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Age-related changes in neuromuscular function of the quadriceps muscle in physically active adults

Anett Mau-Moeller [a,*,1], Martin Behrens [a,1], Tobias Lindner [b], Rainer Bader [b], Sven Bruhn [a]

[a] Department of Exercise Science, University of Rostock, Ulmenstrasse 69, 18057 Rostock, Germany
[b] Department of Orthopaedics, University Medicine Rostock, Doberaner Str. 142, 18057 Rostock, Germany

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ABSTRACT

Substantial evidence exists for the age-related decline in maximal strength and strength development. Despite the importance of knee extensor strength for physical function and mobility in the elderly, studies focusing on the underlying neuromuscular mechanisms of the quadriceps muscle weakness are limited.

The aim of this study was to investigate the contributions of age-related neural and muscular changes in the quadriceps muscle to decreases in isometric maximal voluntary torque (iMVT) and explosive voluntary strength. The interpolated twitch technique and normalized surface electromyography (EMG) signal during iMVT were analyzed to assess changes in neural drive to the muscles of 15 young and 15 elderly volunteers. The maximal rate of torque development as well as rate of torque development, impulse and neuromuscular activation in the early phase of contraction were determined. Spinal excitability was estimated using the *H* reflex technique. Changes at the muscle level were evaluated by analyzing the contractile properties and lean mass.

The age-related decrease in iMVT was accompanied by a decline in voluntary activation and normalized surface EMG amplitude. Mechanical parameters of explosive voluntary strength were reduced while the corresponding muscle activation remained primarily unchanged. The spinal excitability of the vastus medialis was not different while *M* wave latency was longer. Contractile properties and lean mass were reduced.

In conclusion, the age-related decline in iMVT of the quadriceps muscle might be due to a reduced neural drive and changes in skeletal muscle properties. The decrease in explosive voluntary strength seemed to be more affected by muscular than by neural changes.

1. Introduction

The age-related decrease in muscle strength (dynapenia) and strength development is well-documented and might be caused by neural modulations and alterations of skeletal muscle properties (Clark and Taylor, 2011; Manini and Clark, 2011). However, the results differ in part between the investigated muscle groups possibly due to differences in the function and physiological profile of the muscles (Clark and Taylor, 2011).

Numerous studies have described the modulations of voluntary strength and morphology of the quadriceps muscle with aging (Porter et al., 1995; Roos et al., 1999). Due to its functional importance for gait (Murdock and Hubley-Kozey, 2012) and maintaining posture (Barbeau et al., 2000), it is surprising that studies focusing on the underlying neuromuscular mechanisms of the knee extensor weakness are limited. Moreover, the reported results are partially conflicting, particularly with regard to changes in neural drive to the quadriceps muscle (Harridge et al., 1999; Roos et al., 1999; Stevens et al., 2003; Wilder and Cannon, 2009). The ability to voluntarily activate the knee extensors during isometric contractions has been estimated using either the interpolated twitch technique or the central activation ratio. The inconsistent findings may be primarily related to methodological limitations and differences of these two techniques (Klass et al., 2007). Thus, the simultaneous application of two different methods may provide greater insight into modulations of neural drive to the muscle. Only one study has considered a twofold approach to detecting age-related changes in efferent motoneuron output to the knee extensors (Cannon et al., 2007). Besides the interpolated twitch technique, Cannon et al. have used normalized muscle activity during isometric maximal strength to estimate the neural drive. Both parameters were not changed indicating no differences in efferent motoneuron output to the quadriceps muscle. However, the authors used the standard formula for estimating voluntary activation. It has been demonstrated that the interpolated twitch technique has its limitations when the standard formula is applied (Folland and Williams, 2007). The moment when the stimulus is delivered is not always the time point of maximal strength. Thus, the use of a corrected

* Corresponding author. Tel.: +49 3814982760.
E-mail address: anett.mau@uni-rostock.de (A. Mau-Moeller).
[1] Authors contributed equally to this work.

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formula which includes the variations of the torque level has been recommended (Strojnik and Komi, 1998). Only Suetta et al. (2009) applied this corrected formula and also demonstrated no age-related change in voluntary activation under isometric conditions. However, these authors did not use a second method to assess the neural drive to the muscle in order to confirm their results.

It is further noteworthy that age-related changes in neural drive to the quadriceps during strength development have been less frequently investigated. Dynapenia of the quadriceps is a determinant of fall risk (Lord et al., 1994) and mortality (Newman et al., 2006). Considering the fact that the capacity to activate the muscle quickly may be more essential for maintaining balance and preventing falls than the maximal strength (Schultz, 1995), neuromuscular modulations of the quadriceps muscle during strength development should be investigated more closely.

In summary, there is some lack of knowledge about the neuromuscular mechanisms behind the modulations of maximal strength and strength development of the quadriceps muscle with advancing age. The aim of the present study was to investigate the contributions of age-related neural and muscular changes to decreases in isometric maximal voluntary torque (iMVT) and explosive voluntary strength. Explosive voluntary strength was analyzed by calculating the maximal rate of torque development (MRTD) as well as the rate of torque development (RTD) and impulse (IMP) in the early phase of contraction in time intervals of 0–50 ms, 50–100 ms, 100–150 ms and 150–200 ms after torque onset. The neural drive to the muscle during iMVT was estimated using two approaches: the interpolated twitch technique (corrected formula) and the root mean square of the EMG signal (RMS–EMG) normalized to maximal M wave (M_{max}). The neural drive to the muscle during MRTD and RTD was assessed using the RMS–EMG normalized to the M_{max} and normalized to the RMS–EMG during iMVT. Age-related changes in α-motoneuron excitability via Ia afferents were determined with the H reflex technique. Modulations at the skeletal muscle level were evaluated by analyzing the twitch torque signal induced by supramaximal electrical stimulation and by determining the lean mass of the leg.

It was hypothesized that iMVT, MRTD, RTD and IMP were reduced with aging accompanied by changes in neural drive to the quadriceps muscle. It was further assumed that aging would affect spinal excitability, contractile properties and skeletal muscle mass.

2. Methods

2.1. Subjects

Thirty physically active and healthy subjects with no history of neurological and musculoskeletal disorders or injuries volunteered to participate in this study. Physically active and healthy subjects were chosen in order to take account of the problem of lack of motivation and disuse atrophy. The subjects were assigned to two groups: (1) young, (2) elderly, each with 15 participants who refrained from consuming caffeine or alcohol and performing strenuous leg exercise 24 h and 48 h preceding the experiment. Prior to participation written informed consent was obtained from all subjects. The study was conducted according to the declaration of Helsinki and approved by the local ethics committee (A 2009 52). Subject characteristics are displayed in Table 1.

2.2. Experimental procedure

The subjects participated in three experimental sessions. The first session included the measurement of body composition using dual-energy X-ray absorptiometry (DXA) followed by two sessions of neuromuscular tests: (1) familiarization, (2) experiment, separated by one week. Subjects were seated in a standardized position on a CYBEX NORM dynamometer. Prior to the experiment subjects sat passively for 15 min without any warm-up in order to avoid potentiation effects (Folland et al., 2008). The neuromuscular tests were carried out on the quadriceps muscle of the dominant leg. A schematic illustration of the neuromuscular tests is displayed in Fig. 1.

Table 1
Subject characteristics and lean mass of the leg. *Denotes a significant difference between the groups (*<0.05, **<0.01).

	Young (n = 15)	Elderly (n = 15)	p
Men, n (%)	8 (53.3)	8 (53.3)	
Age, yrs, Mean (SD)	25.3 (3.6)	69.6 (3.1)	0.000**
Weight, kg, Mean (SD)	71.3 (11.6)	72.6 (9.9)	0.750
Height, m, Mean (SD)	1.75 (0.9)	1.69 (0.9)	0.058
Physical activity, h/week, Mean (SD)	4.6 (3.6)	3.7 (3.3)	0.134
Lean mass, kg, Mean (SD)	9.27 (1.65)	7.79 (1.72)	0.028*

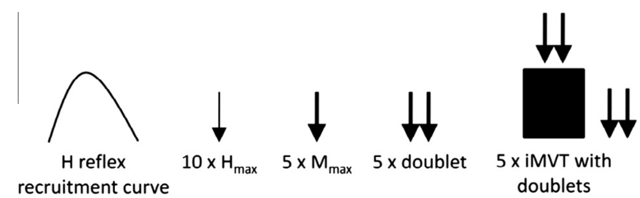

Fig. 1. Schematic illustration of neuromuscular tests. The *thin arrow* indicates stimulation at H_{max} intensity, the *thick arrow* indicates stimulation at supramaximal intensity, *double thick arrow* indicates doublet at supramaximal intensity.

2.3. Torque and EMG recordings

Torque signals were measured using a CYBEX NORM dynamometer (Computer Sports Medicine®, Inc., Stoughton, MA). The tests were performed in a sitting position with a knee angle of 75° and a hip angle of 50° (0° = full extension). The iMVT was tested by asking the subjects to exert isometric knee extensions as forcefully and as fast as possible against the lever arm of the dynamometer for 3 s. The maximal attempts were recorded until the coefficient of variance of five subsequent trials was below 5%. A rest period of 2 min was allowed between the trials.

The surface EMG was recorded using bipolar EMG Ambu® Blue Sensor N electrodes (2 cm diameter). The electrodes were applied to the shaved, abraded and cleaned skin over the middle of the muscle bellies of the vastus medialis, vastus lateralis and rectus femoris. Signals were amplified (2500×), band-pass filtered (10–450 Hz) and digitized with a sampling frequency of 5 kHz through an analog-to-digital converter (DAQ Card™-6024E, National Instruments, USA). The EMG and torque signals were analyzed using a custom built LABVIEW® based program (Imago, Pfisoft, Germany). A detailed description of EMG and torque measurements has been given previously (Behrens et al., 2012).

2.4. Transcutaneous electrical stimulation

Transcutaneous electrical stimulation was used to assess voluntary activation, spinal excitability and contractile properties of the quadriceps muscle. The anode (self-adhesive electrode, 35 × 45 mm, Spes Medica, Italy) was placed over the greater trochanter. The cathode (ball electrode, 1 cm diameter) was fixed to the subject's femoral triangle, 3–5 cm below the inguinal ligament.