FORCE GENERATION IN SPRINT RUNNING IS RELATED TO MUSCLE PROPERTIES IN MALE SPRINTERS

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The aim of this study was to investigate the relationship between muscle properties (MP) and force production (F) during a sprint running acceleration phase in 18 male sprinters (Age: 24.4±4 years; personal best: 10.66±0.5 s). MP (muscle thickness, fascicle length and pennation angle) of the lower limb muscles were measured by B-mode ultrasonography and F was modelled at each instant by derivation of running velocity. All MP variables showed significant correlations with peak force values ($p>0.01$): longer fascicle length, greater thickness and lower pennation angle are associated with greater force production and subsequent acceleration ability.

KEYWORDS: muscle thickness, acceleration, pennation angle, fascicle length, ultrasonography, force generation

INTRODUCTION: The 100 m event is a “multifactorial skill” determined by 3 factors: the forward acceleration, the maximum attained speed and the ability to maintain that speed throughout the race. The ability to produce a high forward acceleration has been related to the capability to produce a high power output and external force during the sprint acceleration phase. This capability is well described by the lower limbs force-velocity relationship (F-v) (Samozino et al., 2015). The maximal force generated by the muscle fibres during a stretch-shortening cycle depends on muscle architecture (Cormie et al., 2011). As an example, the maximal force generated by muscles is proportional to their cross-sectional area (CSA), and the maximal velocity of sarcomeres is proportional to their length. Consequently, force generation during running depends on the interaction between different architectural parameters (e.g. fascicle length, pennation angle, muscle thickness). Previous correlational studies have reported significant relationships between muscle-tendon properties and 100 m sprint time in both men and women. (Abe et al., 1999; 2001; Kumagai et al., 2000; Kubo et al., 2011; Karamanidis et al., 2011). As an example, Abe et al. (2001) concluded that a longer fascicle length is associated to a greater sprint performance in both genders, while Kubo et al. (2011) reported significant correlations between muscle thickness at medial side of knee extensors and 100 m racing time ($r = -0.616$). In addition, Lee and Piazza (2009) showed that the Achilles tendon moment arms were 25% smaller in sprinters than in non-sprinters and that the sprinters’ fascicles were 11% longer than in non-sprinters. However, Karamanidis et al. (2011) and Kubo et al. (2016) reported no significant differences in plantar flexor muscle-tendon components between fast and slow sprinters and between sprinters and untrained participants.

Since the most important indicator of the acceleration performance is the capability to produce a high forward force, the aim of this study was to examine the relationships between architectural characteristics (fascicle length, pennation angle, muscle thickness) of lower limb muscles and force production during the acceleration phase in sprint running.

METHODS: Eighteen male sprint athletes participated in this study (age: 24.36±5.0 years; mass: 74.5±5.92 kg; stature: 178±5.94 cm; 100 m personal best: 10.66±0.51 s); they were free from any type of injury (this was verified by means of an interview) and were asked to abstain from training in the 24 hours before the testing session. All participants received written and oral instructions before the study and gave their written informed consent to the experimental procedure.

After 10 min of resting, the muscle thickness of vastus lateralis (VL), rectus femoris (RF), vastus intermedium (VI), vastus medialis (VM) (at a point 50% between the lateral condyle of the femur and greater trochanter), gastrocnemius medialis and lateralis and soleus (GM, GL, SOL) (at a point 30% proximal between the lateral malleolus of the fibula and the lateral condyle of the tibia) were measured in vivo as described previously (Abe et al., 1999, 2001; Kawakami et al., 2000) using the B-mode ultrasound apparatus (SIEMENS P50). Pennation angle was also measured for VL, VI, VM, GM, GL and SOL (RF is a bi-pennate muscle, therefore for more simplicity no pennation angle was determined for this muscle).

Briefly, the transducer was placed perpendicularly to the muscle to obtain a cross-sectional image (Figure 1) and was then shifted to a position parallel to the specific muscle resulting in a longitudinal image. The distance between subcutaneous adipose tissue interface and inter-muscular interface in the cross-sectional image was utilized to assess muscle thickness. The angle between the deep aponeurosis of the muscle and the interspaces among the muscles' fascicles in the longitudinal image was utilized to assess pennation angle. All images were analysed with the ImageJ software. The fascicle length across the deep and superficial aponeurosis was estimated as: fascicle length = muscle thickness / sin ß (where ß is the pennation angle). The relative fascicle length for each muscle was calculated by the ratio of fascicle length and segment length (thigh or shank).

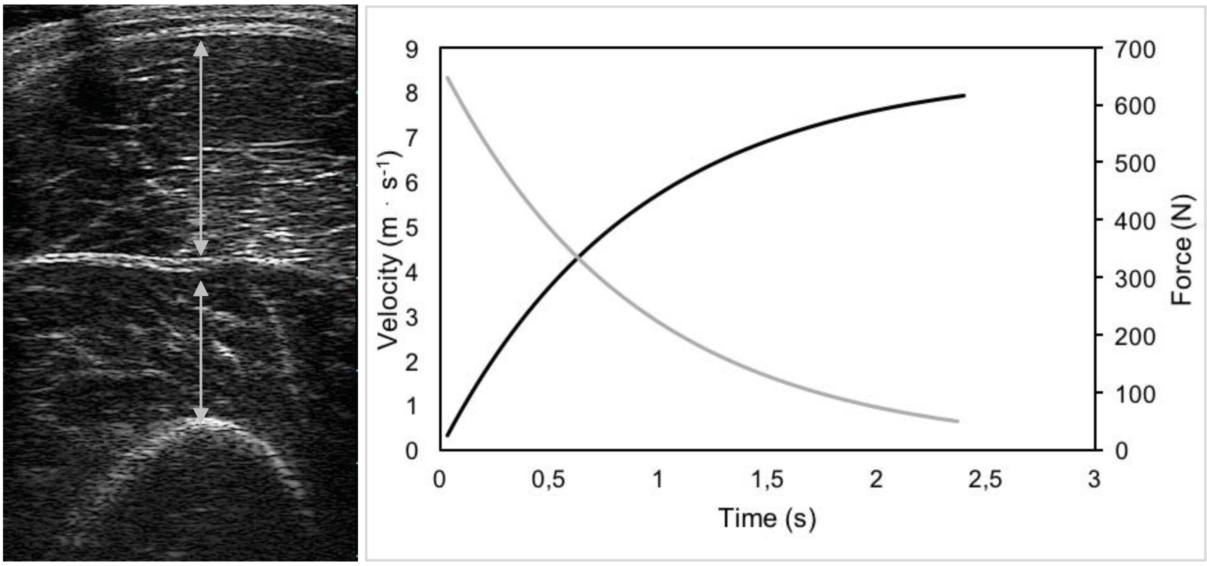

Figure 1: left panel: muscle thickness of vastus lateralis (upper arrow) and vastus intermedius (lower arrow); right panel: velocity (black) and force (grey) as a function of running time in a 20 m sprint.

After the MP measurements, each athlete performed a standardized 20 min warm-up (i.e. running, specific gaits and dynamic stretching) following which he was asked to perform 2 maximal trials over a 20 m distance; only the trial with the best acceleration phase was analysed.

Instantaneous velocity (*v*) was measured at a sampling rate of 46 Hz with a radar system (Stalker ATS II System) placed on a tripod 10 m behind the starting line at a height of 1 m, corresponding approximately to the height of body centre of mass, and the running velocity was fitted with a mono-exponential function; $v(t) = v_{max} \cdot (1- e^{-t/Tau})$ (e.g. di Prampero et al., 2005).

The horizontal position (*x*) and acceleration (*a*) of the athletes over time during the acceleration phase were obtained by integration and derivation of *v(t)* over time, respectively. The horizontal force (*F*) was obtained by multiplying *a(t)* over time for the sprinter's mass. From these data, the peak and mean force (F_{peak}, F_{mean}) generated by athletes were calculated. A typical tracing of *F* and *v* during a sprint are reported in Figure 1.

All variables are expressed as mean ± standard deviations (SD). Relationships between muscle-tendon variables and mechanical power were examined using Pearson correlations.

RESULTS: The mean values and corresponding standard deviations of the running variables are reported in Table 1, along with the MP parameters.

Table 1
Peak and mean running variables and MP parameters

	Velocity (m/s)	Force (N)
Mean	6.31±0.59	277.4±77.4
Peak	8.88±0.98	715.8±153.4

	Thickness (cm)	Angle (°)	Length (cm)	Relative Length (cm/cm)
VL	2.89±0.21	17.8±2.6	9.38±1.49	0.22±0.04
VM	3.53±0.25	11.6±1.6	17.56±3.01	0.41±0.07
VI	2.01±0.19	9.1±0.9	12.71±2.03	0.29±0.04
RF	2.81±0.22	/	/	/
GL	1.82±0.18	12.3±1.6	8.54±1.48	0.20±0.05
GM	2.32±0.30	20.8±1.7	6.51±1.35	0.15±0.04
SOL	1.86±0.08	20.1±1.5	5.43±1.01	0.12±0.03

The correlation coefficients (r) between force values and muscle properties are reported in Table 2. Muscle thickness and fascicle length were positively correlated with mean/peak force production in all analysed muscles while negative correlations were observed between pennation angle and mean/peak force. Significant correlations are indicated by bold characters (p<0.05 for r>0.47; p<0.001 for r>0.71). The muscle with the larger correlations between MP and force production during accelerated running was GM.

Table 2
r values between mean/peak force values and muscle properties

Muscle thickness

	Thigh muscles				**Plantar flexor muscles**		
	VL	*VM*	*VI*	*RF*	*GL*	*GM*	*SOL*
F_{mean}	0.41	**0.47**	0.45	**0.77**	**0.58**	**0.81**	**0.65**
F_{peak}	**0.65**	**0.79**	**0.71**	**0.82**	**0.82**	**0.91**	**0.71**

Pennation angle

	Thigh muscles				**Plantar flexor muscles**		
	VL	*VM*	*VI*	*RF*	*GL*	*GM*	*SOL*
F_{mean}	-0.46	**-0.52**	-0.44	/	**-0.52**	**-0.53**	-0.40
F_{peak}	**-0.68**	**-0.72**	**-0.66**	/	**-0.75**	**-0.82**	**-0.68**

Relative muscle length

	Thigh muscles				**Plantar flexor muscles**		
	VL	*VM*	*VI*	*RF*	*GL*	*GM*	*SOL*
F_{mean}	**0.51**	**0.58**	**0.56**	/	**0.57**	**0.65**	0.39
F_{peak}	**0.88**	**0.81**	**0.84**	/	**0.82**	**0.87**	**0.81**

DISCUSSION: It is well known that muscle characteristics play a significant role in maximum force generation during different movements (Cormie et al., 2011). However, less is known about the role of muscle architecture in force production during a sprint running acceleration phase. The findings of the present study demonstrate that pennation angle, fascicle length and muscle thickness are significantly related with force production during sprint running.

Previous studies demonstrated that fascicle length in male and female 100 m sprinters is correlated with sprint performance (Abe et al., 1999; 2000; Kumagai et al., 2000) and our data showed a significant correlation also between force production and relative fascicle length. The maximal force generated by a muscle is related to its thickness and CSA (Cormie et al., 2011) and our data showed that muscle thickness is indeed related with maximal force production.

Pennation angle has an important effect on maximal power output. When pennation angle increases, more sarcomeres can be arranged in parallel and the muscle can produce more force. However, larger pennation angles are also associated with slower velocities and thus, an increase in this parameter may negatively affect running velocity. Indeed, we found a significant negative relationship between pennation angle and force production. According with previous studies, GL is the muscle with the longest fascicle length in the triceps surae group while GM has a larger pennation angle and a shorter fascicle length in respect to GL (e.g. Abe et al., 2000; Kubo et al., 2016; Lee & Piazza 2011). Our data, indeed, showed a stronger correlation between peak force production and pennation angle in GM (r = -0.82) than in GL (r = -0.75).

It can be assumed that "better" muscle characteristics in fast sprinters are genetically conferred but muscle properties can also derive from a specific adaptation to high-intensity training or sprint training in sprinters. As an example, extensive research has established that heavy strength training is an effective stimulus to improve muscle thickness and maximal force (Cormie et al., 2011). Moreover, Blazevich et al., (2003) reported that fascicle length increases in response to resistance training, as well as in subjects that performed jump and sprint training. Finally, pennation angle increases and decreases in response to strength and sprint training, respectively. In fact, Abe et al. (2001) and Kumagai et al. (2000) showed that highly trained sprinters have a smaller pennation angle than both less trained sprinters and untrained subject.

CONCLUSION: Our data indicate that muscle thickness and fascicle length are significantly correlated with peak force generation during sprinting. Consequently, these architectural characteristics appear to coincide with the determinants of maximum force production, determining a faster sprint performance. Future research should focus on sprint training adaptations to understand the role of genetics vs. training methodology in determining sprinting performance.

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