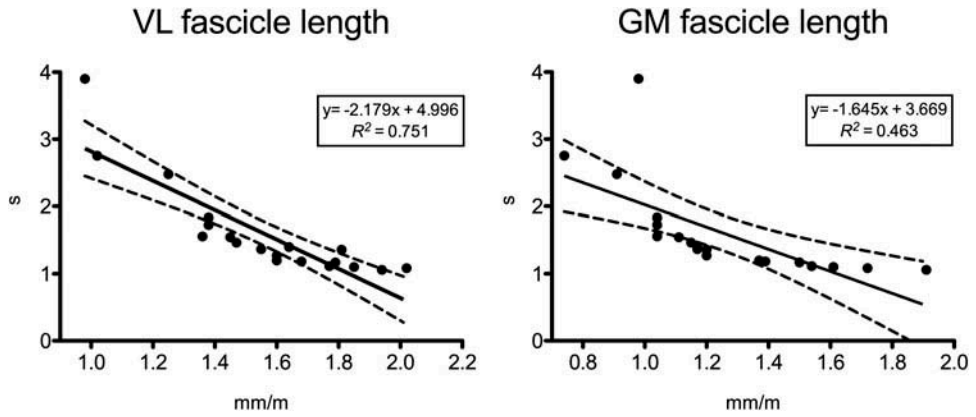

Figure 2. The linear regressions between VL (*vastus lateralis*) and GM (*gastrocnemius medialis*) fascicle length and time-to-peak-power are shown. The correlations are shown with the 95% confidence interval bands. The linear regression analysis and R^2 have been calculated and reported for each dataset.

gastrocnemii ACSA was predictors of the relative peak-power, coherently with their contribution reported in sprint cycling (Akima et al., 2005; Perez-Gomez et al., 2008). Interestingly, cycling exercise was shown to stimulate *small* increments in muscle size (Ozaki, Loenneke, Thiebaud, & Abe, 2015), thus a kind of bidirectional correlation between muscle size and regular cycling could be argued. However, it is not possible to exclude that the present participants could have been previously engaged in regular resistance training.

Force, and consequently power, depends also on pennation angle, whose increment increases the number of in-parallel sarcomeres that simultaneously contract to exert force and participates in the increment in the physiological cross-sectional area (Blazevich et al., 2006). However, physiological cross-sectional area was

not a relative peak-power predictive in elite cyclists (van der Zwaard et al., 2017) and rowers (van der Zwaard et al., 2018). The present findings seem in line, given the non-predictive role of VL and GM pennation angle in relative peak-power. This contrasts with the positive association reported between the quadriceps physiological cross-sectional area (partially depending on pennation angle) and the vertical jump relative power (Murtagh et al., 2018). However, albeit non-predictors, VL and GM pennation angle were correlated with relative peak-power. It was reported that VL pennation angle was positively correlated with unilateral vertical and medial jump height and relative power, highlighting the underpinning role of pennation angle in producing force and consequently power (Murtagh et al., 2018). It could be argued that the different training background and different task may have accounted for these discordant results.

The time-to-peak-power provides useful information about the rate of power production, since it indicates the time necessary to develop the maximal power. To the best of the authors' knowledge, the present study was the first to show that normalized VL fascicle length explained 75% of the time-to-peak-power variance. Additionally, *very large* and *large* negative correlation between normalized VL and GM fascicle length and time-to-peak-power, i.e., longer fascicles corresponded to a shorter time-to-peak-power. Longer fascicles are known to be associated with higher muscle contraction velocity (Blazevich et al., 2006). Such theoretical association was found to have practical perspectives since longer normalized VL and GM fascicles were related to lower sprint time in running (Kumagai et al., 2000). Similarly, normalized VL and *gastrocnemius lateralis* fascicle length negatively correlated with 50-m swimming sprint time (Nasirzade et al., 2014). Additionally, longer normalized VL and GM fascicles were reported in sprinters than in endurance athletes or sedentary people (Abe et al., 2000). Moreover, performance in high-speed movements like jumps was positively correlated with absolute VL fascicle length (Methenitis et al., 2016). In another study, absolute VL fascicle length was positively correlated to the isokinetic peak torque exerted at high but not low angular velocity (Coratella et al., 2018). Furthermore, the resistance training-induced absolute VL fascicle elongation reflected the increments in the rate of force development, i.e., the force developed in the first 250 ms of a maximal isometric contraction (Zaras et al., 2016).

The present findings show *small* correlations between normalized VL and GM fascicle length with relative peak-power. Interestingly, it was found that sprint cyclists have normalized VL fascicle length similar to road cyclists, apparently showing that fascicle length *per se* may not be a determinant sprint factor in cycling (van der Zwaard et al., 2017). The authors showed also that in road cyclists but not in sprint cyclists, absolute VL fascicle length was reported to partially explain relative peak-power, together with the fast-type fiber percentage (van der Zwaard et al., 2017). In another study, absolute VL fascicle length partially explained relative peak-power in male but not in female rowers (van der Zwaard et al., 2018). Albeit the authors did not focus on this discrepancy, the sex-difference in baseline muscle architecture and training-induced adaptation responsiveness (Coratella et al., 2018) could have possibly shed light on the topic. Interestingly, it was shown that the role of absolute VL fascicle length in peak-power activities (i.e., jumping and throwing) increases with the training experience, showing non-significant correlations in amateurs (Methenitis et al., 2016). Therefore, the current amateur population seems to be in line with the less-experienced track-and-field athletes involved in the aforementioned study. However, the present design could not add further explanations to the underlying mechanisms.

The present investigation has some acknowledged limitations. Firstly, ACSA was measured here, although less representative of the muscle size in pennate muscles and it is acknowledged that both muscle volume and the physiological cross-sectional area may have been more accurate for this purpose. However, both parameters require a magnetic resonance or 3D ultrasound to be accurately measured (Erskine, Jones, Maganaris, & Degens, 2009; Weide, van der Zwaard, Huijing, Jaspers, & Harlaar, 2017), and this was not available in our laboratory. However, the training-induced changes in ACSA are correlated to those in muscle volume measured by magnetic resonance imaging (Franchi et al., 2018). Therefore, we are confident that ACSA could have been a valid representative of the whole muscle size. Secondly, although the ultrasound scans were performed by an experienced operator and respected the major guidelines in the literature (Franchi et al., 2018; Noorkoiv et al., 2010, 2010), they can only refer to the regional site where the images were collected so caution is needed when interpreting these results. Thirdly, although the EFOV technique allows tracking the entire visible length of fascicles, the image was not acquired in three – but in two-dimension. Therefore, possible curved portions of the fascicles on the non-visible plane could have been neglected during the measurements. Fourthly, the present results are specific for the population involved here. Different populations (e.g., women, elderly) might

result in different outcomes. Fifthly, although the present sample size was similar to previous studies (Nasirzade et al., 2014; van der Zwaard et al., 2018) a larger sample size could have allowed a more robust statistical approach (e.g., cross-validation to test for generalizability of the multiple regression models). Lastly, the contribution of the hip extensors and knee flexors muscle architecture has not been investigated here and might be of interest in future studies.

What does this article add?

In conclusion, it is shown here that quadriceps and gastrocnemii ACSA are predictors of relative peak-power. Similarly, normalized VL fascicle length explained the time-to-peak-power variance. Although muscle size and architecture are just two out of the factors that affect the power generation, the present findings open some interesting perspectives related to the specific architectural resistance training-induced adaptations. Indeed, while concentric training is mainly associated with increments in pennation angle (Franchi, Reeves, & Narici, 2017), eccentric training seems to cause mainly fascicle elongation (Coratella, Milanese, & Schena, 2015; Franchi et al., 2017). Consequently, it might be argued that these training modalities could be used to induce specific adaptations in muscle architecture. However, whether or not these adaptations could reflect specific changes in peak-power or time-to-peak-power remains to be proven clearly.

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