

Muscle Architecture, Muscle Quality, and Neuromuscular Function of the Knee Extensor Muscle: A Comparison between Middle-aged and Older Endurance Runners

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Abstract

Problem statement: Changes in the neuromuscular system owing to aging can decrease strength and muscle power. Additionally, muscle architecture and quality are affected by the natural aging process. However, it has been suggested that lifelong physical exercise may attenuate or even prevent age-related decline in physical function. Nevertheless, it is still uncertain to what extent chronic and predominantly aerobic physical training delays age-related decreases in neuromuscular function, architecture, and muscle quality. **Purpose:** This study was designed to compare the muscle architecture, muscle quality, and neuromuscular function of the knee extensor muscles between middle-aged runners (MR, N = 25; 53.9 ± 2.5 y, 76.5 ± 12.3 kg) and older runners (OR, N = 16; 64.4 ± 3.5 y, 70.5 ± 9.8 kg). **Approach:** Measures of muscle architecture were: cross-sectional area, pennation angle, fascicle length, and muscle thickness of the vastus lateralis muscle. Echo intensity of the vastus lateralis muscle was used as a marker of muscle quality, while isometric absolute and relative peak torque, rate of torque development, voluntary activation level, peak twitch torque, contraction time, and half-relaxation time of the knee extensor muscles were used as markers of neuromuscular function. **Results:** The OR group presented lower cross-sectional area, pennation angle, muscle thickness, absolute peak twitch torque, 100–200 ms rate of torque development, and greater echo intensity. There were no other significant differences between OR and MR groups. **Conclusions:** These findings suggest that though older runners have approximately 20 years of running training, they presented lower values for some markers of muscle architecture and neuromuscular function, as well as lower muscle quality compared to middle-aged runners.

Key Words: Master Athlete; Running; Human Ageing; Neuromuscular function

Introduction

Aging is associated with changes in neuromuscular function, muscle architecture, and muscle quality (Aagaard et al. 2010; Baroni et al. 2013). Changes in neuromuscular function might include an age-induced reduction in the efferent drive to the active muscle, which would reduce voluntary activation level (VAL) during a maximal voluntary isometric contraction (Unhjem et al. 2016; Mckendry, 2018). However, some studies have failed to demonstrate an aging-induced impairment in VAL (Jakobi and Rice 2002). In addition, aging may also affect other markers of neuromuscular function such as isometric peak torque, rate of torque development, and contractile muscle properties (e.g., electrically evoked peak twitch torque, contraction time, and half-relaxation time (Aagaard et al. 2010). Changes in muscle architecture and quality with aging include a decrease in muscle mass replaced by connective tissue (e.g., fat infiltration into the lean tissue) (Fukumoto et al. 2012; Sipila & Suominen 1993) and a reduction in pennation angle, fascicle length, and muscle thickness (Kubo et al. 2003; Narici et al. 2003). All these changes can compromise the muscle capacity to generate force (Aagaard et al. 2010).

A driving factor underlying the age-related loss of muscle architecture, muscle quality, and neuromuscular function is the reduction in the number and quality of motor units (Allen et al. 2021). In this regard, life-long training may assist to preserve the number and quality of motor units in older individuals (Allen et al. 2021; Power et al. 2017, 2010). The maintenance of the number and/or quality of motor units induced by training may assist to preserve muscle architecture, muscle quality, and neuromuscular function. Strength training is widely used as a strategy to attenuate age-induced impairments in the neuromuscular system (Booth et al. 2011; Stephen Harridge & Lazarus 2017). However, a growing number of older individuals are also engaged in endurance running training (Reaburn & Dascombe 2008). For example, master runners comprise most of the participants in marathons and ultra-marathons (Lee et al. 2017). Nevertheless, while it is well known that long-term running

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training improves metabolic and cardiorespiratory factors (Kusy, Krzysztof, Zielinski 2014; Reaburn & Dascombe 2008; Tanaka & Seals 2008), there is a lack of studies investigating the influence of long-term running on muscle architecture, muscle quality, and neuromuscular function.

Some studies investigated master endurance athletes including different sports modalities such as cyclists, skiers, and runners, and demonstrated that chronic endurance training might preserve some aspects of neuromuscular function, muscle architecture, and muscle quality (Sipila & Suominen 1993; Tarpenning et al. 2004). However, other studies failed to demonstrate that endurance training preserved age-related neuromuscular alterations (Karamanidis & Arampatzis 2006; Marcell et al. 2014; Power et al. 2016). Furthermore, studies usually compared groups of master endurance athletes with age-matched sedentary or young athletes. To our knowledge, there is a limited number of research comparing muscle strength between master runners of different ages. A study compared male master runners from 40 to 80 years old and found no reduction in muscle strength of knee extensors until 70 years old, suggesting that endurance training can delay the decline in muscle strength (Tarpenning et al. 2004). On the contrary, another study involving women master runners from 40 to 60 years found a reduction in muscle strength of knee extensors as age progressed (Tarpenning et al. 2006). Corroborating these findings, another study found that the older individuals and master athletes had lower muscle strength than the young individuals, but this study investigated the tibialis anterior muscle (Piasecki et al. 2016).

However, women may have greater decrease in muscle mass, strength, and performance caused by menopause-related reduction of estrogen levels (Maltais et al. 2009). Thus, it is still unknown if muscle architecture, muscle quality, and neuromuscular function of knee extensor muscles are preserved in male master endurance runners, and it deserves further investigation.

Therefore, this study aimed to compare the muscle architecture and muscle quality of the vastus lateralis, and neuromuscular function of the knee extensor muscles between middle-aged and older runners. We hypothesized that muscle architecture, quality, and neuromuscular function would not differ between middle-aged and older runners.

Materials and methods

Participants

Forty-one male runners aged between 50 and 71 years, exposed to regular running endurance training, were recruited from the local running clubs. The inclusion criteria were: 1) training for at least five years; (2) running training at least 15 km/week and competing at least three times a year in local running competitions. The exclusion criteria were: (1) present a history of lower limb musculoskeletal injuries; (2) cardiovascular disorders or any contraindication to performing the experimental tests.

The volunteers were allocated into one of the two groups: middle-aged runners (MR; n = 25; 50–59 y) or older runners (OR; n=16; 60–71y). The sample size was calculated using the Epiinfo calculator developed by the Center for Disease Control and Prevention. The following parameters were inputted: 350 participants (based on the number of male runners above 50 years old participating in local running events), anticipated frequency of 50%, the confidence level of 10%, and design effect of 1.0. A total sample size of 41 participants resulted in a statistical power of 80%. All participants signed written informed consent. This study was approved by the Ethics Committee of the Federal University of Parana.

Experimental Procedures

Participants visited the laboratory and were submitted to the experimental procedures in the following order: 1. Completed a questionnaire of training background; 2. height and body mass measurements; 3. Muscle architecture [cross-sectional area (CSA), pennation angle (PA), muscle thickness (MT), and fascicle length (FL)] and muscle quality (echo intensity) assessments; 4. neuromuscular function assessment. Participants were asked to refrain from intense physical activity 48 h before the measurements. A single experienced evaluator performed all measurements. In addition, participants of both groups were familiar with neuromuscular function assessment as they had been in other studies from our laboratory. Even so, all participants performed a standardized familiarization before data collection.

Training Background

Training characteristics were obtained through a semi-structured questionnaire. The time of running practice, frequency, duration of training sessions, and weekly training minutes (volume). The relative performance level of runners was determined from the aged-graded running calculator of Masters Athletics (*Masters Athletics Rankings, Track and Field - World Rankings*, n.d.), and classified as: >100% = World record level; > 90% = World-class level; > 80% = National class level; > 70% = Regional class level and > 0% = Local class level.

Height and body mass measurements

Body mass was measured to the nearest 0.1 kg using a calibrated electronic scale Balmak, model Class III (Labstore, Curitiba, PR, Brazil). Stature was determined to the nearest 0.1 cm with a stadiometer attached to

the scale. The measurements were performed with the participants wearing light clothes and without shoes. Body mass index (BMI) was calculated using the following formula: body mass (kg) / [height (m)]².

Ultrasonography

An experienced researcher identified the location of the scanning site (middle point between lateral epicondyle and greater trochanter of the right femur). This point was marked with semi-permanent ink and used as a reference. Subsequently, participants lay in a supine position for 20 min, with their legs extended and relaxed to allow fluid shifts. After that, the skin was marked with a pencil marker every 3 cm from the reference point toward the medial and lateral aspects of the thigh (Berg et al. 1993). The muscle evaluated was the vastus lateralis due to its great relevance in the running. It plays a significant role in the support phase (eccentric contraction), being one of the most recruited muscles (Cappellini et al. 2006; Hamner et al. 2010).

Ultrasonographic (US) images of the vastus lateralis were taken at each transverse (cross-sectional area) and longitudinal (pennation angle, fascicle length and muscle thickness) site. A mode-B US (Konica Minolta® - Sonimage HS1, JPY) with a multi-frequency linear probe (8–12 MHz) and a linear ray transducer (5 x 2 cm) was used to obtain the axial-plane images. Sequential US images were acquired, aligning the superior edge of the probe with each mark in the skin following a middle-to-lateral direction. Care was taken to apply minimal pressure during scanning, and a generous amount of conductive gel was used. Participants were instructed to maintain their leg muscles relaxed during the entire procedure. The same investigator, who had extensive experience in ultrasonography, obtained all images.

The VL muscle images from the procedures previously described were reconstructed for further determination of muscle architecture and muscle quality (Reeves et al. 2004). First, the US images were digitized and sequentially opened in Power Point (Microsoft, Redmond, WA, USA). Next, each image was manually rotated until the whole fascia of the VL muscle had been reconstructed, and CSA was determined (Lixandrao et al. 2014). Subsequently, US images were analyzed with Image-J software (National Institute of Health, USA). The software was calibrated with fixed distance scales displayed in the US images.

The distance between deep and superficial aponeurosis was calculated to obtain the MT through the mean value of 5 parallel lines drawn at right angles. The best fascicle image in each assessment was used for PA and FL analysis. The PA was calculated as the angle between the muscle fascicle and the deep aponeurosis. The FL was assessed by the length of the fascicular path between the two aponeuroses. For reliability and reproducibility of measurements, a pilot study was carried out on two different days as recommended (Hopkins 2000). The coefficients of variation (CV), intraclass correlation coefficient (ICC), and the standard error of measurements (SEM) were calculated. To cross-sectional area the results were 0.11, 0.97 and 0.28, to fascicle length 0.12, 0.89 and 0.29, to pennation angle 0.13, 0.94 and 0.69 and to muscle thickness were 0.09, 0.81 and 0.08 respectively. The between-day coefficient of variation for CSA, MT, PA, and FL was lower than 1.7%.

Echo intensity (muscle quality) of CSA was assessed using the mean and median of gray-scale values and calculated by the standard histogram function. The gray-scale values range from 0 (black) to 255 (white), where higher values represent a greater amount of fat and fibrous tissue in the muscle (Pillen et al. 2009, Young, 2015).

Neuromuscular function assessment

Participants were positioned with their hip and Knee at 90° and their right leg strapped to the lever arm of an isokinetic dynamometer (Biodex System 3 Pro, Biodex Medical System, USA), following the manufacturer's recommendation to evaluate the force of knee extensors. The rotational axis of the dynamometer was visually aligned to the lateral femoral epicondyle, and the leg was attached to the dynamometer lever arm 2 cm above the lateral malleolus.

Participants were also fixed at the correct position by the equipment straps. The torque data were smoothed using a zero-lag eighth-order low-pass digital Butterworth filter. The cut-off frequency was determined by residual analysis and set at 8 Hz. The magnitude of torque was calibrated based on the Biodex System measurement.

Torque measurement

Participants performed four 5-s isometric contractions (25, 50, 75, and 100% of perceived maximal voluntary isometric contraction, MVIC) for warm-up. After a 3-min rest, participants performed three 5-s MVICs, with a 2-min rest period between MVICs. If the coefficient of variation exceeded 5% between contractions, an additional attempt was performed and the attempt out the 5% variation was excluded from analysis. Explicit instructions to contract as hard and as fast as possible were given. Visual feedback of torque signal was provided to the participants on a PC screen. Participants reported no pain or any unusual discomfort during the contractions.

The MVIC with the highest peak torque (N.m) was considered for analysis. Peak torque was also expressed relative to CSA (Ptcsa) (Aagaard et al. 2007). The rate of torque development (RTD) was calculated

between different time intervals (i.e., 0 to 30, 0 to 50, 0 to 100, and 0 to 200ms), as previously suggested (Aagaard et al. 2002).

EMG recording

The EMG activity was recorded from the VL muscle using the Delsys Trigno Wireless EMG system (Trigno™ Wireless System, Delsys® Inc., Boston, MA) following the recommendations of SENIAM (Surface EMG for the Non-Invasive Assessment of Muscles). Before the electrode placement, the skin was shaved, abraded with emery paper, and cleaned with alcohol to reduce skin impedance below 5 kΩ. The EMG signal was captured at a sampling frequency of 2kHz, bandwidth 10-500 Hz at -3 dB (digital filter), gain 2000. For synchronization with the Biodex System, torque data were acquired simultaneously and inputted into an additional channel of the Delsys Trigno Wireless System.

Electrical stimulation

Electrical stimuli were delivered to the femoral nerve using an electrical stimulator (Neuro IOM 9-channel, Neurosoft®, Ivanovo, Russia). Surface monopolar electrodes (Ambu® Neuroline 715, Ballerup Denmark) were placed on the femoral nerve (cathode) and gluteal fold (anode). The optimal motor point for femoral nerve stimulation was identified approximately 2 cm from the femoral pulse. The cathode location was moved around the inguinal triangle delivering percutaneous electrical nerve stimuli (30 mA) until both the highest peak twitch torque of knee extensors and peak-to-peak amplitude of the compound muscle action potential (M-wave) of the VL muscle were detected.

The optimal intensity of electrical stimulation was identified by offering single stimuli at relaxed quadriceps, starting at 30 mA and increasing 5 mA every 30 seconds until the attainment of a plateau in both peak twitch torque and M-wave during three consecutive stimuli. The optimal stimulation intensity for neuromuscular function assessment was set at 120% of the plateau (range 50 to 110 mA) to ensure maximal stimulation during the tests (Neyroud et al. 2014).

A first single stimulus (1-ms duration, 1 Hz frequency) was delivered at the torque plateau during the MVIC (superimposed twitch), approximately 1.5 s after the torque onset. Then, a second stimulus (1-ms duration, 1 Hz frequency) was delivered on the relaxed muscle (potentiated twitch) 2 s after the MVIC (Allen et al. 1995; Millet et al. 2011; Shield & Zhou 2004). Then, the voluntary activation level (VAL) was calculated by the twitch interpolation technique (Merton et al. 1954), using the following equation (Allen et al., 1995): $VAL (\%) = [1 - (\text{superimposed twitch} / \text{potentiated twitch})] \times 100$.

The following parameters were also obtained from the mechanical response of the evoked potentiated twitch on relaxed muscle: (1) peak twitch torque (Ptt) - the highest twitch torque; (2) contraction time (Ct) - the time from the beginning of the mechanical response to Pt; and (3) half relaxation time (HRT) - the time from the peak twitch torque to 50% of its decline. All data analyses were performed on the Neuromuscular Tool (Mayor et al 2020), using a custom-built Matlab-based software (version 2019a, Mathworks Inc.)

Statistical Analysis

Data are expressed as means $\pm$ SD. The Shapiro-Wilk test checked the data normality. When data normality was not confirmed (weight, BMI, level of vigorous physical activity, practice time, voluntary activation level, contraction time, peak twitch torque, and rate of torque development at 50 ms), data were log-transformed. Comparisons between the MR and OR groups were performed using the Student t-test for independent samples. When data were non-normally distributed even after log transformation, non-parametric Mann-Whitney U test was used to compare MR and OR. The significance level was set at $p < 0.05$. All statistical analysis was performed using SPSS version 22 (IBM Corporation, Armonk, New York, USA).

Results

Participants characteristics

Apart from the expected differences in age ($p < 0.001$), no differences were observed in anthropometric and training characteristics between OR and MR groups ($p > 0.05$, Table 1). The athletic performance level was similar between OR and MR groups in two running distances (10km: $69.6 \pm 12.9\%$ for MR and $71.2 \pm 12.2\%$ for OR; 21km: $71.3 \pm 11.9\%$ for MR and $74.2 \pm 10.6\%$ for OR). The majority of runners were classified at the regional level.

Table 1 Participants characteristics (means $\pm$ SD) of middle-age (MR) and older (OR) runners.

Variable	MR (n=25)	OR (n=16)	P-value
Age (years)	53.9 $\pm$ 2.5	64.4 $\pm$ 3.5	<.001
Weight (kg)	76.5 $\pm$ 12.3	70.5 $\pm$ 9.8	.08
Height (m)	1.74 $\pm$ 0.06	1.73 $\pm$ 0.06	.51
BMI (kg/m ²)	25.1 $\pm$ 3.7	23.6 $\pm$ 3.1	.31

Vigorous physical activity (min/week)	309.4±186.1	315.6±147.2	.46
Time of running practice (years)	17.5±10.5	19.6±10.9	.73
Frequency of running training (session/week)	4.4±2.3	4.4±0.9	.52
Duration of running training session (min/session)	68.2±18.8	78.1±31	.41

Muscle architecture and muscle quality

Muscle architecture and quality are described in Table 2. Muscle CSA, pennation angle, and muscle thickness were lower in the OR than in the MR group ($p < 0.05$). There was no significant difference between OR and MR groups for fascicle length ($p > 0.05$). Echo intensity was greater in the OR than in the MR group ($p < 0.05$).

Table 2 *Parameters of muscle architecture and muscle quality of middle-age (MR) and older (OR) runners*

Variable	MR (n=25)	OR (n=16)	Difference	P values
CSA (cm ²)	23±5.3	19.4±4.9	16%	.03
PA (°)	18.7±3.7	16.3±2.8	13%	.04
FL (cm)	7.8±1.4	6.9±1.7	12%	.06
MT(cm)	2.7±0.6	2.3±0.7	15%	.02
EI (UA)	58.1±11.6	67.7±9.0	14%	<.01

Note. CSA – cross-sectional area; PA – pennation angle; FL – fascicle length; MT – muscle thickness; EI – echo intensity.

Neuromuscular function

Parameters of neuromuscular function are reported in Table 3. Absolute (N.m) but not relative peak torque (N.m/cm²) was different between OR and MR groups ($p = 0.02$ and 0.50 , respectively). The OR group also presented a lower RTD 100ms ($p = 0.04$) and RTD 200 ms ($p = 0.03$), but not RTD 30 ms ($p = 0.18$) and RTD 50 ms ($p = 0.08$). Voluntary activation level, contraction time, half-time relaxation, and peak twitch torque were similar between OR and MR ($p > 0.05$).

Table 3

Parameters of neuromuscular function of middle-age (MR) and older runners (OR)

Variable	MR (n=25)	OR (n=16)	Difference	P values
Pt (N.m)	238.1±55.2	195.5±57.9	18%	.02
Ptcsa (N.m/cm ²)	10.6±2.4	10.2±2.4	3%	0.50
RTD 30 (N.m.s ⁻¹)	680.9±457.5	501.4±344.1	26%	0.18
RTD 50 (N.m.s ⁻¹)	733.6±471.1	501.1±273.2	31%	0.08
RTD 100(N.m.s ⁻¹)	730.5±402.8	504.5±237.2	30%	.04
RTD 200(N.m.s ⁻¹)	598.5±260.9	439.2±175.6	26%	.03
Ct (ms)	101.3±31.2	128.2±175.6	20%	.14
Ptt (N.m)	42.3±15.4	40.9±13.2	3%	.75
HRT (ms)	136.7±75.7	174.9±76.9	21%	.12
VAL (%)	94.3±3.6	92.3.6±7.5	2%	.07

Note. Pt – absolute peak torque; Ptcsa – peak torque relative to the cross-sectional area; RTD 30, 50, 100, and 200 ms – rate of torque development from 0-30, 0-50, 0-100 and 0-200, respectively; Ct – contraction time; Ptt – peak twitch torque; HRT – half relaxation time; VAL – voluntary activation level.

Discussion

The present study compared muscle architecture and muscle quality of the vastus lateralis muscle and neuromuscular function of knee extensor muscles between middle-aged and older runners. The main findings of this study were that older runners presented lower pennation angle, cross-sectional area, and muscle thickness than middle-aged runners. In addition, older runners also showed lower muscle quality, absolute peak torque, and RTD 100 and 200 ms. However, there was no difference between groups for peak torque relative to the cross-sectional area, rate of torque development RTD 30 ms and 50 ms, voluntary activation, and contractile muscle proprieties.

Some parameters related to muscle architecture and muscle quality were lower in the OR than in the MR group, contrary to our hypothesis that there would not be differences in muscle architecture and muscle quality between older and middle-aged runners. Our hypothesis was based on a proposed theoretical model suggesting that master athletes might postpone the age at which muscle architecture and muscle quality alteration occur (Lazarus & Harridge 2017). However, despite the older runners presenting an average of almost 20 years of

running training, the cross-sectional area, pennation angle, and muscle thickness were lower, and echo intensity higher than in the middle-aged runners. Previous studies involving sedentary older adults showed a rate of muscle mass decline of ~1.5 % per year (Goodpaster et al. 2006). Interestingly, the CSA difference between OR and MR groups was ~16%, corresponding to a rate of muscle mass decline of ~1.6 % per year, similar to that reported for sedentary individuals. Furthermore, muscle thickness and pennation angle were lower in the OR than in the MR, which may indicate a lower number of sarcomeres in parallel, while echo intensity was higher in the OR than in the MR, indicating increased infiltration of fat and connective tissue into skeletal muscle and lower muscle quality (Fukumoto et al. 2018; Narici et al. 2003). Together, these findings demonstrated that systematic running training might not be sufficient to fully counteract the natural age-induced alterations in muscle architecture and quality. Nevertheless, previous studies showed that master endurance athletes presented higher quadriceps CSA and better muscle quality than sedentary older adults (Mikkelsen et al. 2013; Mckendry, 2019; Sipilä & Suominen 1991), suggesting that endurance training provides some benefits even with an inevitable loss in muscle architecture and muscle quality with aging. Thus, it is probable that even presenting lower values for some parameters of muscle architecture and quality, the older runners preserve part of the muscle architecture and quality compared to sedentary older adults.

In fact, despite these differences in muscle architecture and quality, voluntary activation level was similar between groups. Voluntary activation indicates the ability of the central nervous system to fully activate the skeletal muscle (Maffiuletti et al. 2016). Thus, the fact that VAL was similar between MR and OR groups indicates that the two age groups of master endurance runners present the same ability to activate their motor unit and musculature optimally. Some studies reported a reduction in VAL of the knee and elbow extensor muscles in sedentary old adults, principally after 75 years (Clark & Taylor 2011; Mau-Moeller et al. 2013). On the other hand, other studies comparing moderately trained young and older individuals found no differences in VAL (Gerstner et al. 2017; Hurley et al. 1998; Roos et al. 1999). Maintaining VAL with aging is important because a small deficit in the VAL represents a significant deficit in force production (Koster et al. 2012). The lack of difference in VAL between OR and MR groups, even with some differences in muscle architecture and quality suggests that running training might assist in preserving neuromuscular function in older age.

Most of the contractile muscle properties were not different between OR and MR groups. Nevertheless, older runners presented lower knee extensor absolute peak torque than middle-aged runners. These differences disappeared, however, when peak torque was normalized by the cross-sectional area of the vastus lateralis muscle. As there was no difference in VAL between OR and MR groups, these findings might indicate that differences in muscle force were likely due to changes in muscle architecture, particularly changes in muscle mass. These results agree with previous studies of master endurance athletes that reported that regular endurance training could delay the age of a significant decline in knee extensor peak torque normalized by lean body mass (Tarpenning et al. 2004). However, other studies suggested that regular endurance training was not effective to maintain muscle strength (Harridge et al. 1997; Karamanidis & Arampatzis 2005; Marcell 2014; Power et al. 2016). These controversial results may be explained by differences in the characteristics of the participants. These studies included either very old subjects (70-100 years) that not necessarily participated in endurance competitions (Harridge et al. 1997) or masters runners that trained between 175 and 250 minutes per week (Marcell 2014), which is lower than those values reported by our older participants (~300 min/week). Apart from these discrepancies, our findings indicate that the age-induced loss of muscle mass might explain the reduction in absolute peak torque in the OR group.

No differences were observed between OR and MR in RTD 30 ms and RTD 50 ms, indicating that despite the age differences between groups (~10 years), older runners showed a similar capacity to rapidly-produce torque at the early phase of the muscle contraction. However, OR presented lower RTD 100 ms and RTD 200 ms than MR group. The rate of torque development is an important parameter indicating the ability of the neuromuscular system to rapidly develop torque (Andersen & Aagaard 2006), but different physiological parameters affect the RTD depending on the analyzed time intervals (Andersen & Aagaard 2006). For example, the RTD of the knee extensors at time intervals up to 90 ms is moderately correlated with the twitch muscle contractile properties (Andersen & Aagaard 2006), while time intervals longer than 90 ms are more dependent on maximum strength (Andersen & Aagaard 2006; Maffiuletti et al. 2016). Indeed, our findings showed no difference between groups for parameters related to the twitch muscle contractile properties but a lower absolute peak torque in the OR than in the MR group. Thus, the lower RTD 100 ms and RTD 200 ms in OR than MR group might be due to the lower absolute peak torque in the former than in the last. Furthermore, the difference between OR and MR runners was 26% and 30% for RTD 100 ms and RTD 200 ms, respectively, which is lower than the 30% and 47% observed in previous studies that compared young and older sedentary individuals (Gerstner et al. 2017; Jenkins et al. 2014; Mau-Moeller et al. 2013; Thompson et al. 2013). These findings suggest that endurance running training might attenuate the age-induced reduction of the late phase of the rate of torque development. These findings are also relevant because muscle contraction velocity is a stronger predictor of performance during functional tasks than muscle strength (Bento et al. 2010). Thus, even that only partially attenuates loss in the rate of torque development, endurance training might contribute to maintaining functionality in older people.

Together, our findings indicate that older runners present lower values of some markers of muscle architecture (pennation angle, cross-sectional area, and muscle thickness), neuromuscular function (absolute peak torque and rate of torque development), and lower muscle quality (i.e., higher echo intensity), in comparison with middle-aged runners. However, it is probable that even with these alterations, older runners present better markers of muscle architecture, neuromuscular function, and muscle quality than sedentary older individuals (Allen et al. 202; Mckendry et al. 2018). In addition, some of the reported alterations might be due to training adaptations rather than a genuine loss with aging. For example, a lower pennation angle may be more energetically advantageous during running; therefore, older runners may present a regarding

The present study has some limitations. The main limitation is the lack of corresponding groups composed of sedentary individuals and groups of younger runners. Including these groups would have assisted in a better understanding of the role of endurance running training on muscle architecture, muscle quality, and neuromuscular function during the aging process. However, we aimed to analyze the age-related neuromuscular alterations in two groups of very active people. Sedentarism is usually associated with chronic disease and accelerates the loss of muscle mass. In addition, this is a cross-sectional study, which precludes to infer about cause-effect relationships.

Conclusions

Findings of the present study suggest that older runners present lower values of some markers of muscle architecture (pennation angle, cross-sectional area, and muscle thickness), neuromuscular function (absolute peak torque and rate of torque development), and lower muscle quality (i.e., higher echo intensity) when compared with middle-aged runners. However, the relative peak torque, voluntary activation, twitch muscle contractile properties, and capacity to rapidly develop muscular torque in an early phase of an explosive contraction (30-50 ms) did not differ between the two age-group of master long-distance runners. These results suggest that long-term endurance running training may partially contribute to preserving some aspects of the neuromuscular performance with aging. Longitudinal studies are required to confirm this supposition.

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