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Time to Task Failure Differs with Load Type when Old Adults Perform a Submaximal Fatiguing Contraction

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Abstract

Young adults exhibit a longer time to task failure when performing a submaximal isometric contraction by pushing against a force transducer (force task) than when supporting an equivalent inertial load (position task).

The purpose of this study was to compare the time to failure for old adults when they performed a force task and a position task with the elbow flexor muscles. Eighteen old adults (72 ± 4 years) performed the force and position tasks at 20% maximal voluntary contraction (MVC) force until task failure. The time to task failure was briefer for the position task (10.6 ± 6.1 min) than the force task (22.8 ± 9.1 min, $P < 0.05$). The rate of increase in electromyographic (EMG) bursting activity, ratings of perceived exertion, mean arterial pressure, heart rate, and fluctuations in motor output during the fatiguing contraction were greater for the position task. However, the increase in averaged EMG for the elbow flexor muscles was greater at termination of the force task. The difference in time to failure for the two tasks was due to a higher level of central neural activity during the position task and was similar to that observed for young adults. These findings indicate that the type of load supported influences the mechanisms and time to task failure for sustained contractions in old adults, and have implications for the design of tasks for rehabilitation and for tasks that minimize fatigue. Muscle Nerve, 2005

When an individual sustains a submaximal contraction, the gradual reduction in force capacity of the muscle due to impairment of neural and muscle processes eventually causes task failure.[11, 28, 29, 37] The rate of impairment varies with the type of task performed. Young adults, for example, exhibit a longer time to task failure when performing a submaximal isometric contraction by pushing against a force transducer (force task) than when supporting an equivalent inertial load (position task).[19, 20, 22] Despite a similar load torque for the two tasks, the briefer time to task failure for the position task is attributable to more rapid recruitment of the motor unit pool.[30, 33]

Age-related changes in the neuromuscular system purportedly increase its susceptibility to impairment during a fatiguing contraction.[2] For example, sites proximal to the neuromuscular junction may limit the force capacity of muscle during a voluntary contraction more in old than young adults.[3, 4, 38] Nonetheless, old adults seem to be less fatigable than young adults when performing both isometric and dynamic contractions,[27] which vary in their demands, perhaps due to a more gradual impairment of mechanisms distal to the sarcolemma.[8, 17, 27] Given the significant decline in motor unit number with advancing age,[14, 39] however, the advantage of age in sustained fatiguing contractions may disappear in tasks that are limited by neural adjustments.

The purpose of this study was to compare the time to failure for old adults performing submaximal isometric contractions with the elbow flexor muscles when the wrist was attached to a force transducer (force task) and when the wrist supported an equivalent inertial load (position task). We hypothesized that, despite fewer motor units in the involved muscles, old adults would exhibit a longer time to failure for the force task compared with the position task, and that this difference would be similar to that observed in young adults. The central neural activity underlying the performance of the tasks was characterized with measures of motor output and cardiovascular adjustments. Some of these results have been presented in preliminary form.[21]

METHODS

Eighteen old adults (8 women, 10 men; 65–80 years) volunteered to participate in the study. All subjects were healthy with no known neurological or cardiovascular diseases and were naive to the protocol. Prior to participation in the study, each subject provided informed consent, and the institutional review board approved the protocol.

The physical activity level for each subject was assessed with a questionnaire that estimated the relative kilocalorie expenditure of energy per week.[26] All subjects were right-handed as estimated using the Edinburgh Handedness Inventory.[34] None of the women was on hormone replacement therapy and all had been postmenopausal for at least 10 years.

Subjects reported to the laboratory on three occasions: once for a familiarization session followed by two experimental sessions that were 7–10 days apart, to perform a protocol that focused on a fatiguing contraction with the elbow flexor muscles of the nondominant arm. In one experimental session, the fatiguing contraction involved maintaining a force that was equal to 20% of the maximal voluntary contraction (MVC) force for as long as possible (force task). In the other session, the fatiguing contraction involved maintaining the elbow joint at a right angle while supporting an inertial load equivalent to the 20% MVC force (position task). The order of the tasks was randomized across subjects. The load torque applied at the wrist for the two tasks was identical for each subject. The subject was provided with visual feedback of the force exerted by the wrist during the force task and of the elbow angle during the position task. For both tasks, the subject was required to sustain the fatiguing contraction for as long as possible.

Mechanical Recordings.

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 90° 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 transducer (JR-3 Force-Moment Sensor; JR-3, Inc., 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, Cambridge, UK). The force exerted in the vertical direction was displayed on a 17-inch monitor located 1.5 m in front of the subject.

Elbow angle during the position task was measured with an electrogoniometer (XM110 and K100; Penny & Giles, Cwmfelinfach, Gwent, UK) taped to the lateral side of the elbow joint. The output was recorded on-line using a Power 1401 A-D converter and Spike2 software and then displayed on the monitor. The subject's hand and forearm were placed in a modified wrist–hand–thumb orthosis and an inertial load equivalent to 20% of MVC force was suspended from the wrist, at the site that contacted the force transducer. Two uniaxial accelerometers (7265A-HS; Endevco, San Juan Capistrano, CA) were mounted on a right-angled aluminum platform secured to the orthosis near the thumb. The accelerometers were aligned to record acceleration in the vertical and horizontal directions. The accelerations were recorded on-line using a Power 1401 A-D converter and Spike2 software.

In addition to the force exerted at the wrist, the force under the elbow joint was measured with a load cell (L2761 100lb; Futek Advanced Sensor Technology, Irvine, CA) placed under the padded elbow support, displayed on an oscilloscope, and recorded on-line. The force, position, and acceleration signals were all digitized at 500 samples/s.

Electrical Recordings.

Electromyographic (EMG) signals were recorded with bipolar surface electrodes (Ag—AgCl, 8-mm diameter; 16 mm between electrodes) that were placed over the biceps brachii (long and short heads), 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 that comprised two stainless-steel wires (100-µm diameter) insulated with Formvar (California Fine Wire Co., Grover Beach, CA). Intramuscular recordings were made because the brachialis lies beneath the biceps brachii and typically has a limited muscle area close to the skin to secure recordings that are not contaminated by other muscle activity. One wire in each pair had the insulation removed for about 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 (500–2000-fold) and bandpass filtered (13–1000 HZ for the surface and intramuscular EMG) with Coulbourn modules (Coulbourn Instruments, Allentown, PA) prior to being recorded directly to computer using the Power 1401 A-D converter (CED, Cambridge, UK) and displayed on an oscilloscope. The EMG signals were digitized at 2000 samples/s.

Cardiovascular Measurements.

Heart rate and blood pressure were monitored during the fatiguing contractions because these adjustments involve both central and peripheral processes.[32, 35] Both 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 on-line to the computer at 500 samples/s.

Experimental Protocol.

The protocol for each experimental session 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, performance of a fatiguing contraction, and a subsequent MVC with the elbow flexor muscles.

MVC Force.

Each subject performed three MVC trials with the elbow flexors, followed by three trials with the elbow extensors. 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 and the visual gain was varied between trials. When 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 subsequent target level for the constant-force and fatiguing contractions for the elbow flexors. Peak EMG was recorded from the MVC for the elbow flexors and extensors and used to normalize the average EMG recorded during the fatiguing contraction.

EMG Activity.

The EMG activity of the involved muscles was recorded in standardized tasks so that the force–EMG relation could be compared across experimental days. The subject performed a sustained constant-force contraction with the elbow flexor muscles for 6 s at target values of 20%, 40%, and 60% MVC force, with a 30-s rest between each contraction. The order of the contractions was randomized across subjects, but remained constant for each subject on the two experimental days.

Fatiguing Contraction.

The fatiguing contractions with the elbow flexor muscles were performed at a target value of 20% MVC force for the force task and with a load equivalent to 20% MVC for the position task. The subject was required to match the vertical target force as displayed on the monitor for the force task and was verbally encouraged to sustain the force for as long as possible. The fatiguing contraction was terminated when either the force declined by 10% of the target value or the subject lifted the elbow off the support for >5 s, despite encouragement to maintain the task. This time was recorded as the time to task failure for the force task. The position task was terminated when either the elbow angle declined by 26° from a right angle or when the subject lifted the elbow off the support for >5 s, despite encouragement. This time was recorded as the time to task failure for the position task. Subjects were not informed of their time to task failure until completion of the second session. Neither the subject nor the investigator who terminated the task knew the time during the tasks.

An index of perceived effort, the rating of perceived exertion (RPE), was assessed with the modified Borg 10-point scale.[5] 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.

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

The fluctuations in force during the force task and in acceleration during the position task were quantified 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 amplitude of the force fluctuations was quantified as the coefficient of variation (CV = SD/mean × 100) and the fluctuations of acceleration for the position task were characterized as the standard deviation (SD) of acceleration.

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 1% of the time to task failure intervals. The EMG was normalized to the peak EMG obtained during the MVC.

To quantify the bursts of EMG activity, 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 5-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 $>0.20\ s^{-1}$ for the surface EMG and $0.23\ s^{-1}$ for the intramuscular EMG. These values represented 3 SD above the mean of the smoothed, differentiated EMG signal. The 3-SD criterion was based on EMG records from 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 this failed to occur, however, the end of the burst was identified as the time when the differentiated EMG signal became most negative prior to 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 mean arterial pressure (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: $\text{MAP} = \text{DBP} + \frac{1}{3}(\text{SBP} - \text{DBP})$.

Statistical Analysis.

Data are reported as means (± SD) within the text, and displayed as means (± SE) in the figures. Separate analyses of variance (ANOVAs) were used to compare the time to task failure and percent decline in MVC force across the fatiguing tasks. Multifactorial ANOVAs with repeated measures on time and task were used to compare the dependent variables of MVC force, heart rate, MAP, RPE, fluctuations in motor output, EMG–force relation for the 6-s constant-force contractions, and EMG burst rate and AEMG during the fatiguing contraction. Post hoc analyses (Tukey–Kramer) were used to test for differences among pairs when appropriate. Because EMG bursts were sometimes absent during a one-third interval of the time to task failure, 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. Paired *t*-tests were used to test the rates of increase in averaged EMG, MAP, and heart rate. 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

MVC Torque and Time to Task Failure.

MVC force performed in the force-task session (180 ± 55 N) was similar to that in the position-task session (178 ± 61 N, $P > 0.05$), indicating that similar net torques were exerted by the limb during the two fatiguing contractions. The decline in MVC force performed after the fatiguing contraction (29 ± 12%) was similar for force (125 ± 37 N) and position (128 ± 50 N, $P > 0.05$) tasks, indicating that the old adults were fatigued to similar magnitudes after the two fatiguing tasks.

Despite the similar net muscle torque exerted for each task, comparable criteria for termination of tasks, and equivalent reductions in MVC force after the fatiguing contraction, the time to failure for the force task (22.8 ± 9.1 min) was twice as long as that for the position task (10.6 ± 6.1 min, $P < 0.05$; Fig. **1**). The fatiguing contractions were terminated when the net muscle torque exerted by the subject declined by >1.5% of MVC (equivalent to 10% of target force) for >5 s. The position task was most often terminated by an abrupt inability to maintain the forearm in a horizontal position, and the force task by a slow reduction in the ability to generate the required force. There was no main effect for gender and no interaction between task and gender ($P > 0.05$); thus, the men and women had similar times to task failure for the force task (24.1 ± 8.1 and 21.3 ± 10.6 min, respectively) and position task (9.3 ± 6.0 and 12.2 ± 6.4 min).

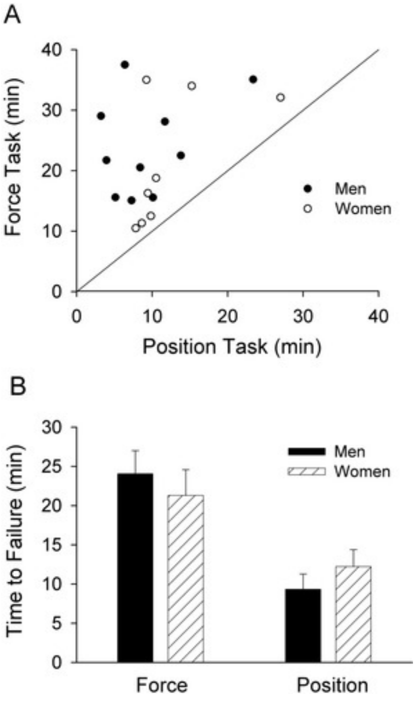

Figure 1

Time to task failure for old men (*n* = 10) and women (*n* = 8) for a force task and a position task. (**A**) The time to task failure for the individual subjects for the two tasks. Data above the line of identity indicate that the time to failure for the force task was longer than for the position task. (**B**) Mean (± SE) time to task failure for the force task was longer than for the position task ($P < 0.05$) for men and women.

The average force exerted under the elbow during the fatiguing contraction was similar for the force (14.3 ± 11.1 N) and position (19.7 ± 25.2 N, $P > 0.05$) tasks. The change in elbow force during the tasks was described by a quadratic function, indicating that the force increased toward the end of the fatiguing contraction ($P < 0.05$). There were no interactions between task, time, and gender ($P > 0.05$), which indicates that the increase in elbow force was similar across the tasks. However, there was a main effect for gender ($P < 0.05$), because the force exerted by the old women was less than that for the old men during both tasks.

EMG–Force Relation.

The average rectified EMG (AEMG; % peak EMG) for the elbow flexors was determined during isometric contractions held at 20%, 40%, and 60% of MVC for both testing sessions. AEMG increased with contraction intensity ($P < 0.05$), but similarly on both occasions ($P > 0.05$). The average AEMG for the elbow flexor muscles during the force and position task sessions was 15.3 ± 5.3% and 15.4 ± 3.7%, respectively, for the 20% contraction, 30.2 ± 8.2% and 32.4 ± 8.8% for the 40% contraction, and 52.7 ± 9.3% and 54.3 ± 11.6% for the 60% contraction. The AEMG of the brachialis muscle was significantly greater than for the other elbow flexors across both testing days ($P < 0.05$), although the difference was more pronounced at lower forces.

Average EMG during the Fatiguing Contraction.

The amplitude of the AEMG (% peak EMG) for each elbow flexor muscle increased during the fatiguing contraction for both tasks ($P < 0.05$). The average AEMG for all the elbow flexor muscles (Fig. **2**) was similar for the force task and position task in the first 30 s of the fatiguing contraction (16.1 ± 10.9% and 14.7 ± 8.6%). However, the AEMG at termination of the force task was greater than at termination of the position task (34.4 ± 18.6% vs. 21.3 ± 11.5%, $P < 0.05$). Nonetheless, the average rates of increase of AEMG between the start and end of the contractions were similar for the force and position tasks (0.86 ± 0.45%.min^{-1} and 0.80 ± 0.73%.min^{-1}, $P > 0.05$). The position task, however, had a slower rate of rise at the start of the contraction. For example, the AEMG at the 25% and 50% timepoints during the position task were less than that at the 25% timepoint during the force task ($P < 0.05$).

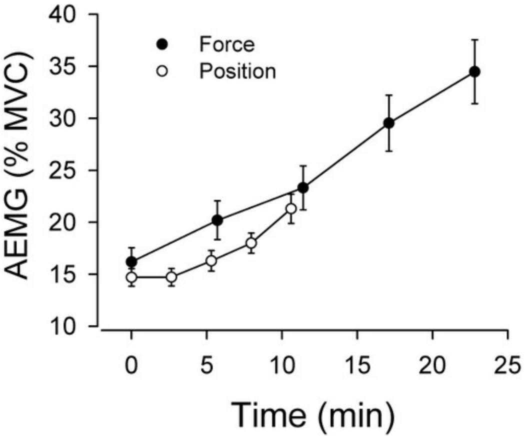

Figure 2

The average rectified EMG (AEMG, expressed as a percentage of the maximal voluntary contraction value) of all the elbow flexors throughout the fatiguing contraction for the force and position tasks. Each data point represents the mean ± SE of the AEMG at the 25% interval of the time to task failure for all elbow flexor muscles.

The AEMG differed across muscles ($P < 0.05$) similarly for both tasks ($P > 0.05$; Fig. **3**). The mean AEMG during the force task was greater ($P < 0.05$) for the brachialis compared with the short and long heads of biceps brachii and brachioradialis. Similarly, the mean AEMG during the position task was greater ($P < 0.05$) for the brachialis compared with the short and long heads of biceps brachii and brachioradialis. For both tasks, the short head of the biceps brachii had less AEMG than the long head of the biceps brachii and brachioradialis ($P < 0.05$).

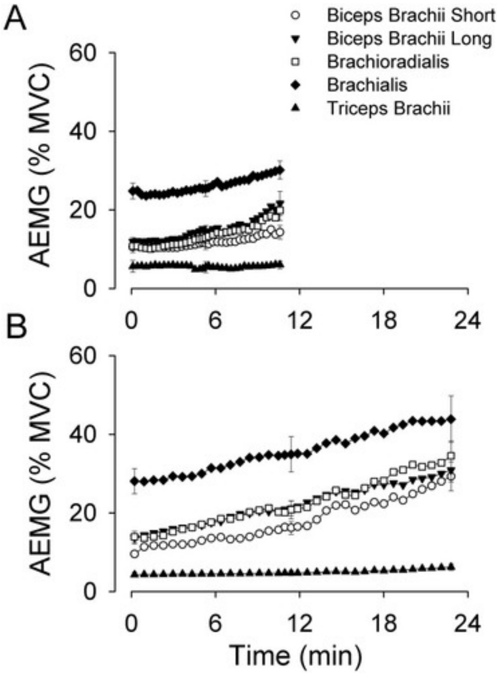

Figure 3

The average rectified EMG (AEMG, % MVC peak) of the elbow flexor and extensor muscles during the fatiguing contraction for the position (**A**) and force (**B**) tasks. Each data point represents the mean AEMG amplitude for 1% of the time to task failure, with every third 1% interval plotted. SE bars are shown for the first, middle, and last data points for each muscle.

The mean AEMG of the triceps brachii muscle was similar for the force and position tasks. The AEMG for triceps brachii muscle was substantially less than for the elbow flexor muscles during both tasks (Fig. **3**; $P < 0.05$). The triceps brachii AEMG increased ($P < 0.05$) at a similar rate during the force and position tasks ($0.10 \pm 0.11\%.\text{min}^{-1}$ and $0.14 \pm 0.58\%.\text{min}^{-1}$, $P > 0.05$).

Bursts of EMG Activity during the Fatiguing Contraction.

There was a progressive increase in the number of bursts in EMG activity during both tasks (main effect of time: $P < 0.05$; Fig. **4**). However, burst rate for the elbow flexor muscles was greater for the position task (0.75 ± 1.3 bursts.min^{-1}) compared with the force task (0.52 ± 0.97 bursts.min^{-1}, $P < 0.05$) (main effect of task). There was no interaction between task and time, which indicates that the bursting activity was greater during the first third, middle third, and last third of time to failure during the position task compared with the force task. However, the rate of increase in the average bursting activity was greater for the position task (Fig. **4**A).

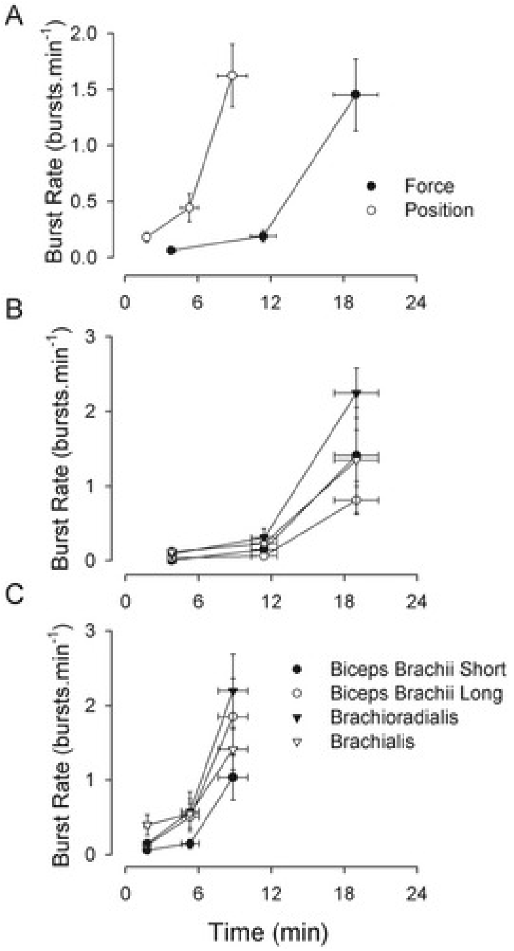

Figure 4

Burst rate of the rectified EMG for the elbow flexor muscles for the fatiguing contractions. Values are expressed as mean ± SE for the first third, middle third, and last third of the time to task failure. (**A**) Average burst rate for the force and position tasks (all elbow flexor muscles combined). (**B**) Average burst rate for the four elbow flexor muscles during the force task. (**C**) Average burst rate for the four elbow flexor muscles during the position task.

EMG bursting activity differed between muscles ($P < 0.05$) for both tasks (Fig. **4**B,C). The brachioradialis had greater burst activity than the other elbow flexor muscles ($P < 0.05$), especially during the last third of the contraction (muscle × time interaction). Burst rate in the brachioradialis was greater during the last third of the contraction compared with the short head of biceps brachii, the long head of biceps brachii, and brachialis. The interaction between muscle and task did not reach statistical significance ($P = 0.08$, effect size of 5.5); however, the effect size and low *P*-value indicate a trend toward the bursting activity for the long head of biceps brachii and brachioradialis being greater during the position than force task, whereas the activity for the short head of biceps brachii and brachioradialis muscles were similar.

The antagonist muscle triceps brachii also experienced an increase in EMG bursting activity from 0.4 ± 0.7 bursts.min^{-1} in the first third to 1.2 ± 1.9 bursts.min^{-1} in the last third. However, the considerable variability in this bursting activity resulted in similar values during the force and position tasks (0.5 ± 1.3 bursts.min^{-1} and 0.9 ± 1.2 bursts.min^{-1}, respectively; $P > 0.05$).

Mean burst duration for the elbow flexor muscles during the fatiguing contractions was 5.7 ± 8.2 s, which was similar for the position task (5.5 ± 9.6 s) and force task (5.8 ± 6.4 s, $P > 0.05$) with no change in time or difference across the elbow flexors: short head of biceps brachii, 6.0 ± 5.5 s; long head of biceps brachii, 5.3 ± 6.6 s; brachioradialis, 5.7 ± 9.5 s; and brachialis, 5.7 ± 10.0 s.

Mean Arterial Blood Pressure (MAP) and Heart Rate.

MAP increased during both tasks (*P* < 0.05, Fig. **5**A). When compared at the same relative time (start, 25%, 50%, 75%, and 100% of time to failure), the MAP was similar at the beginning of the fatiguing contractions for the force and position tasks and at task failure. However, the rate of increase in MAP was greater for the position than force task (4.2 ± 2.5 and 2.0 ± 1.3 mmHg.min^{-1}, respectively; *P* < 0.05).

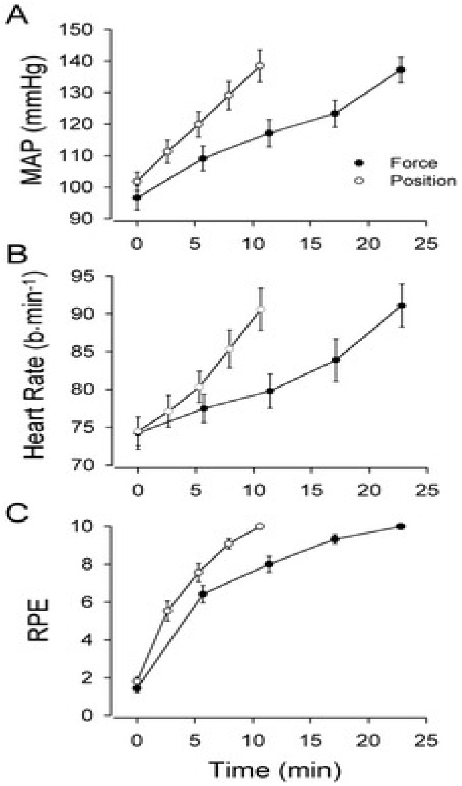

Figure 5

The mean arterial pressure (MAP) (**A**), heart rate (**B**), and ratings of perceived exertion (RPE) (**C**) during the force and position tasks. Values expressed as mean ± SE at 25% increments of the time to task failure. Averages of 15-s intervals were used for the MAP and heart rate. The rates of increase in MAP, heart rate, and RPE were greater for the position task compared with the force task (*P* < 0.05).

Heart rate also increased during the fatiguing contraction (*P* < 0.05; Fig. **5**B). When compared at the same relative time (start, 25%, 50%, 75% and 100% of time to failure), the heart rate was similar at the beginning of the force and position tasks and at task failure. However, the rate of increase in the heart rate was more gradual for the force than position task (0.9 ± 0.7 beats.min^{-1} and 2.0 ± 1.8 beats.min^{-1}, respectively).

Perceived Exertion during the Fatiguing Tasks.

The rating of perceived exertion (RPE) increased during the fatiguing contraction (*P* < 0.05; Fig. **5**C). RPE was similar at the beginning and end of the fatiguing contraction (*P* > 0.05) for the force and position tasks. At the same relative time during the fatiguing contractions, the RPE was similar for the force and position tasks. However, the rate of increase in the RPE was more gradual during the force task in absolute time (*P* < 0.05).

Fluctuations in Force and Acceleration during the Fatiguing Contractions.

The amplitude of the vertical and horizontal fluctuations in force and acceleration increased progressively during the two tasks (*P* < 0.05). However, the relative increase in the acceleration fluctuations during the position task was greater than the increase in force fluctuations during the force task for both the vertical and horizontal directions (*P* < 0.05; Fig. **6**). To compare the fluctuations in the two tasks, the force fluctuations in the position task were estimated by determining the product of vertical acceleration and the inertial load. There was a time × task interaction (*P* < 0.05) indicating that the SD of force for the vertical direction was similar for the force task (0.64 ± 0.45 N) compared with the position task (0.89 ± 0.30 N) at the start of the fatiguing contraction, and at the 25% interval (0.83 ± 0.40 N and 0.86 ± 0.75 N, respectively), but less at failure for the force task (1.98 ± 0.63 N) compared with the position task (3.48 ± 2.24 N). There was no association between the increase of EMG burst rate during the last third of the contraction and either the force fluctuations at the end of the force task (*r* = 0.31, *n* = 18, *P* = 0.10, muscles pooled) or the acceleration fluctuations at the end of the position task (*r* = 0.01, *n* = 18, *P* > 0.05).

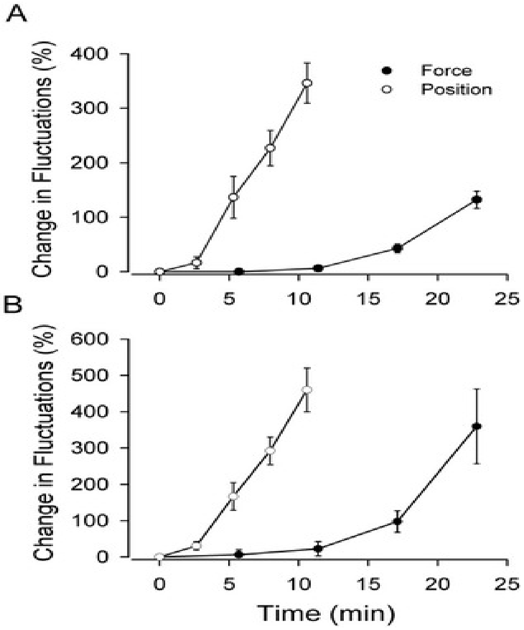

Figure 6

Percent changes (mean ± SE) in the SD of force in the vertical (**A**) and side-to-side directions (**B**) in 25% increments of time to failure for the force and position tasks. The force fluctuations during the position task were estimated as the product of acceleration and mass. The change is expressed as a percent of the value measured during the first 30-s interval at the start of the fatiguing contraction.

DISCUSSION

The main finding of this study was that the time to task failure was briefer for the position than the force task, despite each old adult exerting a similar load torque for the two tasks. The position task involved more rapid rates of increase in mean arterial pressure, heart rate, perceived effort, EMG bursting activity, and fluctuations in motor output. In contrast, the AEMG activity at task failure was less for the position task than the force task, and the average rate of increase was similar when compared at failure of the position task. These results indicate that the difference in the time to failure for the two tasks when performed by the old adults was attributable to a greater level of central neural activity during the position task, as observed for young adults.[22]

The difference in time to failure between the two tasks performed by old adults was not due to differences in motivation or relative performance: (1) the decline in maximal strength at task failure was similar for the force and position tasks (29%); (2) the effort (RPE) exerted during the contraction and at task failure was similar for the two tasks; and (3) the force under the elbow joint was similar for the two tasks. Thus, the time to task failure was briefer for the position task despite a similar load torque and similar magnitudes of fatigue at task failure.

There were also differences during the tasks in the rate of change in mean arterial pressure, heart rate, and perceived effort, which indicated a greater rate of change in neural activity during the position task. These adjustments likely involved both central and peripheral processes. For example, the increase in mean arterial pressure is driven by central command and peripheral reflexes during isometric fatiguing contractions (group III and IV afferent feedback to the spinal cord),[1, 32, 35] heart rate is modulated by central command,[10, 12, 13] and perceived effort is modulated by descending drive.[6, 15, 33] Consequently, the position task involved a greater rate of increase in a broad range of neural processes compared with the force task, despite a similar load torque for the two tasks. Furthermore, the differences in these indices between the force and position tasks were similar to those observed for young adults when performing the two tasks.[22]

Consistent with these findings, the fluctuations in motor output increased more rapidly during the position task than force task, as observed for young adults.[22] Because the amplitude of the fluctuations increases with contraction intensity,[7, 16] the greater rate of increase in the fluctuations in motor output during the position task likely indicates a more rapid recruitment of the motor unit pool. When young adults performed the force and position tasks, the average EMG activity of the elbow flexor muscles increased at a similar rate,[22] but there was a greater change in the discharge rate and recruitment of motor units in biceps brachii during the position task than force task.[33] This discrepancy underscores the insensitivity of the surface EMG signal, as recorded by a standard pair of electrodes, in detecting modest changes in motor unit activity[9, 23] when the tasks were performed with the upper arm vertical and the forearm horizontal to the ground.

The old adults also exhibited similar average EMG values at the time of failure for the position task when performed with the elbow flexor muscles with the upper limb in a similar position. However, when the tasks were performed by young adults with the arm rotated forward so that the upper arm was horizontal, the EMG activity of the elbow flexors increased more rapidly during the position than force task, and the time to failure was briefer for the position task than force task; the difference between tasks, however, was less than in the present study.**36** Comparison of these results suggests that some other mechanism independent of the elbow flexors, but unique to the posture adopted for these experiments, contributed to premature failure of the position task.

Furthermore, the rate of change in EMG activity is not always similar during the force and position tasks. The rate of increase in average EMG between the two tasks during the first part of the fatiguing contractions was not the same for the old adults, suggesting significant differences in motor unit activity. In the young adults, when the arm was horizontal, the EMG activity of the elbow flexor muscles increased more rapidly during the position task and the time to failure was briefer compared with the force task at 20% MVC force.[36] Similar relations were observed when the two tasks were performed with the first dorsal interosseous muscle at 20% MVC force, but not when the load exceeded the upper limit of motor unit recruitment.[30] These earlier findings indicate that the input received by the motor neuron pool during the performance of the force and position tasks varies with the muscle used for the task, the position of the limb, and the intensity of the contraction. The current findings suggest that the age of the individual should be added to this list of factors that influence the rate of change in motor output during fatiguing contractions.

The primary mechanism for the difference in time to failure between the force and position tasks likely involves a greater level of central neural activity for the position task due to the reduced limb support at the wrist.

Consistent with this interpretation, the bursts of EMG activity, which correspond to the transient recruitment of motor units,[18, 25] increased more rapidly during the position task than force task of the elbow flexor muscles in the old adults. However, because there was no difference between tasks in the transient increase in motor unit activity of the triceps brachii muscles, the difference in time to failure for the tasks was not influenced by the antagonist activity.

The mechanisms contributing to the briefer duration for the position task, which involves less support at the wrist and greater excitatory drive to the motor neuron pool, are likely to be similar for healthy young and old adults. The time to task failure for young adults was similarly longer for the force task than position task when the elbow flexor muscles sustained forces at 15%[22] and 20% of MVC.[19, 20] The time to failure for the 20% MVC contraction was 213% longer for the force task relative to the position task for the young adults, and 115% longer for the old adults. Furthermore, the old adults were able to sustain the contractions for a longer duration than the young adults for both tasks, which is consistent with the greater fatigue resistance that has previously been observed during the force task for old adults.[4, 17, 24] Thus, the differences in time to task failure between the force task and position tasks was not compromised with age, but preserved in the old, healthy adults, and was similar to that of the young adults.

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Abbreviations

AEMG, average, rectified electromyogram; ANOVA, analysis of variance; CV, coefficient of variation; DBP, diastolic blood pressure; EMG, electromyogram; MAP, mean arterial pressure; MVC, maximal voluntary contraction, RPE, rating of perceived exertion; SBP, systolic blood pressure

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