Muscle endurance is greater for old men compared with strength-matched young men

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Hunter, Sandra K., Ashley Critchlow, and Roger M. Enoka. Muscle endurance is greater for old men compared with strength-matched young men. J Appl Physiol 99: 890–897, 2005. First published May 5, 2005; doi:10.1152/japplphysiol.00243.2005.—The purpose was to compare the time to task failure for a sustained isometric contraction performed at a submaximal intensity with the elbow flexor muscles by young and old men who were matched for strength. Eight young men (18–31 yr) and eight old men (67–76 yr) sustained an isometric contraction at 20% of maximal voluntary contraction (MVC) torque until the target torque could no longer be achieved for at least 5 s. The maximal torque exerted at the wrist was similar for the young and old men before the fatiguing task (65.9 ± 8.0 vs. 65.4 ± 8.7 N·m; P > 0.05), and they experienced similar reductions in MVC torque after the fatiguing contraction (31.4 ± 10.6%; P < 0.05). The time to task failure was longer for the old men (22.6 ± 7.4 min) compared with the strength-matched young men (13.0 ± 5.2 min; P < 0.05), despite each group sustaining a similar torque during the fatiguing contraction (P > 0.05). The increases in torque fluctuations, electromyographic (EMG) bursting activity, and heart rate were greater for young men compared with the old men, and they were less at task failure for the old men (P < 0.05). Mean arterial pressure increased at a similar rate for both groups of men (P > 0.05), whereas the averaged EMG activity and rating of perceived exertion reached similar values at task failure for the young and old men (P > 0.05). These findings indicate that the longer time to task failure for the old men when performing the submaximal contraction was not due to the absolute target torque exerted during the contraction.

OLD ADULTS ARE OFTEN MORE fatigue resistant when performing sustained and intermittent contractions than young adults (6, 7, 11, 21, 22, 33, 38), although not always (2, 4, 21, 49, 50) (for review see Ref. 3). The mechanism responsible for the reduced fatigability may depend on the details of the task performed (3), but it appears to be located distal to the sarcolemma (29, 32, 39), although there may be a contribution by central mechanisms for some muscle groups (6, 10, 50).

In young adults, the time to failure for a sustained contraction is related to the absolute target force exerted during the task (23, 26), probably due to the stronger young adults experiencing greater intramuscular pressures (48), blood flow occlusion (5, 28), accumulation of metabolites, impairment of oxygen delivery to the muscle, and an earlier onset of task failure during a sustained contraction. When comparisons are made with weaker individuals, therefore, the lower absolute target force exerted may explain the longer time to failure, such as has been observed for old adults. Accordingly, Hunter et al. (22) found that the time to task failure for a group of young and old adults was inversely related to target force. However, when the times to failure for old adults (men and women) were analyzed separately, there was no relation between target force and time to failure, which suggests that age-related reductions in strength may have a limited role in muscle fatigability of old adults.

These observations led to the following question: What is the contribution of the reduction in strength to the increased fatigability exhibited by old adults during a sustained submaximal contraction? The purpose of this study was to compare the time to failure for a sustained isometric contraction performed at a submaximal intensity with the elbow flexor muscles by young and old men who were matched for strength. Strategies used by subjects to perform the task were characterized by the measurement of electromyographic (EMG) activity of various muscles, mean arterial pressure (MAP), heart rate, and fluctuations in motor output during the fatiguing contraction.

METHODS

Eight young men (21.5 ± 4.4 yr; range, 18–31 yr; 176 ± 5 cm, and 65 ± 5 kg) and 8 old men (71.3 ± 2.9 yr; range, 67–76 yr; 181 ± 6 cm, and 81 ± 13 kg) volunteered to participate in the study. All subjects were healthy with no known neurological or cardiovascular diseases and were naive to the protocol. Before participation in the study, each subject provided informed consent, and the Human Subjects Committee at the University of Colorado approved the protocol.

The physical activity level for each subject was assessed with a questionnaire (36) that estimated the relative kilocalorie expenditure of energy per week. Arm dominance was estimated using the Edinburgh Handedness Inventory (45); all subjects were right handed.

Mechanical Recording

Subjects were seated upright in an adjustable chair with the nondominant arm abducted slightly and the elbow resting on a padded support. The elbow joint was flexed to 1.57 rad so that the forearm was horizontal to the ground and the force at the wrist was directed upward when the elbow flexor muscles were activated during a voluntary contraction. Two nylon straps were placed vertically over each shoulder to restrain the subject and minimize shoulder movement. The hand and forearm were placed in a modified wrist-hand-thumb orthosis (Orthomerica, Newport Beach, CA), and the forearm was placed midway between pronation and supination. The forces exerted by the wrist in the vertical and horizontal (side-to-side) directions were measured with a force transducer (Force-Moment...
Sensor, JR-3, Woodland, CA) that was mounted on a custom-designed, adjustable support. The orthosis was rigidly attached to the force transducer. The forces detected by the transducer were recorded on line using a Power 1401 A-D converter and Spike2 software [Cambridge Electronics Design (CED), Cambridge, UK]. The force exerted in the vertical direction was displayed on a 17-in. monitor located 1.5 m in front of the subject. The force signal was digitized at 500 samples/s.

**Electrical Recordings**

EMG signals were recorded with bipolar surface electrodes (Ag-AgCl, 8-mm diameter; 16 mm between electrodes) that were placed over the long head of biceps brachii, the short head of biceps brachii, brachioradialis, and triceps brachii muscles. Reference electrodes were placed on a bony prominence at the elbow or shoulder. The EMG of the brachialis muscle was measured with an intramuscular bipolar electrode comprised of two stainless steel wires (100-μm diameter) that were insulated with Formvar (California Fine Wire, Grover Beach, CA). Intramuscular recordings were necessary for brachialis because of the contamination of surface recordings by volume-conducted signals from more superficial muscles. One wire in each pair had the insulation removed for ~2 mm to increase the recording volume of the electrode. The electrode was inserted into the muscle 4–5 cm proximal to the antecubital fold with a hypodermic needle that was removed immediately after insertion. A surface electrode (8-mm diameter) placed on a bony prominence served as the reference electrode. The EMG signal was amplified (500–2,000×) and band-pass filtered (13–1,000 Hz for the surface and intramuscular EMG signals) with Coulbourn modules (Coulbourn Instruments, Allentown, PA) before being recorded directly to computer using the Power 1401 A-D converter (CED) and displayed on an oscilloscope. The EMG signals were digitized at 2,000 samples/s.

**Cardiovascular Measurements**

Heart rate and blood pressure were monitored during the fatiguing contractions because these adjustments involve both central and peripheral processes (14, 18, 42, 47). Heart rate and blood pressure were monitored with an automated beat-by-beat, blood pressure monitor (Finapres 2300, Ohmeda, Madison, WI). The blood pressure cuff was placed around the middle finger of the relaxed, dominant hand with the arm placed on a table adjacent to the subject at heart level. The blood pressure signal was recorded online by a computer at 500 samples/s.

**Experimental Protocol**

Each subject visited the laboratory for an introductory session to become familiar with the equipment and perform maximal voluntary contractions (MVC) and to participate in one experimental session. The protocol for the experiment comprised an assessment of the MVC force for the elbow flexor and elbow extensor muscles, determination of the EMG-force relations for the elbow flexor muscles, and performance of a fatiguing contraction. Within 10 s of completing the fatiguing contraction, an MVC was performed with the elbow flexor muscles.

**MVC torque.** Each subject performed three MVC trials with the elbow flexor muscles, followed by three trials with the elbow extensor muscles. The MVC task consisted of a gradual increase in force from zero to maximum over 3 s, with the maximal force held for 2–3 s. The force exerted by the wrist was displayed on a monitor, and each subject was verbally encouraged to achieve maximal force. There was a 60-s rest between trials. If the peak forces from two of the three trials were not within 5% of each other, additional trials were performed until this was accomplished. The greatest force achieved by the subject was taken as the MVC force and used as the reference to calculate the 20% target level for the fatiguing contraction. The MVC torque was calculated as the product of MVC force and the distance between the elbow joint and the point at which the wrist was connected to the force transducer.

**EMG activity.** The EMG activity of the involved muscles was recorded in standardized tasks so that the EMG-torque relation could be compared between the young and old men in the nonfatigued state. Each subject performed a sustained constant-torque contraction with the elbow flexor muscles for 6 s at target values of 20, 40, and 60% MVC. The subject was given a 30-s rest between each contraction. These relations for the two groups of subjects were examined to ensure that changes in EMG during the fatiguing contraction represented physiological adjustments and were not due to differences in recording conditions between the two groups.

**Fatiguing contraction.** The fatiguing contraction of the elbow flexor muscles was performed at a target value of 20% MVC torque. The subject was required to match the target torque as displayed on the monitor and was verbally encouraged to sustain the torque for as long as possible. The fatiguing contraction was terminated when either the torque declined by 10% of the target value for greater than ~5 s or when the subject lifted the elbow off the support for greater than ~5 s, despite strong verbal encouragement to maintain the task. Neither the subject nor the investigator who terminated the task knew the time during the task.

An index of perceived effort, the rating of perceived exertion (RPE), was assessed with the modified Borg 10-point scale (8). The subjects were instructed to focus the assessment of effort on the arm muscles performing the task. The scale was anchored so that 0 represented the resting state and 10 corresponded to the strongest contraction that the arm muscles could perform. The RPE was measured at 30-s intervals during the fatiguing contraction.

**Data Analysis**

All data collected during the experiments were recorded on line using a Power 1401 A-D converter (CED) and analyzed offline using the Spike2 data-analysis system (CED).

The MVC torque was quantified as the peak value achieved during the MVC. Similarly, the maximal EMG for each muscle was determined as the average value over a 0.5-s interval that was centered about the peak rectified EMG. The rectified EMG of the constant-torque contractions for the elbow flexor muscles performed at 20, 40, and 60% of MVC torque was averaged over the middle 4 s of the 6-s contraction.

The fluctuations in torque during the fatiguing contraction were quantified in the vertical direction as the coefficient of variation (CV) for torque (SD/mean × 100) for the first 30 s; 15 s on both sides of 25, 50, and 75% of time to task failure; and the last 30 s of the task duration.

The EMG activity of the elbow flexor muscles and elbow extensor muscles during the fatiguing contraction was quantified in two ways: 1) for statistical purposes, as averages of the rectified EMG (AEMG) over the first 30 s; 15 s on both sides of 25%, 50%, and 75% of time to task failure; and the last 30 s of the time to task failure for the fatiguing contraction; and 2) for graphic presentation, as the AEMG for every 1% of the time to task failure. The EMG was normalized to the peak EMG obtained during the MVC.

Low-intensity contractions of long duration are characterized by bursts of EMG activity, which were quantified by the process described previously (23, 27). The rectified EMG signal was 1) smoothed with a low-pass filter at 2 Hz for surface EMG signals and at 3.8 Hz for the intramuscular EMG (brachialis), 2) differentiated over five-point averages, and 3) divided by the average of the rectified EMG so that muscles with different EMG amplitudes could be compared. The differentiated signal represents the rate of change for the low-pass-filtered EMG signal and was used to identify rapid changes in the EMG signal. A burst was identified when the smoothed, differentiated EMG signal increased by more >0.20 s⁻¹.
for the surface EMG and >0.23 s\(^{-1}\) for the intramuscular EMG. These values represented 3 SDs above the mean of the smoothed, differentiated EMG signal. The 3-SD criterion was based on EMG records from a subset of fatiguing contractions of the present data set when the EMG signal displayed minimal bursting during the contraction. The end of a burst was identified as the time when the smoothed EMG signal decreased to the same amplitude as at the start of the burst. When the EMG signal did not decline to the same EMG amplitude at the start of the burst, however, the end of the burst was then identified as the time that the differentiated EMG signal became most negative before the start of the next burst. This criterion represented the time at which the signal decreased most rapidly before the beginning of the next burst. The start of a second burst was constrained to be >2 s apart from the previous burst, and the minimal burst duration was 0.5 s.

Heart rate and MAP recorded during the fatiguing contraction were analyzed by comparing ~15-s averages at 25% intervals throughout the fatiguing contraction. For each interval, the blood pressure signal was analyzed for the mean peaks [systolic blood pressure (SBP)], mean troughs [diastolic blood pressure (DBP)], and the number of pulses per second (multiplied by 60 to determine heart rate). MAP was calculated for each epoch with the following equation: MAP = DBP + 1/3(SBP − DBP).

**Statistical Analysis**

Data are reported as means ± SD within the text and displayed as means ± SE in the figures. Separate analysis of variances (ANOVA, SPSS version 12.0) were used to compare the time to task failure and percent decline in MVC torque between the old and young men. Separate ANOVAs (age × time) with repeated measures on time were used to compare the dependent variables of heart rate, MAP, RPE, CV of torque, EMG-torque relation for the 6-s constant-torque contractions, EMG burst rate, and AEMG during the fatiguing contraction. Consequently, each age group was included in the one ANOVA for each variable. Post hoc analyses (Tukey) were used to test for differences among groups and time intervals when appropriate. Because EMG bursts were sometimes absent during a one-third interval of the task for some subjects, averages of the burst duration are reported, and the results of independent \(t\)-tests are indicated where these analyses were possible. Independent \(t\)-tests were used to test for differences among pairs of means when appropriate; a Bonferroni correction for statistical significance was used in these instances. Associations were determined between some variables using Pearson’s correlation analysis. A significance level of \(P < 0.05\) was used to identify statistical significance, except when modified by the Bonferroni correction.

**RESULTS**

There was a trend for the old men to be less physically active compared with the young men \([51 ± 41 \text{ metabolic equivalents (MET)}\cdot\text{h/ wk vs. } 132 ± 115 \text{ MET}\cdot\text{h/ wk}; \ P = 0.08]\), but this did not reach statistical significance because of the large variance within groups.

**MVC Torque and Time to Task Failure**

The eight young men and eight old men were matched for strength within 5% of maximal torque of the elbow flexor muscles (Fig. 1A). The maximal torque exerted at the wrist was similar for the young \((65.9 ± 8.0 \text{ N m})\) and old men \((65.4 ± 8.7 \text{ N m})\) before the fatiguing task \((P > 0.05)\), which meant that the average torque exerted during the fatiguing contraction was similar for the two groups. Although the moment arm for the old men \((27.0 ± 0.9 \text{ cm})\) was slightly longer than for the young men \((26.1 ± 0.4 \text{ cm}; \ P < 0.05)\), the maximal force exerted at the wrist was similar for both groups \((P < 0.05)\). After the fatiguing contraction, the groups of men showed similar and significant reductions in MVC strength \((31.4 ± 10.6\% ; \ P < 0.05)\). However, the time to task failure was longer for the old men \((22.6 ± 7.4 \text{ min})\) compared with the strength-matched young men \((13.0 ± 5.2 \text{ min}; \ P < 0.05; \text{Fig. 1B})\).

**EMG-Torque Relation**

The AEMG (% peak EMG) for the elbow flexor muscles was determined during isometric contractions held at 20, 40, and 60% of MVC. AEMG increased similarly with contraction intensity for the young and old strength-matched men \((P < 0.05)\). For the elbow flexor muscles, the AEMG for the 20, 40, and 60% of MVC was 10.7 ± 3.4, 28.6 ± 7.2, and 52.6 ± 11.6%, respectively, for the young men and 14.8 ± 5.0, 29.7 ± 7.8, and 51.6 ± 7.8% for the old men. The AEMG of the brachialis muscle was significantly greater than the other elbow flexor muscles at the 20 and 40% contraction (muscle × force
interaction; \( P < 0.05 \), but this difference was similar for both groups of men. Because the EMG-force relations for the young and old men were similar across the muscles and contraction intensity, any differences in EMG during the fatiguing contraction represented physiological adjustments and were not due to differences in recording conditions between the two groups.

**AEMG During the Fatiguing Contraction**

The amplitude of the AEMG (% peak EMG) for each elbow flexor muscle increased during the fatiguing contraction for the young and old men \( (P < 0.05; \) Fig. 2). The AEMG for the elbow flexor muscles pooled was similar for the young and old men at the start (11.3 ± 8.8 and 14.9 ± 8.9%) and end (32.2 ± 14.6 and 31.6 ± 14.5%) of the fatiguing contraction. Because the old men had a longer time to failure, however, the rate of increase in AEMG for the old men was less for all muscles compared with the young men \( (P < 0.05) \).

The AEMG differed across muscles \( (P < 0.05) \). The AEMG for the entire contraction for brachialis \( (27.7 ± 11.1\%) \) was greater \( (P < 0.05) \) than the other elbow flexor muscle for both the young and old men, including the short head of biceps brachii \( (16.0 ± 4.2\%) \) and long heads of biceps brachii \( (20.4 ± 4.3\%) \) and brachioradialis \( (21.1 ± 8.5\%) \). Furthermore, the AEMG of the biceps brachii was less than all the other elbow flexor muscles for both the young and old men \( (P < 0.05) \). The triceps brachii was activated during the fatiguing contractions, but the AEMG was considerably less than for the elbow flexor muscles \( (P < 0.05; \) Fig. 2; \( P < 0.05) \). The triceps brachii increased to similar amplitudes for the young and old men during the fatiguing contraction from 2.1 ± 1.4% at the start of the contraction to 3.6 ± 1.8% at the conclusion \( (P < 0.05) \).

**Bursts of EMG Activity During the Fatiguing Contraction**

There was a progressive increase in the number of bursts in EMG activity during the fatiguing contraction for the young and old men \( (P < 0.05) \). However, a time \( \times \) age interaction \( (P < 0.05) \) indicated that the young men had greater EMG bursting activity compared with the old men for the middle and last third of the contraction \( (P > 0.05; \) Fig. 3A). The increase in burst rate was similar among the elbow flexor muscles \( (P > 0.05; \) Fig. 3, B and C).

The burst duration was similar \( (P = 0.2) \) for the young \( (4.4 ± 2.2\ s) \) and old men \( (6.2 ± 5.4\ s) \) when all the elbow flexor muscles were pooled. The burst duration did not differ across the fatiguing contractions for either group \( (P > 0.05) \), and it was similar among the elbow flexor muscles: short head of biceps brachii \( (6.0 ± 3.3\ s) \), long head of biceps brachii \( (6.4 ± 5.0\ s) \), brachioradialis \( (5.0 ± 2.5\ s) \) and brachialis \( (3.9 ± 3.0\ s) \).

**RPE During the Fatiguing Contraction**

RPE increased during the fatiguing contraction \( (P < 0.05) \), but it was similar for old and young men at the beginning and end of the fatiguing contraction \( (P > 0.05) \). The RPE values progressed for the young and old men from 1.4 ± 1.1 and 1.3 ± 0.8, respectively, at the start of the contraction to 5.1 ± 1.3 and 6.4 ± 2.2 at 25% of time to failure, 7.9 ± 1.1 and 7.9 ± 1.9 at 50% of time to failure, 9.4 ± 0.7 and 9.4 ± 0.7 at 75% of time to failure, and 10 ± 0.0 for both groups at task failure. However, the rate of increase in the RPE was more gradual for the old adults because of the longer duration of the contraction.

**Fluctuations in Torque During the Fatiguing Contraction**

The normalized amplitude of the vertical fluctuations in torque \( (CV) \) increased for the young and old men \( (P < 0.05) \). However, the amplitude of the fluctuations was greater at task failure for the young men than for the old men, and the fluctuations for the young men increased at a greater rate \( (P < 0.05; \) Fig. 4). The young men increased by 226 ± 135% from the first 30 s to the last 30 s of the fatiguing contraction, whereas the old men increased to 162 ± 84%. There was a positive association between the absolute increases in CV for torque and the burst rate of EMG throughout the contraction \( (r^2 = 0.68; n = 16; P < 0.05) \), indicating that 68% of the increase in the torque fluctuations was explained by the increase in EMG burst rate.

**MAP and Heart Rate**

MAP increased during the fatiguing contractions for the young and old men \( (P < 0.05; \) Fig. 5A). There was no main effect for age, indicating that the MAP was similar for the young and old men \( (P > 0.05) \). At task failure, MAP was 137 ± 18 mmHg for the young men and 142 ± 11 mmHg for the old men \( (P > 0.05) \). Furthermore, the rate of rise in MAP was not different \( (P = 0.09) \) between the young \( (3.2 ± 1.8 \) mmHg/min) and old men \( (1.8 ± 1.0 \) mmHg/min), despite differences in the time to failure.

Heart rate also increased during the fatiguing contraction for the young and old men \( (P < 0.05; \) Fig. 5B). There was a
time × age interaction \((P < 0.05)\) because heart rate was similar at the start of the task for the young \((82 ± 13\) beats/min) and old men \((75 ± 13\) mmHg/min), but it was greater for the young men \((107 ± 16\) beats/min) at task failure compared with the old men \((93 ± 15\) mmHg/min). Accordingly, heart rate increased at a lower rate \((P < 0.05)\) for the old

Fig. 3. Burst rate of the rectified EMG of the elbow flexor muscles during the fatiguing contractions. Values are means ± SE for the first third, middle third, and last third of the time to task failure for the elbow flexor muscles. A: old men had a lower burst rate compared with the young men \((P < 0.05)\). B and C: burst rate of the individual elbow flexor muscles for the young \((B)\) and old men \((C)\).

Fig. 4. Fluctuations in torque in the vertical direction were quantified as the coefficient of variation (CV) for the torque exerted at the wrist. Mean \((±\) SE) CV of the torque is shown for the young and old men for 30-s intervals at the beginning and 25, 50, 75, and 100% of the time to task failure. CV was less for the old men compared with the strength-matched young men during the contraction and at failure of the task \((P < 0.05)\).

Fig. 5. Changes in mean arterial pressure (MAP) and heart rate during the fatiguing contraction for the young and old men. Values are means ± SE of 15-s intervals at 25% increments of the time to task failure. The increase in MAP \((A)\) was similar for the young and old strength-matched men \((P > 0.05)\), but the increase in heart rate \((B)\) was greater for the young men \((P < 0.05)\).
men (0.8 ± 0.3 beats/min) compared with the young men (2.2 ± 1.5 beats/min).

**DISCUSSION**

The purpose of this study was to compare the time to task failure for a sustained isometric contraction performed at a submaximal intensity with the elbow flexor muscles by young and old men who were matched for strength. The main finding was that the time to task failure was longer for the old men, despite similar target torques and reductions in the MVC torque performed after the fatiguing task. The two groups of men started and ended the contraction at similar values for MAP, AEMG, and RPE. However, the fluctuations in torque, bursting activity of the EMG signal, and heart rate were lower at task failure for the old men compared with the young men. Thus it appears that the contribution of strength to the age-related decrease in muscle endurance for this task is limited.

The difference in time to task failure between the young and old men was not due to a difference in motivation or relative performance. The decline in maximal strength (MVC force) recorded after task failure, which is the consensus index for the amount of fatigue experienced during physical activity (16), was similar for the young and old strength-matched men. Furthermore, the effort exerted at task failure (indicated by the RPE) was similar for the two groups.

In young adults, the longer time to task failure for a sustained contraction performed by a group of women, who were weaker than a group of men, was primarily explained by the absolute force exerted when performing a submaximal fatiguing contraction (20, 23, 26). In the present study, however, two groups of subjects with comparable strength exhibited marked differences in the time to task failure. Young men were only able to sustain the task for 42% of the duration achieved by the strength-matched old men. This age-related difference in the time to failure is consistent with results obtained previously when young men, who were 40% stronger than the old men, could sustain the submaximal contraction for 37% of the duration achieved by the old men (22). The present results indicate that the longer time to failure for the old adults was not due to differences in absolute strength.

Some clues to the potential physiological mechanisms that can account for the difference in the time to failure are suggested by the variables that were measured during the fatiguing task. There was no difference between the two groups in either the initial and final values for MAP or its rate of increase. Consequently, those peripheral and central regulatory mechanisms (14, 31, 42, 47) that attempt to sustain muscle perfusion during a sustained contraction operated at similar levels for the strength-matched young and old men. In contrast, average EMG and RPE began and ended at similar values for the two groups of subjects, but the rates of increase were greater for the young men. Furthermore, the rate of increase in heart rate, and the final values of the old men at task failure, were less than those for the young men. Although heart rate is controlled primarily by central command (1, 17, 18) during a fatiguing contraction, the lesser heart rate for the old men at task failure may be explained by the decline in maximal heart rate that occurs with advancing age (15). Consistent with these findings, others reported similar results for a fatiguing contraction indicating that the differential increase in heart rate between young and old adults did not influence the time to failure (49).

Despite a similar torque exerted during the contraction, the old men exhibited a slower rate of rise in the average EMG compared with the young men, although the values at task failure were similar for each group. The relative EMG activity was similar in the young and old men when compared for nonfatiguing contractions at various intensities of contraction. Thus the different EMG activity at the same absolute time during the task for the young and old men indicated different rates of either recruitment or alterations in discharge rate for the two groups of men. In young adults, the increase in EMG activity during a low-force fatiguing contraction is largely due to recruitment of larger motor units as the muscle becomes progressively fatigued, with minimal contribution from discharge rate (9, 13, 19, 41, 44). When young and old adults exert a similar relative submaximal force, the old adults can have reduced discharge rates (46) but not always (30). If the change in discharge rates were similar for the young and old men during the task, then the EMG recordings suggest that recruitment of the motor unit pool was likely more gradual for the old men. Because the AEMG was similar at task failure, it is likely that a similar proportion of the motor unit pool was recruited by the two groups of men during the contraction (13, 19, 44). However, the difference in bursts of EMG activity indicates that the young men had to rely more on the transient recruitment of motor units (24, 25, 35) to sustain the task. Presumably, the additional motor units that were activated for brief bursts of activity were necessary to compensate for the decline in the force capacity of the active muscle fibers. Given the preferential loss of type II fiber area that has been observed in old adults (29, 34, 39, 40), perhaps the old men experienced a more gradual reduction in the force capacity of the active muscle fibers, which were likely to have greater oxidative capacity.

One consequence of the greater EMG bursting activity was a more rapid increase in the torque fluctuations for the young men ($r^2 = 0.68$). The amplitude of the fluctuations in torque increased more rapidly for the young men and was greater at task failure for the young men compared with the old men, even though the target torque and decline in maximal force capacity (fatigue) was similar for both groups. At the start of the isometric contractions, the old men had greater fluctuations in torque than the young men (Fig. 4), as has been observed in other isometric tasks for young and old adults (12). The greater amplitude of torque fluctuations for the old adults is likely due, at least in part, to a more variable discharge rate of the active motor units (37, 51). In contrast, the young men had a much greater increase in fluctuations of torque as fatigue developed during the sustained contraction, which probably reflects a more rapid rate of recruitment of higher threshold motor units that have greater discharge rate variability (43) during the task and at task failure.

In conclusion, the time to task failure for a submaximal contraction with the elbow flexor muscles was longer for old men compared with strength-matched young men. Measurements of fluctuations in torque and EMG suggest that motor unit activity increased most rapidly during the fatiguing contraction for the young men. Consequently, the mechanisms responsible for the longer time to failure for the old men were...
not related to strength but seemed to involve a reduced need for the transient recruitment of motor units.

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