Older adults can maximally activate the biceps brachii muscle by voluntary command

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De Serres, Sophie J., and Roger M. Enoka. Older adults can maximally activate the biceps brachii muscle by voluntary command. J. Appl. Physiol. 84(1): 284–291, 1998.—Because some of the decline in strength with age may be explained by an impairment of muscle activation, the purpose of this study was to determine the activation level achieved in biceps brachii by older adults during a maximum voluntary contraction (MVC). This capability was assessed with two superimposition techniques: one calculated the activation level that was achieved during an MVC, and the other provided an estimate of the expected MVC force based on extrapolation with submaximal forces. The activation level in biceps brachii was incomplete (<100%) for the young (n = 16) and elderly (n = 16) subjects, with the elderly subjects exhibiting the greater deficit. In contrast, there was no difference between the measured and expected MVC forces for either group of subjects, whether the extrapolation involved a third-order polynomial or linearization of the data. Because of the lower signal-to-noise ratio associated with the measurement of activation level and the greater number of measurements that contributed to the estimate of the expected MVC force, we conclude that the older adults were able to achieve complete activation of the biceps brachii muscle during an MVC.

muscle strength; maximum voluntary contraction; evoked force; activation level

THE DECLINE IN THE MAXIMUM voluntary contraction (MVC) force that occurs with age is typically greater than expected on the basis of the loss of muscle mass (7, 12, 17, 21). Because this dissociation might be explained by a reduced ability to activate the available muscle mass by voluntary command, there has been an interest in assessing this capability in older adults.

The ability to achieve complete activation of muscle is commonly assessed with the twitch interpolation technique (16), which involves delivering a supramaximal electrical pulse to a muscle while a subject performs an MVC. It is assumed that the superimposed stimulation will recruit muscle fibers that are not activated by the voluntary effort and thereby will produce an extra force that is superimposed on the voluntary force. With this protocol, the level of voluntary activation can be calculated as follows (1): AL (% = (1 – superimposed twitch force at MVC/mean resting twitch force) × 100, where AL is the activation level. When the muscle is fully activated by voluntary command, no extra force will be elicited by the stimulation and voluntary activation will be estimated as 100%. With this technique, young subjects appear to be capable of complete muscle activation by voluntary command (1, 4, 6, 10, 11, 13, 14, 16, 18, 19), although they achieve this state in only ~25% of the trials (1).

Similar results have been obtained with a smaller sample of older adults (7, 17, 21).

Because administration of this technique has often relied on a single pulse for the superimposed stimulus, some investigators have questioned the accuracy of these measurements. Kent-Braun and LeBlanc (13), for example, compared the effect of the number of pulses in the superimposed stimulus on quantification of the AL. Stimuli comprising a single pulse, two pulses, and a train of 50 pulses at 50 Hz were applied to the peroneal nerve during an MVC exerted by the ankle dorsiflexor muscles. When the superimposed stimulus involved a single or a double pulse, few of the healthy subjects exhibited an impairment of activation during an MVC. In contrast, the results obtained with the 50-pulse train indicated that 7 of 21 healthy subjects were unable to activate the ankle dorsiflexor muscles maximally by voluntary command; the mean central activation ratio [MVC force/(MVC force + evoked force)] for the seven subjects was 0.89.

An alternative approach to quantifying the AL during an MVC is to stimulate the muscle at several different levels of voluntary force and to extrapolate the expected MVC force (5, 9, 16, 19). With this approach, Behm et al. (3) found no difference between the MVC force exerted by the plantar flexor and knee extensor muscles of young, healthy subjects and the expected MVC force estimated from an extrapolation of the evoked force-voluntary force relationship. Similarly, Phillips et al. (17) reported no difference between the expected and measured MVC forces for the adductor pollicis muscle of three older adults.

The purpose of this study was to determine the level of voluntary activation achieved in biceps brachii by older adults during an MVC performed with the elbow flexor muscles. Two superimposition techniques were used to make this assessment: 1) quantification of the AL during an MVC and 2) comparison of the measured and expected MVC forces. Although one superimposition technique suggested an impairment of the AL, which was greater for the elderly subjects, the other technique indicated that the young and the elderly subjects were able to achieve the expected MVC force.

METHODS

Subjects. Sixteen young (9 male, 7 female; 28 ± 5 yr, range 18–39 yr) and 16 older (8 male, 8 female; 74 ± 6 yr, range 65–82 yr) adults participated in the study. All subjects were healthy and had no known neuromuscular disorders at the time of the study. The experimental procedures were approved by the Institutional Review Board for Human Subjects at the Cleveland Clinic Foundation. All subjects gave informed consent before participation in the study.
Subjects were seated facing an oscilloscope, with the left arm comfortably supported, the forearm in a neutral position, and the wrist-hand restrained in an orthosis (model OA-1000 (small), model 1001 (medium), or model 1002 (large), Ortho-merica, PEL Supply, Cleveland, OH). The angle of the elbow joint was ~100° and remained constant throughout each experimental session (Fig. 1). The left shoulder was securely clamped to the back of the chair to prevent shoulder movement during the evoked and voluntary contractions.

Electrical stimulation. The electrical stimulation was delivered by a digital stimulator (Grass S8800, Astro-Med, West Warwick, RI) through two carbonized rubber stimulating electrodes (4.5 × 4.5 cm) attached to the skin overlying the biceps brachii muscle. The cathode was placed directly over the muscle belly; the anode was placed over the tendon near the elbow. The maximal output of the stimulator was used for all the subjects during data acquisition (maximal intensity 160 V). However, subjects were given a period of adaptation, during which the stimulus intensity was gradually increased to the maximum.

A pilot study was conducted with seven healthy volunteers (31 ± 6 yr) to determine the stimulus parameters that maximize the evoked force. The parameters tested were the number of pulses (1, 2, and 10) and pulse duration (0.1, 0.2, and 0.3 ms). The results showed a significant increase (2-way analysis of variance) in the force produced by the train of 10 pulses (100 Hz) compared with the force evoked by the single- and double-pulse stimuli (P < 0.001, Fig. 2). The magnitudes of the evoked forces were 9 ± 4% MVC for the single pulse, 19 ± 8% MVC for the double pulse, and 38 ± 13% MVC for the 10-pulse train. In contrast, there were no significant differences in the forces evoked by the three pulse durations (P > 0.1). Therefore, subsequent tests were performed with the 10-pulse train, but with pulse duration varying across subjects depending on which evoked the greatest force in the resting muscle. The 0.3-ms pulse was used for 16 subjects, the 0.2-ms pulse for 9 subjects, and the 0.1-ms pulse for 7 subjects.

Experimental protocol. Each experimental session began with the subject performing three to four trials of MVCs with

Fig. 1. Schematic representation of experimental apparatus with subject’s left forearm enclosed in an orthosis. Force transducer is the circular structure located beneath the wrist.
The maximal voluntary force for the elbow flexor muscles of the left arm of the elderly group (150 ± 53 N, range 64–242 N) was significantly less (P < 0.01) than that of the young subjects (207 ± 62 N, range 96–343 N; Fig. 3A). The force evoked by stimulating (10-pulse train) the biceps brachii muscle at rest was 49 ± 28 N (range 8–115 N) for the older adults compared with 76 ± 33 N (range 23–136 N, P < 0.02; Fig. 3B) for the young subjects. The ratio of the force evoked at rest to the MVC force was not significantly different for the two groups (elderly subjects: 0.33 ± 0.05, range 0.13–0.68; young subjects: 0.37 ± 0.02; Fig. 3A). At the end of the experimental session, MVC force was reduced by 6% (as measured in 15 of 32 subjects) and the force evoked at rest was 13% less than that at the beginning of the session.

Evoked force. The magnitude of the evoked force decreased as the level of the force exerted by the subject.
increased. Figure 4A shows an example of this effect for an elderly subject; these were typical data for the young and the elderly subjects. Each trace represents the force evoked by the 10-pulse train after the subject had reached the target force.

In contrast to the typical evoked responses (Fig. 4A), 9 subjects (5 young, 4 elderly) presented a depression in the evoked force when the exerted force was ≥60% MVC (Fig. 4B). The force depression was present in one subject (the only subject so tested on 2 different days) when the superimposed stimulus involved the 10-pulse train or a single pulse.

The latency from the beginning of the stimulus train to the peak of the evoked force declined significantly (P < 0.01) as the target force increased. For both groups of subjects combined, the latency was 179 ± 25 ms in the resting muscle and 100 ± 32 ms for the MVC. (These measurements do not include those in the subjects who exhibited a depression in the evoked force at the higher target forces.) This decrease in the latency was not due to a change in the time from the beginning of the stimulus to the onset of force, inasmuch as this remained relatively constant across target forces (43 ± 4 ms). Rather, the decrease in the latency was due to a decline in the duration of force development. No significant differences were found between the two groups of subjects in any of these latency measurements (P > 0.05).

AL based on the extra force evoked during an MVC. Measurement of the extra force evoked during an MVC allowed the calculation of the AL for the biceps brachii muscle (see METHODS). Each data point in Fig. 5 represents the mean AL for a subject averaged from the one to three MVC trials. The mean AL was 95.0 ± 4.8% for the elderly group (with 1 subject at 100%) and 97.8 ± 2.6% for the young subjects (with 7 subjects at 100%). A one-tailed t-test performed for each group indicated that the mean AL was different from 100% for both groups (P < 0.0025), suggesting incomplete activation of the biceps brachii muscle. Also, the mean AL for the elderly group was significantly lower (P < 0.03) than the value for the group of young subjects.

Estimation of the expected MVC. The relationship between the evoked force and the target force for one young subject is shown in Fig. 6A. A visual inspection of this relationship indicates a greater decline in the magnitude of the evoked force at low target forces, with a trend for the evoked force to plateau at >60% MVC. A third-order polynomial was fitted to the data for each subject, and the x-intercept was extrapolated to identify the expected MVC. The expected MVC values obtained for each subject of both groups are presented in Fig. 7A. The mean expected MVC was 99.5 ± 9.9% for the young group (range 78.6–114.3%, n = 10) and 101.0 ± 7.4% for the elderly group (range 86.8–115.4%, n = 13). There were no significant differences between the two groups (P > 0.5) or for either group relative to 100% MVC (P > 0.5). On the basis of this analysis, both groups were able to achieve complete activation of the biceps brachii muscle during an MVC.

Even though the third-order polynomial regression appeared to be an appropriate curve-fitting method (r² = 0.96), an x-intercept could not be obtained for 9 subjects (6 young, 3 elderly). This limitation was overcome by linearizing the evoked force data (17) with the modification that the linearization factor (k; see METHODS) could vary for each subject. The resulting factors ranged from 0.408 to 1.499 for the young subjects and from 0.305 to 1.661 for the elderly subjects. An example of the normalized and linearized relationship, along with the 99% confidence interval, is presented in Fig. 6B. The expected MVC was estimated by extrapolation of the linearized fit for each subject to identify the x-intercept (Fig. 7B). The mean expected MVC obtained by this procedure was 100.4 ± 9.2% for the young subjects and 102.3 ± 14.4% for the elderly group. Again, there was no significant difference between the two groups (P > 0.5) or for either group relative to 100% MVC (P > 0.2). The main benefit of the linearization method is the assurance of obtaining an expected MVC value for every subject while retaining high regression values (mean r² = 0.94 for both groups). When the 99% confidence limits included the coordinate of 100%, zero (MVC, evoked force), this indicated that full activation of the muscle was achieved (Fig. 6B). This criterion was met by 9 of 16 young and 10 of 16 elderly subjects. However, the entire confidence interval was >100% for only three young and two elderly subjects, reinforcing the conclusion that young and elderly subjects were capable of a complete activation of the biceps brachii muscle. The average magnitude of the confidence intervals was 16.1 ± 7.2% for the young and 16.4 ± 7.7% for the elderly subjects.

There was a mixed association between AL and the expected MVC force (as determined by extrapolation) for the two groups of subjects. There was a strong negative correlation (r² = −0.61) between AL and the polynomial-based estimate of the expected MVC force for the young (P < 0.04) and elderly (P < 0.008).
subjects, matching a <100% AL with a >100% expected MVC force. In contrast, only the young subjects exhibited a significant correlation ($r^2 = -0.68, P < 0.005$) between AL and the linearization-based estimate of the expected MVC force. For the elderly subjects, the correlation was not significant ($r^2 = -0.08, P > 0.05$).

The expected MVC force was also estimated by excluding the data acquired when the stimulus was delivered during an MVC. The results obtained from the third-order polynomial regression produced an expected MVC force of 93.4 ± 4.6% for the young subjects (range 86.8–101.9%, $n = 9$) and 99.0 ± 4.5% for the elderly subjects (range 90.6–106.9%, $n = 12$). The mean expected MVC force was significantly <100% for the young group ($P < 0.001$) but not for the elderly group ($P > 0.05$). After linearization, the expected MVC force was 102.4 ± 19.4% for the young subjects and 102.6 ± 20.0% for the elderly subjects. These results were not significantly different from 100% ($P > 0.05$) and parallel the results obtained when the 100% MVC data were included in the regression analysis.

**DISCUSSION**

The primary finding of this study was a mixed effect of age on the ability of healthy adults to activate the biceps brachii muscle during an MVC. The two superimposition techniques yielded different conclusions regarding the ability of the young and elderly subjects to achieve maximal activation of the biceps brachii.

Fig. 4. A: evoked forces when stimulus was superimposed on contractions that ranged from 0 to 100% MVC, as performed by an older adult. Time of stimulation is indicated by vertical dotted line, and target force is indicated on left side of each trace. B: in 9 of 32 subjects, there was a depression in forces evoked at higher target forces. Traces are from a young subject, but this behavior was seen in young and elderly subjects.
was significantly <100% for both groups of subjects and that the elderly subjects exhibited a greater impairment. In contrast, the other technique, which was based on an extrapolated estimate of an expected MVC force, indicated that both groups of subjects were able to achieve complete activation of the biceps brachii.

Comparison of the superimposition techniques. The mean AL was 97.8% for the young subjects and 95.0% for the elderly subjects, with both values significantly <100% and with a significant difference between the two groups. These values are similar to those reported previously for biceps brachii. For example, Allen et al. (1) reported median scores for voluntary activation ranging from 90.3±2.3 to 99.8±0.3 (SD)% across five subjects. Although some of these values are statistically <100%, there is some uncertainty over the functional significance of this deficit. When Allen et al. (2) examined the elbow flexor muscles in subjects with prior poliomyelitis, they found significantly lower ALs in these subjects (90.6 and 92.2% for men and women, respectively) than in control subjects (95.7 and 97.3% for men and women, respectively), yet there was no difference in the MVC force. This suggests that either the subjects with prior poliomyelitis were potentially stronger or the estimate of AL is inaccurate. Because the second possibility is more likely, these data (2) seem to indicate that the deficit in AL can be at least 5% without an effect on MVC force.

Consistent with this interpretation, the results obtained with the extrapolation procedures in this study suggested that the young and elderly subjects were able to activate the biceps brachii muscle completely.
This conclusion was based on the lack of a statistically significant difference between the measured and expected MVC forces for each group of subjects. Because the extrapolation procedure relies on the use of evoked forces at multiple target forces (0–100%), this assessment of maximalism has a greater signal-to-noise ratio and is more accurate than that based on the measurement of an evoked force at a single target force (3, 17).

One of the concerns with the extrapolation technique, however, is the adequacy of the curve-fitting procedure that is used to estimate the expected MVC force. Because the relationship between evoked force and voluntary force is curvilinear (4, 8, 9, 19), the regression strategy must involve a nonlinear function (e.g., 3rd-order polynomial) or linearization of the data. For the nonlinear function approach, we found that a third-order polynomial provided a better least-squares fit to the data than a second-order polynomial. Although Behm et al. (3) used a second-order polynomial, it is unclear whether this function would have been adequate had the regression included the force evoked at 0% MVC. However, whatever the order of the polynomial function, as with an exponential function (9), the regression line does not always cross the x-axis and permit identification of an expected MVC force for all subjects. In contrast, linearization always produced an x-intercept value (expected MVC force) for each subject and still provided a reasonable least-squares fit to the data.

Age and activation capability. The assessment of AL in the ankle dorsiflexor muscles during an MVC performed by older adults has indicated no impairment when the superimposed stimulus involved a single pulse (7, 21) but a significant impairment when a train of stimuli was used (13). In contrast, Phillips et al. (17) linearized the forces evoked in the adductor pollicis muscle of four elderly subjects to estimate an expected MVC force and found no difference between that and the measured MVC force. Our results are consistent with both observations; there was an effect of age on AL but not on the ability to exert the expected MVC force. Although our AL results did indicate a statistically significant reduction of AL in the biceps brachii of older adults during an MVC, the functional significance of this difference seems questionable. Because of this uncertainty and the greater signal-to-noise ratio with the extrapolation technique, we conclude that the older adults we tested were able to achieve complete activation of the biceps brachii muscle by voluntary command.

Depression in evoked force. One of the inconsistent findings in the present study was the occasional presence of a depression in the evoked force, especially at the higher target forces (Fig. 4B). This response, which was exhibited by five young and four elderly subjects, is typically explained as being due to a collision between the antidromic volley and the efferent output (20), particularly when the superimposed stimulus has a duration that is greater than a few pulses. However, two observations in the present study cast doubt on this explanation. First, the force depression was not present in the responses of most subjects (23 of 32), despite a common superimposition stimulus. Second, the force depression was present in one subject (the only subject so tested) when the superimposition stimulus had a relatively long duration (10-pulse train) or a short duration (single pulse). Merton (15) suggested that some of the “silent period” (force depression) might be caused by an unloading of the muscle spindles, afterhyperpolarization of the motor neurons, or inhibition of motor neurons by Renshaw cells and Ib afferents. Some of the variability in the appearance of a force depression might be attributable to differences across subjects in the spread of current with percutaneous stimulation; stimulation over the muscle nerve produces a more consistent force depression (J. Duchateau, personal communication). However, we did not distinguish among these possibilities in the present study.

In conclusion, despite divergent results from the two superimposition techniques that were used to assess the ability of older adults to achieve maximal activation of the biceps brachii muscle, we conclude that this capability was not impaired with age. The MVC force that was exerted by the elbow flexor muscles of young and elderly subjects appeared to be similar to an expected value that was derived from multiple measurements in the evoked force-voluntary force domain. The decline in strength with age, therefore, does not appear to result from an impairment of the neural drive to muscle.

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