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ORIGINAL RESEARCH

Effects of age and physical activity on response speed in knee flexor and extensor muscles

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Abstract This study aims to determine the normalized response speed (V_{rn}) in vastus lateralis (VL) and biceps femoris (BF) muscles in different age groups using tensiomyography. Eighty-four male subjects were divided into four age groups: teenage subjects (T); undergraduate students (U), adult subjects (A), and the elderly group (E). Differences in V_{rn} were observed between E and T (p=0.000), E and U (p=0.000), and E and A (p=0.018) for right VL and between E and T (p<0.000) and U (p=0.003) for left VL; between T and U (p=0.010) and A (p=0.000) for right VL, and A (p=0.004) for left VL. V_{rn} in the BF displayed different behavior from that of the VL, increasing moderately or stabilizing and declining slightly in E, in right leg (p=0.020). The data obtained highlighted a decline in V_{rn} for the VL in both legs with increasing age and, declines in BF response speed were observed only in E.

Keywords Tensiomyography (TMG) · Muscular response speed · Physical activity · Elderly

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Introduction

Loss of muscle mass is one of the leading causes of the functional limitations and disabilities associated with aging [37, 52] and the main cause of reduced strength in adults between 25 and 80 years of age [43]. It is particularly marked in highly sedentary (hypokinetic) subjects.

Among the various muscles most affected by disuse and inactivity, the extensors and non-postural muscles are those showing the greatest atrophy [14, 15, 46]. Atrophy involves changes in the contractile elements of muscle [35, 64, 70], a reduction in the total number of muscle fibers [29], and a loss of motor units [4, 62]. Research has shown that type II, or fast twitch, muscle fibers are more susceptible to atrophy than type I fibers [2, 19, 23, 36, 38, 53].

Of all the body systems, the neuromuscular system displays the most significant differences between sedentary, inactive, and trained or active individuals: muscles that are never used deteriorate more rapidly over time, and at an advanced age, muscle status is poorer, in sedentary subjects than in those who have maintained an adequate training regime [8, 21, 69].

Muscle strength declines more rapidly in the lower extremities than in the upper body [28, 40, 48, 68], in both sexes [9, 28]; this poses a serious problem in elderly people with “fragility syndrome,” due to the greater risk of falls [54].

Loss of muscle mass involves morphological and functional changes which impair the subjects’ quality of life and give rise to problems directly affecting their ability to perform the activities of daily life [25].

The aim of this study was to analyze biomechanical characteristics of selected skeletal muscles and to determine the normalized response speed (V_{rn}) in knee flexor and extensor muscles in different age groups engaged in moderate physical activity using tensiomyography (TMG).

Methods

Sample

A total of 84 male subjects were divided into four age groups (Table 1). Subject selection was based on the following criteria: teenage subjects (T) that regularly trained, three times a week; undergraduate students (U) that were enrolled at the Faculty of Physical Education and Sport Sciences, University of Las Palmas de Gran Canaria, where they are obliged by the curriculum to engage in constant but moderate physical activity; adult subjects (A) that were active at work and engage in recreational physical activity during the week; the elderly group (*E*) that comprised subjects aged 65 or over, whose physical activity was limited to the requirements of daily living.

The vastus lateralis (VL) and biceps femoris (BF) muscles were selected for study, as being the most involved in knee flexion and extension; this choice also enabled comparison between a postural (BF) and a non-postural muscle (VL).

All subjects, and the parents or guardians of subjects under the age of 18, were fully informed of the procedures involved and provided written consent. The study was performed in accordance with the ethical standards laid down in the World Medical Association's *Declaration of Helsinki* on medical research involving human subjects.

Measuring procedure

TMG measures muscle tone [66] and contractile properties [11–13, 47] by means of a displacement sensor positioned directly on the skin over the muscle belly and perpendicular to it [66]; the muscle segment was selected following manufacturer's instructions [16, 22, 58]. Single maximal 1 ms twitch stimulation was applied in bipolar mode (100 mA), through electrodes placed at the proximal and distal ends of the muscle, avoiding the insertion tendons [31, 55, 65]; a pause was included between stimulations in order to rule out post-tetanic activation [6, 49, 55]. The reproducibility of the method and the validity of the experimental procedure used in TMG have been examined in a number of studies, which confirm its value as a high-precision technique [6, 13, 33, 50, 55, 57, 58, 63].

This measurement provides numerical information on the magnitude and timing of radial displacements of transverse muscle fibers [55, 66]. The present study focused on the *normalized response speed* (V_{rn}) [51, 66].

This parameter relates the difference in radial displacement of a muscle belly between 10 and 90 % of the maximal amplitude of the muscle response (Δd_{r}) and the rise time, i.e., the increase in muscle contraction time (Δt_{c}) between 10 and 90 % of the muscle response (Eq.1). Valencic and Knez [66] note that in order to compare the rise time of different muscles, the rise time has to be normalized to the maximum value of a certain response. This is done by dividing the previous equation by the maximum relative displacement (Dm) of each muscle (Eq. 2). Since Δd_{r} equals 0.8×Dm, the normalized response speed equals 0.8 divided by the rise time (Eq. 3):

$$V_{\mathrm{r}} = \frac{\Delta d_{\mathrm{r}}}{\Delta t_{\mathrm{c}}}[\mathrm{mm/s}] \qquad (1)$$

$$V_{\mathrm{rn}} = \frac{V_{\mathrm{r}}}{\mathrm{Dm}} = \frac{\Delta d_{\mathrm{r}}/\Delta t_{\mathrm{c}}}{\mathrm{Dm}}\left[\frac{\mathrm{mm/s}}{\mathrm{mm}}\right] \qquad (2)$$

$$V_{\mathrm{rn}} = \frac{0,8}{t_{\mathrm{c}}}[\mathrm{mm/s}] \qquad (3)$$

Statistical analysis

Data were tested for normal distribution using the Shapiro–Wilk test, and independent sample means for VL and BF (both legs) were compared using the Student's t test for parametric data and the Mann–Whitney adjustment for non-parametric data (significance level $p \leq 0.05$). Statistical analysis was performed using the SPSS-v17 software package (SPSS Inc., Chicago, IL, USA).

Table 1 Study age group

	Teenage	Undergraduate	Adult	Elderly
Number	21	21	21	21
Age (years)	14.9	22.8	56.2	72.4
Mean (SD)	(±0.91)	(±1.99)	(±4.16)	(±4.93)

Results

The data obtained highlighted a decline in the response speed (V_{rn}) for the vastus lateralis muscle in both legs with increasing age (Figs. 1 and 2). The decline was particularly marked in elderly subjects and in the right VL (right (32.5 %) vs. left (27.1 %)).

Statistically significant differences in V_{rn} were observed (Figs. 1 and 2) between the elderly group (E) and the other groups for the right VL (E vs. T, p=0.000; E vs. U, p=0.000; and E vs. A, p=0.018) and between the elderly group and the teenage and undergraduate groups for the left VL (E vs. T, p<0.000; E vs. U, p=0.003). Significant differences were also found between the teenage group and the undergraduate and adult groups for the right VL (T vs. U, p=0.010; T vs. A, p=0.000), and with respect to the adult group for the left VL (T vs. A, p=0.004).

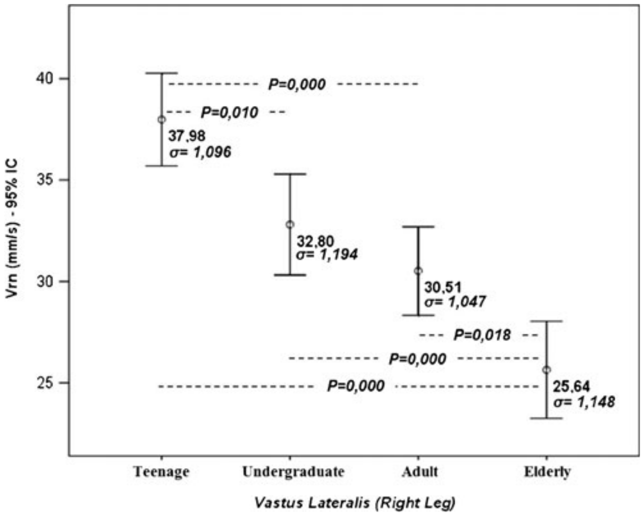

Fig. 1 Mean values for normalized response speed (V_{rn}) expressed in millimeter per second, at a 95 % confidence interval (95 % CI) and σ (standard error of mean), for the right vastus lateralis muscle (VL) for each of the study groups ($p \leq 0.05$)

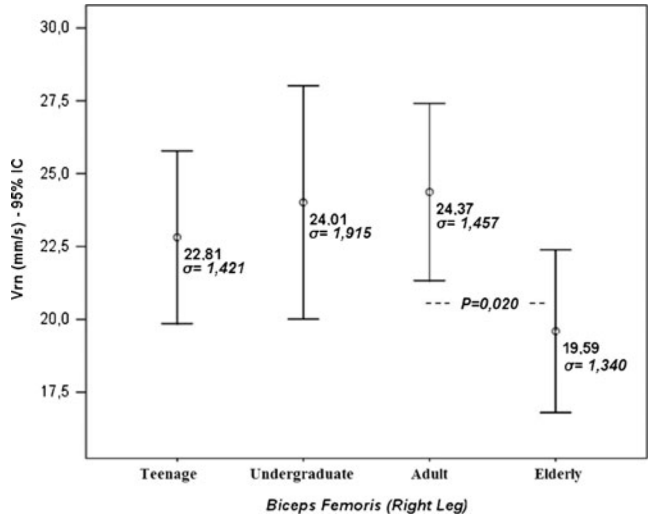

Fig. 3 Mean values for normalized response speed (V_{rn}) expressed in millimeter per second, at a 95 % confidence interval (95 % CI) and σ (standard error of mean), for the right biceps femoris muscle (BF) for each of the study groups ($p \leq 0.05$)

Muscle contraction speed in the BF (Fig. 3) displayed different behavior from that of the VL (Fig. 4), increasing moderately or stabilizing until the fifth or sixth decade of life, and thereafter declining slightly in the elderly group. The decline in speed was more marked in the right leg (p=0.020).

Discussion

The results indicated a decline in V_{rn} in the VL (both legs) with increasing age. By contrast, values in the BF tended to remain stable throughout life, with only a slight decline in the elderly group (E). These functional changes in muscle response in elderly subjects reduce their functional capacity and their ability to perform the tasks of daily life, impairing postural balance control [20, 27] and thus increasing the risk of falls [7, 42, 54, 61]. Additionally, the main muscles used in walking (knee extensors and plantar flexors) lose their functional capacity more rapidly than the muscles used in maintaining postural balance [5, 39, 40, 45, 48, 68].

The decline in response speed (V_{rn}) observed here may be considered indicative of the changes in muscle response taking place due to aging. The magnitude of the decline reflects the loss of muscle mass, a decrease in contractile

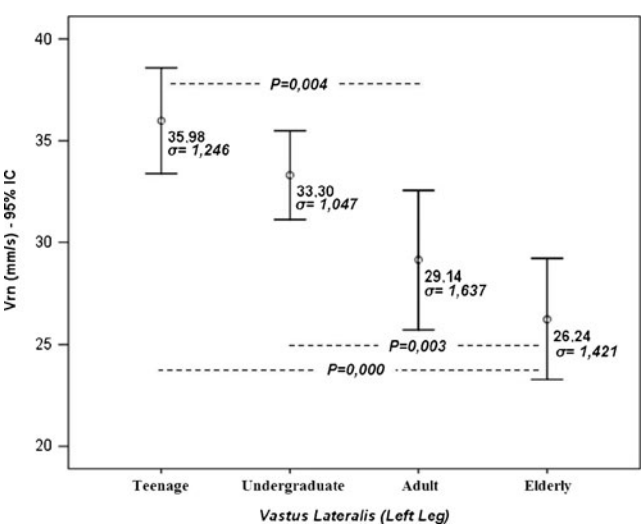

Fig. 2 Mean values for normalized response speed (V_{rn}) expressed in millimeter per second, at a 95 % confidence interval (95 % CI) and σ (standard error of mean), for the left vastus lateralis muscle (VL) for each of the study groups ($p \leq 0.05$)

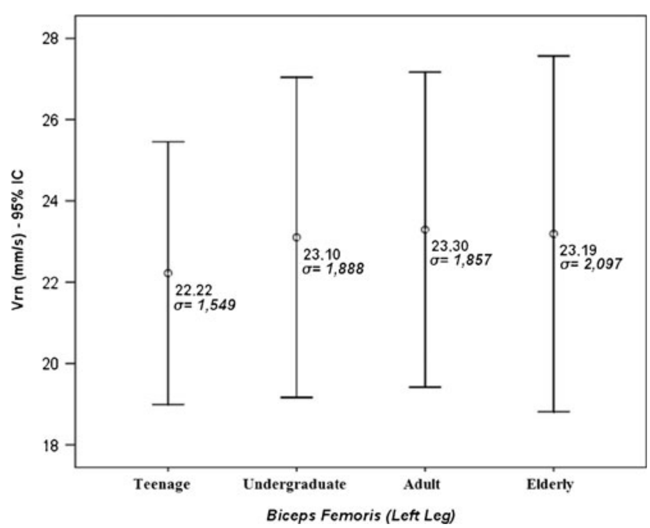

Fig. 4 Mean values for normalized response speed (V_{rn}) expressed in millimeter per second, at a 95 % confidence interval (95 % CI) and σ (standard error of mean), for the left biceps femoris muscle (BF) for each of the study groups ($p \leq 0.05$)

elements [1, 35, 64, 70], neuromuscular alterations [4, 43, 62], and changes in functional balance [17].

Pisot et al. [46] note some dissociation between the contractile changes after long term of complete inactivity occurring at whole-muscle level and those observed at single-fiber level, and their associated changes in myosin heavy chain (MHC) composition. It has been clearly shown that type II muscle fibers are more susceptible to atrophy than type I fibers [2, 3, 30, 32, 59], although a number of studies report similar changes in the two types of fiber [56]. Furthermore, other authors found correlation between high values in the muscle contraction time (Tc) with the highest percentage of type I fibers [30, 31] or with the increased presence of myosin heavy chain (MHC-I) [18].

The extent of changes in muscle composition and response potential is directly linked to the subject's level of physical activity, as long as functional capacity is not governed by some other pathology. Aagard et al. [1] note that strength training induces adaptation of skeletal muscle plasticity as well as improved muscle response in elderly subjects even at a very old age. In the present study, the level of physical activity declined with age, being greatest in the teenage group and lowest in the elderly group. Response speed in the vastus lateralis muscle diminished at a similar rate to physical activity; similar findings have been reported by other authors [8, 21, 69].

The results indicated that the biceps femoris (Fig. 2) had a lower response speed and behaved differently to the VL with increasing age: over the first five or six decades of life, muscle response speed appeared to undergo no significant changes. However, a moderate but statistically significant decline was noted between the adult and elderly groups (p=0.020) for the right BF, indicating a serious impairment of physical activity in the oldest subjects.

Analysis of the results obtained here should take into account that changes in muscle response may be due not only to age but also to the amount and type of physical activity in each group.

The findings of the present study with regard to age-related changes in muscle response speed match those reported by Clark et al. [10] in a study of elderly subjects with limited mobility, elderly subjects with no limitations and middle-aged subjects. These authors found the greatest decline in response speed in elderly subjects with limited mobility and the smallest decline in middle-aged subjects. The decline was more marked in knee extensor muscles (VL, VM, and RF) than in knee flexor muscles (BF and ST). Asaka and Wang [5] report that, with advancing age, the center of pressure moves forward, prompting a constant need for posture rebalancing using the knee flexor muscles, which thus compensate for the progressive loss of knee extensor strength.

It is generally recognized that the ability to make fast movements (dynamic strength) declines more rapidly with age than the ability to maintain static balance (static strength) [26, 27, 34, 60, 67]. It also seems clear that diminished displacement speed increases the risk of falls in elderly subjects [24, 41, 44].

Conclusions

The results obtained indicated a decline in the normalized response speed (V_{rn}) of the vastus lateralis muscle in both legs as subjects grow older and engage in less physical activity. The decline was especially apparent in the elderly group compared to the teenage and undergraduate groups, and between the adult and teenage groups.

In the teenage, undergraduate, and adult groups, flexor muscles behaved differently from extensors. While VL response speed decreased with age, BF increased slightly or remained stable over the first five decades of life; declines in BF response speed were observed only in the elderly group.

The results confirmed that TMG monitoring of muscle response speed using the VL provides an efficient indicator of loss of quality in dynamic movements involving lower limb muscles (ankle and knee joints).

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Disclosures

Conflict of interest D. Rodríguez-Ruiz, J. M. García-Manso, D. Rodríguez-Matoso, S. Sarmiento, M. Da Silva-Grigoletto, R. Pisot declare that they have no conflict of interest.

Informed consent All subjects, and the parents or guardians of subjects under the age of 18, were fully informed of the procedures involved and provided written consent.

Human & animal studies This article does not contain any studies with human or animal subjects performed by the any of the authors.

Ethical statement The study was performed in accordance with the ethical standards laid down in the World Medical Association's Declaration of Helsinki on medical research involving human subjects.

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We can declare that is original research.