Task Differences With the Same Load Torque Alter the Endurance Time of Submaximal Fatiguing Contractions in Humans

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Hunter, Sandra K., Daphne L. Ryan, Justus D. Ortega, and Roger M. Enoka. Task differences with the same load torque alter the endurance time of submaximal fatiguing contractions in humans. J Neurophysiol 88: 3087–3096, 2002; 10.1152/jn.00232.2002. Endurance time, muscle activation, and mean arterial pressure were measured during two types of submaximal fatiguing contractions that required each subject to exert the same net muscle torque in the two tasks. Sixteen men and women performed isometric contractions at 15% of the maximum voluntary contraction (MVC) force with the elbow flexor muscles, either by maintaining a constant force while pushing against a force transducer (force task) or by supporting an equivalent inertial load while maintaining a constant elbow angle (position task). The endurance time for the force task (1402 ± 728 s) was twice as long as that for the position task (702 ± 582 s, P < 0.05), despite a similar reduction in the load torque at exhaustion for each contraction. The rate of increase in average electromyographic activity (EMG, % peak MVC value) for the elbow flexor muscles was similar for the two tasks. However, the average EMG was greater at exhaustion for the force task (22.4 ± 1.2%) compared with the position task (14.9 ± 1.0%, P < 0.05). In contrast, the rates of increase in the mean arterial pressure, the rating of perceived exertion, anterior deltoid EMG, and fluctuations in motor output (force or acceleration) were greater for the position task compared with the force task (P < 0.05). Furthermore, the rate of bursts in EMG activity, which corresponded to the transient recruitment of motor units, was greater for the brachialis muscle during the position task. These results indicate that the briefer endurance time for the position task was associated with greater levels of excitatory and inhibitory input to the motor neurons compared with the force task.

INTRODUCTION

The mechanisms responsible for the decline in force during fatiguing contractions depend on the details of the task being performed (Enoka and Stuart 1992; Gandevia, 2001). For example, the decrease in force that occurs during a high-force contraction appears to be primarily attributable to an impairment of processes that are distal to the neuromuscular junction (Bigland-Ritchie et al. 1986a; Gandevia et al. 1996). Conversely, the reduction in force associated with contractions performed at low-to-moderate forces seems to involve both central and peripheral mechanisms (Löscher et al. 1996a,b; Sacco et al. 2000; Taylor et al. 1996). The central mechanisms include those that contribute to the maximality of muscle activation (Bailey et al. 1993; Bigland-Ritchie et al. 1986a; Millet et al. 2002) and the distribution of activity among the involved muscles (Akima et al. 2002; Mathiassen and Aminoff 1997; Rube and Secher 1990; Semmler et al. 2000; Sjøgaard et al. 1986).

Despite the observation that an impairment of neural mechanisms can contribute to the decline in force during fatiguing contractions, the relative significance of these adjustments is not well defined. To address this issue, we compared the performance of human volunteers as each individual exerted an identical net muscle torque during two static tasks. One task required the subject to push up against a force transducer and to match a submaximal target force by performing an isometric contraction with the elbow flexor muscles. The other task required the subject to keep the elbow joint at a right angle while supporting an equivalent inertial load by performing a postural contraction with the elbow flexor muscles. Based on appropriate feedback signals, the subject was instructed to “maintain force” with the isometric contraction and to “maintain position” with the postural contraction. Such tasks have been shown to require alterations in the distribution of activity among the elbow flexor muscles (Buchanan and Lloyd 1995), to involve differences in the activity of motor units in biceps brachii (Søgaard 1995), and to result in alterations in muscle fatigability during intermittent contractions involving various modes of feedback (Sjøgaard et al. 2000).

The purpose of the study was to compare the effect of task on the neural activity and endurance time of a submaximal fatiguing contraction performed with the elbow flexor muscles. The neural activity underlying the performance of the two tasks was characterized with measures of the motor output and associated cardiovascular adjustments. The motor output measures included the average electromyographic activity (EMG), fluctuations in force and acceleration, and ratings of perceived exertion. The cardiovascular measures comprised heart rate and the pressor response, which is a reflex-mediated increase in mean arterial pressure (MAP) that is predominantly driven by a metaboreflex in response to feedback delivered by group III and IV afferents from the active muscles (Alam and Smirk 1937; Rowell 1993; Rowell and O’Leary 1990). The feedback delivered by these afferent neurons is inhibitory onto the motor neurons within the spinal cord (Bigland-Ritchie et al. 1986b; Garland 1991; Garland and McComas 1990; MacKie et al. 1993). We found that, despite a similar net muscle torque for the two tasks, endurance time was briefer for the postural contraction and this was associated with heightened levels of
neural activity. Preliminary accounts of these results have been published in abstract form (Hunter et al. 2000, 2001).

METHODS

Sixteen healthy adults (8 men and 8 women; mean ± SD, 27 ± 4 yr; range, 20–35 yr) volunteered to participate in the study. None of the subjects had any known neurological disorder or cardiovascular disease. Prior to participation in the study, all subjects gave informed consent. The Human Subjects Committee at the University of Colorado approved the protocol.

Subjects reported to the laboratory on two occasions, 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 session, the fatigue-inducing contraction involved maintaining a force that was equal to 15% of the maximum voluntary contraction (MVC) force for as long as possible; this is referred to as the force task. In the other session, the fatigue-inducing contraction involved maintaining the elbow joint at a right angle while supporting an inertial load that was equivalent to the 15% MVC force; this is referred to as the position task. The order of these two 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 fatigue-inducing contraction until exhaustion.

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 90° so that the forearm was horizontal to ground and the force at the wrist due to activation of the elbow flexor muscles was directed upward. Two nylon straps were placed vertically over each shoulder to restrain the subject and to minimize shoulder movement. The hand and forearm were placed in a modified wrist–hand–thumb orthosis (Orthomeric, Newport Beach, CA) for the MVCs and the force task. The orthosis held the forearm in a position midway between pronation and supination. The force exerted by the wrist in the vertical and side-to-side directions was measured with a force 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 digital tape (DAT Sony PC 116, Montvale, NJ). The force exerted in the vertical direction was displayed on a 14-in. monitor that was located 1 m in front of the subject.

Elbow angle during the position task was measured with an electrogoniometer (XM110 and K100, Penny and Giles, Cwmfelinfach, Gwent, UK) that was taped to the lateral side of the elbow joint. The output was recorded on digital tape and displayed on the 14-in. monitor. The subject’s hand and forearm were placed in a modified wrist–hand–thumb orthosis and an inertial load equivalent to 15% of MVC force was suspended from the wrist, at the same location that contacted the force transducer. Two uniaxial accelerometers (Endevco 7265A-HS, San Juan Capistrano, CA) were mounted on a right-angled aluminum platform that was secured to the orthosis near the thumb. One accelerometer was aligned to record acceleration in the vertical direction and the other accelerometer was oriented to record side-to-side acceleration. The accelerations were recorded on digital tape.

In addition to the force exerted at the wrist, the force under the elbow joint was recorded during the MVC and the two fatigue tasks. The force was measured with an Entran transducer (EL-W-D1–200 l, 0.27 mV/N) placed under the padded elbow support, displayed on an oscilloscope, and stored on digital tape.

Electrical recordings

EMG signals were recorded with bipolar surface electrodes (Ag–AgCl, 8-mm diam; 20-mm distance between electrodes) that were placed over the long head of biceps brachii, the short head of biceps brachii, brachioradialis, and the anterior head of the deltoid muscle. 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 inserted into the muscle about 3 cm proximal to the antecubital fold. The electrode comprised two stainless steel wires (100-μm diam) that were insulated with Formvar (California Fine Wire Company, Grover Beach, CA). One wire in each pair had the insulation removed for about 2 mm to increase the recording volume of the electrode. A surface electrode (8-mm diam) placed on a bony prominence served as the reference electrode. The EMG signal was amplified (500–2,000×), band-pass filtered (20–800 Hz for the surface EMG and 20–1,500 Hz for the intramuscular EMG) with Coulbourn modules (Coulbourn Instruments, Allenton, PA) prior to being recorded on digital tape, and displayed on an oscilloscope.

Cardiovascular measurements

Heart rate and blood pressure were monitored throughout the fatiguing contraction 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 dominant hand and the arm was placed in a sling so that it was relaxed with the hand at heart level. The blood pressure signal was recorded on digital tape.

Experimental protocol

The protocol involved measurement of the MVC force for the elbow flexor muscles, an assessment of the EMG–force relations for the involved muscles, and the performance of a fatiguing contraction. The two sessions for each subject occurred at the same time of the day.

MVC FORCE. Each subject performed several MVC trials with the elbow flexor 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 to 3 s. The force exerted by the wrist was displayed on a 14-in. monitor and each subject was verbally encouraged to achieve maximal force. There was a 60- to 90-s rest between trials. If the peak forces from the three trials were not within 5% of each other, additional trials were performed until this was accomplished. Most subjects performed three MVC trials. The greatest force achieved by the subject was taken as the MVC force and used as the reference value to calculate the target force for the fatiguing contraction. Four subjects (2 men and 2 women) performed three MVC trials with the elbow extensor muscles using similar procedures to those for the elbow flexor muscles.

EMG ACTIVITY. The EMG activity of the involved muscles was recorded in standardized tasks so that the amount of muscle activation could be compared across sessions. For the anterior deltoid muscle, the subject held one of three loads while lying supine with the left arm slightly abducted from the body and horizontal to the ground. The EMG of the anterior deltoid muscle was recorded while the loads (0.5, 1, and 1.5 kg for the women and 2, 2.5, and 3 kg for the men) were held in the hand of the outstretched arm for 6 s. Based on the protocol of Jarvholm et al. (1991), the rectified EMG activity from the middle 2 s of each recording was averaged across the three loads and this value for each subject was used to normalize the measurements made during the fatiguing contraction.

For the elbow flexor muscles, the subject performed an isometric contraction for 6 s at target forces of 25, 50, and 75% MVC force. The subject was given a 60-s rest between each contraction. The order of the contractions was randomized across subjects but remained con-
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 that was centered about the peak rectified EMG. The rectified EMG of the elbow flexor muscles during the isometric contractions performed at 25, 50, and 75% of MVC force was averaged over the middle 4 s of each 6-s contraction.

The fluctuations in force during the force task and the fluctuations in acceleration (vertical and side-to-side) during the position task were high-pass filtered at 4 Hz with a 4th-order Butterworth filter (Coulbourn Instruments). The amplitude of the force fluctuations was quantified as the coefficient of variation (CV = SD/mean × 100) during the first, middle, and last 60 s of the fatiguing contraction. The fluctuations of acceleration for the position task were characterized as the SD (SD) of acceleration during the first, middle, and last 60 s of the fatiguing contraction. The fluctuations in force and acceleration were also compared at the same absolute times relative to the position task by calculating the CV for force and the SD of acceleration at five 30-s intervals: the first 30 s, 15 s on both sides of the time at 25, 50, and 75% of endurance time, and the last 30 s of the endurance time relative to the position task. The CV for force and the SD of acceleration were expressed as percentage changes from the beginning of the task.

The EMG activity of the elbow flexor muscles and elbow extensor muscles during the fatiguing contraction was quantified in two ways: 1) averages of the rectified EMG (AEMG) for the first, middle, and last 60 s of the fatiguing contraction and 2) averages of the rectified EMG for every 1% of the endurance time. The EMG was normalized to the peak EMG obtained during the MVC. The average EMG was also compared at the same absolute times, as described for the fluctuations in force and acceleration.

To quantify the number and duration of the EMG bursts throughout the fatiguing contraction for each muscle (Fig. 1), 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 to identify rapid changes in the EMG signal; and 3) divided by the average of the rectified EMG so that muscles with different EMG amplitudes could be compared. A burst was identified when the smoothed, differentiated EMG signal increased by more than 0.33 s⁻¹, which represented approximately 3 SDs above the mean of the differentiated EMG signal based on 32 samples when the EMG signal displayed minimal bursting during the contraction. The

### Data analysis

All data collected during the experiments were recorded on digital tape at 2.5 kHz and then digitized (A/D converter, 12-bit resolution) and analyzed off-line using the Spike2 data analysis system (Cambridge Electronic Design, Cambridge, UK). The force, position, acceleration, and blood pressure signals were digitized at 200 samples/s, whereas the EMG signals were digitized at 2,000 samples/s.
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 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. Based on pilot observations, the start of two bursts was constrained to be >2 s apart and the minimum burst duration was 0.5 s. Burst rate and duration were compared at relative and absolute times during the fatiguing contractions.

Heart rate and MAP during the fatiguing contraction were compared with 10–15 s averages at 10% intervals throughout the endurance time. The blood pressure signal was analyzed in each 10- to 15-s average 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 as MAP = DBP + \(\frac{1}{3}(SBP - DBP)\).

**Statistical analysis**

Data are reported as means ± SD within the text and table, and as means ± SE in the figures. Separate two-factor (task \(\times\) sex) ANOVAs with repeated-measures on task (StatView, SAS Institute) were used to compare the dependent variables for endurance time, MVC force, and changes in heart rate and MAP. Separate three-factor ANOVAs (task \(\times\) sex \(\times\) time) with repeated measures on task and time were used to compare the dependent variables of heart rate, MAP, RPE, elbow force, anterior deltoid AEMG, and change in CV for force and SD of acceleration. A three-factor ANOVA (day \(\times\) intensity \(\times\) muscle) with repeated measures on day was used to compare the EMG–force relation for the isotonic contractions of the elbow flexor muscles (biceps brachii short head, biceps brachii long head, brachioradialis, and brachialis) at three intensities of contraction (25, 50, and 75% of MVC). A four-factor ANOVA (muscle \(\times\) task \(\times\) sex \(\times\) time) with repeated measures on task and time was used to compare the burst rate and AEMG during the fatiguing contraction for the elbow flexor muscles (biceps brachii short head, biceps brachii long head, brachioradialis, and brachialis). Because bursts were occasionally absent during an interval, averages of the burst duration are reported and the results of independent \(t\)-tests are reported when these analyses were possible. Post hoc analyses (Tukey–Kramer) were used to test for differences among pairs of means when appropriate. A significance level of \(P < 0.05\) was used to identify statistical significance.

**RESULTS**

This study involved the comparison of the endurance time, patterns of muscle activation, and pressor response during two types of fatiguing contractions with the elbow flexor muscles. One fatiguing contraction, referred to as the force task, required the subject to match a target force of 15% MVC force by pushing up against a force transducer with the wrist. The other fatiguing contraction, referred to as the position task, required the subject to maintain the elbow joint at a right angle while supporting an inertial load equivalent to the 15% MVC force. The net muscle torque about the elbow joint was identical for the two tasks for each subject. Each task was performed in a separate session, with the sessions separated by at least 1 wk for each subject.

MVC force was similar in the force task session (308 ± 151 N) compared with the position task session (307 ± 152 N, \(P > 0.05\)), which meant that the net torque exerted by the limb during the two fatiguing contractions was similar for the two sessions. Despite the similar net muscle torque exerted by the subject for each task and similar criteria for termination of the tasks, the endurance time for the force task (1402 ± 728 s) was twice as long as that for the position task (702 ± 582 s, \(P < 0.05\)) (Fig. 2). The fatiguing contractions were terminated when the net muscle torque exerted by the subject declined by \(\approx 1.5\%\) of maximum 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. Furthermore, neither task was terminated due to fluctuations in the motor output because the average duration of the fluctuations (approximately 4 Hz) was much less than the minimum duration (\(>5\ s\)) for the decline in the exerted torque. Because the men (409 ± 144 N) were twice as strong as the women (206 ± 56 N, \(P < 0.05\)), the women (1339 ± 740 s) had a longer endurance time than the men (766 ± 639 s, \(P < 0.05\)) for the two tasks. There was no interaction between task and sex for endurance time (\(P > 0.05\)).

The peak horizontal force exerted at the wrist during the MVC contraction was similar across sessions for the force task (25 ± 29 N) and the position task (25 ± 42 N, \(P > 0.05\)) and for the men (27 ± 48 N) and women (22 ± 16 N, \(P > 0.05\)). The maximal force exerted under the elbow was also similar across the experimental days for the force task (149 ± 94 N) and position task (163 ± 107 N, \(P > 0.05\)) and between the men (169 ± 106 N) and women (142 ± 93 N, \(P > 0.05\)). These data indicate that similar amounts of support were provided by the surroundings during the MVC, from which the target force and inertial load were determined.

**FIG. 2.** Endurance times (ET) of men and women for the force and position tasks. A: mean ± SE endurance time for the force task was longer than that for the position task (\(P < 0.05\)) and endurance times for the women were longer than those for the men (\(P < 0.05\)). B: endurance times of the individual subjects for the two tasks. Data above the line of identity indicate that the endurance times for the force task were longer than those for the position task.
Table 1. Relation between average EMG and net force for the four major elbow flexor muscles

<table>
<thead>
<tr>
<th>Target Force</th>
<th>Force Task</th>
<th>Position Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25%</td>
<td>50%</td>
</tr>
<tr>
<td>Biceps brachii (Short)</td>
<td>13 ± 6</td>
<td>39 ± 12</td>
</tr>
<tr>
<td>Biceps brachii (Long)</td>
<td>13 ± 5</td>
<td>34 ± 12</td>
</tr>
<tr>
<td>Brachioradialis</td>
<td>14 ± 6</td>
<td>43 ± 11</td>
</tr>
<tr>
<td>Brachialis</td>
<td>27 ± 8*</td>
<td>48 ± 12</td>
</tr>
<tr>
<td>Mean of elbow flexor muscles</td>
<td>17 ± 9</td>
<td>41 ± 12</td>
</tr>
</tbody>
</table>

Data are means ± SD of the rectified EMG normalized to the peak EMG during the MVC. AEMG, average electromyographic activity; MVC, maximum voluntary contraction. * P < 0.05 compared with the other muscles at the 25% target force.

The endurance times for the fatiguing contractions were inversely related to MVC force, which meant that stronger individuals had briefer endurance times for both the force task (y = 218 + 2535 × e−0.0035x, R² = 0.81) and the position task (y = 163 + 740 × e−0.0035x, R² = 0.69).

EMG–force relation

The AEMG for the elbow flexor muscles was determined during both sessions with isometric contractions held at 25, 50, and 75% MVC force. AEMG increased with contraction intensity (P < 0.05, Table 1) and was similar across sessions (P > 0.05). However, an interaction between muscle and target force (P < 0.05) indicated that the brachialis muscle had twice the AEMG at the 25% MVC force compared with the biceps brachii (short and long heads) and the brachioradialis muscles. The AEMG was similar among the elbow flexor muscles at the 50 and 75% MVC forces. There was no difference in the AEMG between men and women (P > 0.05). These results indicate that the relation between AEMG and force for the elbow flexor muscles was consistent across the sessions.

Adjustments in average EMG

The amplitude of the normalized average EMG for all elbow flexor muscles increased progressively during the fatiguing contractions (P < 0.05; Fig. 3). The AEMG for the elbow flexor muscles at the beginning of the contraction (first 60 s) was similar for the force task (10.5 ± 0.6%) and the position task (10.2 ± 0.6%). The AEMG at exhaustion (last 60 s), however, was greater for the force task (22.4 ± 1.2%) compared with the position task (14.9 ± 1.0%, P < 0.05) (Fig. 4).

A significant feature of the AEMG records was the similarity of the slopes for each of the muscles across the two tasks (Fig. 4). Furthermore, there was no difference in the AEMG for the two tasks compared at the same absolute time (P > 0.05, Fig. 5). For example, the AEMG at the end of the position task (last 30 s) was 15.4 ± 1.1% compared with 15.5 ± 1.1% at the same absolute time for the force task. Consequently, the rate of increase in AEMG was similar for the two tasks.

Another significant feature of the EMG records was the greater EMG activity in the brachialis muscle compared with the other elbow flexor muscles (Fig. 4). The AEMG for the brachialis muscle during the force and position tasks (24.5 ± 2.1 and 19.6 ± 1.8%, respectively) was significantly greater than that for biceps brachii (short and long heads) and brachioradialis muscles combined (12.9 ± 0.6 and 9.3 ± 0.5%, respectively; P < 0.05).

The AEMG of the anterior deltoid (normalized to the supine posture) was variable between individuals but achieved similar average values for the force task (24 ± 16%) and the position task (29 ± 20%, P > 0.05). The AEMG at the start of contraction (first 60 s) was similar for the force task (27 ±
14%) and position task (25 ± 15%; P > 0.05) and increased to similar levels at exhaustion (36 ± 43 and 36 ± 19%, respectively; P > 0.05). Because the endurance time was less for the position task, the absolute rate of increase in AEMG of the anterior deltoid was greater for this task (P < 0.05). This observation contrasts the similar rates of increase in AEMG for the elbow flexor muscles during the two fatigue tasks.

The AEMG of triceps brachii was recorded for four subjects (2 men and 2 women) during the fatiguing contractions. The AEMG was negligible compared with the elbow flexor muscles and average values were similar for the force task (1%) and the position task (0.7%).

**Bursts of EMG activity**

The fatiguing contractions were characterized by a progressive increase in the number of EMG bursts for both tasks. The burst rate for all the elbow flexor muscles for the force task increased from 0.06 ± 0.12 bursts·min⁻¹ in the first third of the contraction to 0.64 ± 0.75 bursts·min⁻¹ during the last third of the contraction (P < 0.05). Similarly, the burst rate for the position task increased from 0.14 ± 0.46 bursts·min⁻¹ in the first third of the contraction to 0.72 ± 1.23 bursts·min⁻¹ during the last third of the contraction (P < 0.05). The average burst rate was similar for the force task (0.27 ± 0.28 bursts·min⁻¹) and the position task (0.32 ± 0.50 bursts·min⁻¹, P > 0.05). Although there was no main effect for muscle (P > 0.05), there was an interaction for muscle and task (P < 0.05) due to the greater burst rate of the brachialis muscle during the position task (0.59 ± 0.78 bursts·min⁻¹) compared with the force task (0.19 ± 0.26 bursts·min⁻¹, P < 0.05).

Women had a lesser EMG burst rate compared with men for both the force task (0.20 ± 0.23 and 0.33 ± 0.32 bursts·min⁻¹, respectively) and the position task (0.18 ± 0.35 and 0.45 ± 0.60 bursts·min⁻¹, respectively; P < 0.05), although the increase in burst rate across the fatiguing contractions were similar for men and women (P > 0.05).

The mean burst duration for the elbow flexor muscles during the fatiguing contractions was 4.5 ± 4.4 s. The mean burst duration was similar for the force task (5.2 ± 5.5 s) and the position task (3.6 ± 2.1 s, P > 0.05) and did not change across the fatiguing contractions (P > 0.05). There was no difference in burst duration between men and women (P > 0.05). Furthermore, the burst duration was similar for all muscles (P > 0.05): short head of biceps brachii (5.7 ± 5.8 s), long head of biceps brachii (3.8 ± 1.8 s), brachioradialis (4.4 ± 2.6 s), and brachialis (3.9 ± 5.2 s).

**Vertical force exerted under the elbow joint**

The vertical force exerted under the elbow joint was similar for the force task (80 ± 57 N) and the position task (76 ± 68 N, P > 0.05) and was similar at exhaustion (75 ± 52 and 87 ± 60 N, respectively; P > 0.05). There was a trend (P = 0.08) for the men (101 ± 70 and 111 ± 8 N) to exert a larger force than the women (59 ± 35 and 40 ± 28 N) during the force and position tasks, respectively.

**Fluctuations in force and acceleration**

The amplitude of the fluctuations in force and acceleration in the vertical and horizontal directions increased progressively during the two tasks (Fig. 6). The relative increase in the vertical acceleration fluctuations during the position task (mean increase of 430 ± 194% at exhaustion) was greater than the relative increase in the vertical force fluctuations during the force task (mean increase of 121 ± 110%, P < 0.05; Fig. 6A). Similarly, the relative increase in the side-to-side acceleration fluctuations during the position task (mean increase of 451 ± 155% at exhaustion) was greater than the relative increase in the side-to-side force fluctuations during the force task (mean increase of 243 ± 173%, P < 0.05; Fig. 6B). Both men and women exhibited these effects.

The relative increase in the fluctuations at the same absolute time was much less for the force task. At the end of the position task (absolute time), the vertical acceleration fluctuations increased by 491 ± 212% compared with an increase of 37 ± 69% in the vertical force fluctuations during the force task at the same absolute time (P < 0.05). Similarly, the side-to-side acceleration fluctuations increased by 511 ± 175% at the end of the task.
of the position task compared with an increase of 97 ± 175% in the side-to-side force fluctuations in force at the same absolute time during the force task (P < 0.05). These observations were similar for the men and women.

**MAP and heart rate**

MAP increased during both fatiguing contractions but more rapidly for the position task compared with the force task (P < 0.05, Fig. 7A). The resting MAP was similar for the position task (83 ± 8 mmHg) and the force task (83 ± 10 mmHg, P > 0.05) and for men (82 ± 8 mmHg) and women (84 ± 9 mmHg, P > 0.05). MAP was similar at the start of the contraction for the position task (101 ± 8 mmHg) and the force task (100 ± 11 mmHg, P > 0.05) and for men (99 ± 9 mmHg) and women (103 ± 8 mmHg, P > 0.05). At exhaustion, however, MAP was greater for the position task (131 ± 12 mmHg) compared with the force task (121 ± 18 mmHg) for men and women.

Heart rate was similar at rest (69 ± 10 bpm and 68 ± 9 bpm; P > 0.05), at the start of the contraction (80 ± 10 and 75 ± 11 bpm; P > 0.05), and at exhaustion (94 ± 13 and 94 ± 12 bpm; P > 0.05) for the position and force tasks, respectively. Due to the briefer endurance time for the position task, however, the rate of increase in heart rate was more rapid for the position contraction (P < 0.05). This observation was similar for men and for women (P > 0.05).

**RPE**

RPE during the fatiguing contraction began and ended at similar scores for the two tasks (P > 0.05). The rate of increase in RPE was greater for the position task (P < 0.05, Fig. 7B) due to its briefer endurance time.

**DISCUSSION**

The purpose of the study was to compare the effect of task on the neural activity and endurance time of a submaximal fatiguing contraction performed with the elbow flexor muscles. The two tasks examined in the protocol required each subject to exert the same net muscle torque for as long as possible. For the force task, the subject was instructed to match a target force of 15% MVC force with an isometric contraction as the wrist pushed against a force transducer. For the position task, the subject maintained the elbow joint at a right angle with a postural contraction while supporting an inertial load attached to the wrist. The endurance time for the force task was twice as long as that for the position task, despite a similar reduction in load torque at exhaustion for each task. Furthermore, based on two separate studies (Hunter and Enoka 2001; MacGillis et al. 2002), we have shown that the decline in MVC force was not different (28–35% MVC force) for these two tasks. In these studies, the contraction was sustained at 20% of MVC force or an equivalent inertial load was supported until exhaustion. The criterion for ending the contraction was similar to that in the present study.

The rate of increase in average EMG was similar for the two tasks, which meant that the AEMG at exhaustion was less for the position task. In contrast, the rates of increase in the MAP, heart rate, RPE, and AEMG of anterior deltoid were greater for the position task. Furthermore, the relative rate of increase in
the fluctuations of the motor output (force and acceleration) was greater for the position task. These results suggest that the briefer endurance time for the position task was associated with greater levels of excitatory descending drive and inhibitory input to the motor neurons.

The endurance time was different for the two fatiguing contractions despite a similar net muscle torque for each subject, comparable levels of activity in ancillary muscles, similar forces imposed by the surroundings, and identical perceived effort at exhaustion. Although the EMG of the ancillary muscles (anterior deltoid and triceps brachii) and the force under the elbow differed between subjects and during the fatiguing contractions, there were no differences in these measures between the two tasks. Furthermore, the difference in endurance time for the two tasks was independent of the sex difference in endurance time (Hunter and Enoka 2001). Thus there appeared to be no differences in the performance of the two tasks except those neural factors associated with supporting the two types of loads.

Increase in average EMG

The endurance time of a submaximal contraction can be influenced by the distribution of activation within a muscle and across a group of synergist muscles (Fallentin et al. 1993; Kouzaki et al. 2002; Semmler et al. 2000; Sjogaard et al. 1986; Tamaki et al. 1998; Westgaard and DeLuca 1999). The rates of increase in AEMG were similar among the elbow flexor muscles for our two tasks and therefore were not able to account for the difference in endurance time. Despite the similar rates of increase in AEMG, the brachialis muscle had twice the EMG activity compared with the other elbow flexor muscles, which has been reported previously for the force task (Hunter and Enoka 2001; Semmler et al. 2000) but not for the position task. The greater activation of the brachialis muscle, however, was present in both tasks and was consistent across the duration of the fatiguing contractions.

The increase in EMG activity during a fatiguing contraction at a submaximal intensity is attributable to an increase in motor unit activity (Denny-Brown 1949; Edwards and Lippold 1956; Lloyd 1971). Because the modulation of discharge rate during such contractions is modest, the increase in average EMG is largely due to the recruitment of motor units (Carpentier et al. 2001; Christova and Kossev 2001; Fallentin et al. 1993; Garland et al. 1994). The difference in AEMG at exhaustion for the two tasks, therefore, was primarily due to a difference in the number of motor units that were recruited. Nonetheless, the similarity of the rates of increase in AEMG indicates that the balance of excitatory and inhibitory inputs received by the motor neurons was comparable for the two tasks and that at exhaustion different proportions of the motor unit population were active.

Although the balance of excitation and inhibition of the motor neuron pool were likely similar, the absolute values were probably different, which resulted in a briefer endurance time for the endurance task. Consistent with the interpretation, the rate of EMG bursts increased during the fatiguing contraction for both tasks but at a greater rate in brachialis during the position task. Because a burst of EMG activity indicates the transient recruitment of motor units (Fallentin et al. 1993; Tamaki et al. 1998), the presence of EMG bursts superimposed on an increasing level of average EMG indicates the progressive recruitment of more fatigable motor units. Thus the transient recruitment of motor units was greater in brachialis during the position task, which suggests a difference in the net input received by the motor neuron pools during the two tasks.

Rates of increase in MAP and RPE

In contrast to the similar rates of increase in AEMG for the two tasks, the MAP increased more rapidly for the position task compared with the force task. The increase in MAP, which is known as the pressor response, is mediated by the central command and by peripheral reflexes involving the group III and IV afferents (Alam and Smirk 1937; Fisher and White 1999; Gandevia and Hobbs 1990; Kaufman et al. 1983, 1988; Mitchell 1990; Mitchell et al. 1983; Rowell and O’Leary 1990). Because the pressor response is dominated by the peripheral reflexes after the onset of a fatiguing contraction (Alam and Smirk 1937; Rowell 1993; Rowell and O’Leary 1990), the greater increase of the MAP for the position task suggests a more rapid increase in the inhibitory input from group III and IV afferents onto the motor neurons (Bigland-Ritchie et al. 1986a; Garland 1991; Garland and McComas 1990; Macefield et al. 1993) during this task.

A similar effect was noted for the RPE, which increased more rapidly for the position task compared with the force task. Eventually, all subjects achieved a rating of 10 for each fatiguing contraction, but this was achieved more rapidly for the position task. The RPE is a measure of the individual’s sense of the relative intensity of sustained physical activity and is probably based on the descending voluntary command (Carson et al. 2002). The dissociation in the rates of increase in AEMG and RPE during the two fatiguing contractions underscores a different origin for the two measures. In contrast to the central origin of the RPE, the EMG is based on the peripheral measure of muscle fiber action potentials, for which the summed signal does not correspond to the absolute output of the motor neuron pool (Day and Hulliger 2001; Yao et al. 2000). The faster rate of increase in the RPE for the position task is consistent with a greater rate of increase in the descending drive to the motor neurons for this task.

Fluctuations in force and acceleration

Fatiguing contractions sustained to exhaustion at low-to-moderate forces become more tremulous with time (Cresswell and Loscher 2000; Ebenbichler et al. 2000; Gottlieb and Lippold 1983; Loscher et al. 1996a; Semmler et al. 2000), which is attributable to an increase in the physiological tremor (6–12 Hz) due to enhanced rhythmicities in the descending drive and peripheral afferent feedback (Cresswell and Loscher 2000; McAuley et al. 1997; McAuley and Marsden 2000). The amplitude of the fluctuations in the vertical and horizontal directions increased more for the position task compared with the force task, despite a briefer endurance time for the position task. These results underscore the difference in the rate of increase in the descending drive and peripheral feedback for the two tasks.

In summary, the endurance time when performing an isometric contraction for the force task was twice as long as that when producing a postural contraction for the position task,
despite each subject exerting the same net muscle torque in the two tasks. Although the EMG of the elbow flexor muscles increased at the same rate for the two fatiguing contractions, the different rates of change in MAP, heart rate, RPE, anterior deltoid EMG, and the fluctuations in force and acceleration indicated that the rates of increase in excitatory and inhibitory inputs onto the motor neuron pools was different for the two tasks. These results suggest that the shorter endurance time for the position task compared with the force task was attributable to greater levels of excitation and inhibition of the motor neurons innervating the elbow flexor muscles during the postural contraction.

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REFERENCES


CARSON RG, RIEK S, AND SHAHBAZPOUR N. Central and peripheral modulation of human force sensation following eccentric or concentric contractions. J Physiol (Lond) 539: 913–925, 2002.


