Accessory muscle activity contributes to the variation in time to task failure for different arm postures and loads

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Rudroff T, Barry BK, Stone AL, Barry CJ, Enoka RM. Accessory muscle activity contributes to the variation in time to task failure for different arm postures and loads. J Appl Physiol 102: 1000–1006, 2007. First published November 9, 2006; doi:10.1152/japplphysiol.00564.2006.—Time to failure and electromyogram activity were measured during two types of sustained submaximal contractions with the elbow flexors that required each subject to exert the same net muscle torque with the forearm in two different postures. Twenty men performed the tasks, either by maintaining a constant force while pushing against a force transducer (force task), or by supporting an equivalent load while maintaining a constant elbow angle (position task). The time to failure for the position task with the elbow flexed at 1.57 rad and the forearm horizontal was less than that for the force task (5.2 ± 2.6 and 8.8 ± 3.6 min, \( P = 0.003 \)), whereas it was similar when the forearm was vertical (7.9 ± 4.1 and 7.8 ± 4.5 min, \( P = 0.995 \)). The activity of the rotator cuff muscles was greater during the position tasks (25.1 ± 10.1% maximal voluntary contraction) compared with the force tasks (15.2 ± 5.4% maximal voluntary contraction, \( P < 0.001 \)) in both forearm postures. However, the rates of increase in electromyogram of the accessory muscles and mean arterial pressure were greater for the position task only when the forearm was horizontal (\( P < 0.05 \)), whereas it was similar for the elbow flexors. These findings indicate that forearm posture influences the difference in the time to failure for the two fatiguing contractions. When there was a difference between the two tasks, the task with the briefer time to failure involved greater rates of increase in accessory muscle activity and mean arterial pressure.

The type of load supported during a sustained, submaximal contraction with the elbow flexor muscles influences both the time to task failure and the rates of change in selected biomechanical (e.g., moments, forces) and physiological variables [e.g., muscle activation, mean arterial pressure (MAP), heart rate (HR)] (2, 4, 19). The time to task failure for an isometric contraction is typically longer when an individual exerts a submaximal force against a rigid restraint (force task) than when maintaining a constant limb position (position task), despite the two tasks requiring a similar net muscle torque (10, 27). The difference in the time to failure for the two tasks when performed with the elbow flexor muscles, however, is greater when the forearm is in a horizontal position compared with a vertical position (27).

Although the rate of increase in average electromyogram (aEMG) activity of the elbow flexor muscles was similar for the two tasks when the forearm was in both postures, four observations suggest that the relative demands associated with the position task differed significantly in the two arm postures (10, 26). First, the rate of increase in MAP differed for the two tasks only when the forearm was horizontal. Second, the rate of increase in the electromyogram (EMG) activity of anterior deltoid was greater during the position task than the force task when the forearm was horizontal but not when the forearm was vertical. Third, the relative increase in the standard deviation of hand acceleration at failure of the position task was much greater when the forearm was horizontal (430%) compared with when it was vertical (220%). Fourth, the slight abduction of the arm when the forearm is horizontal (\( \sim 0.25 \) rad) requires an external-rotation torque about the shoulder joint to maintain the required limb position when supporting an inertial load (position task) but not when the force transducer restrains the forearm (force task). When the forearm is in the vertical posture, it is not abducted, and there is no requirement for an external torque.

These differences, along with anecdotal reports by the subjects, suggest that involvement of the accessory muscles, especially the shoulder muscles, was more substantial during the position task when the forearm was in the horizontal position. The purpose of the study was to compare the level of activity in accessory muscles and the times to failure for the force and position tasks with the arm in two positions. The hypothesis was that a briefer time to failure for a position task would be associated with the involvement of a greater active muscle mass and that this would occur when the forearm was horizontal but not when it was vertical. Some of these data have been presented in abstract form (28).

METHODS

Twenty healthy, normotensive men (27 ± 5 yr) volunteered to participate in the study. All subjects completed a general health screening, and none of the subjects reported any neurological or cardiovascular disorders. All subjects provided informed, written consent before participating in the study. The Human Subjects Committee at the University of Colorado approved the protocol. The experimental design and procedures were similar to those described previously (10, 19, 27).

Experimental arrangement. Each subject visited the laboratory on five occasions. The first occasion was a familiarization session in which subjects were introduced to the equipment and procedures. Subsequent sessions involved performing the force and position tasks in two different arm postures (Fig. 1). The force task required the subject to maintain a force that was equal to 20% of the maximal voluntary contraction (MVC) force achieved in each forearm posture, which is, without a correction for the difference in the weight of the forearm and hand in the two postures. In the position task, the submaximal contraction involved maintaining the elbow joint at a right angle while supporting an inertial load that was equivalent to

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were placed in a modified wrist-hand-thumb orthosis (Orthoamerica, Newport Beach, CA) that was tightly secured to the force transducer for the force task or supported an inertial load for the position task. The force was measured with a JR-3 Force-Moment Sensor (900-N range, 90.0 N/V JR-3, Woodland, CA), displayed on an oscilloscope, and stored on a personal computer. The force under the elbow joint was measured with an Entran transducer (ELW-D1–2001, 0.27 mV/N, Hampton, VA). Elbow joint angle during the position task was measured with an electrogoniometer (SG110 and K100, Biometrics, Cwmfelinfach, Gwent, UK) that was secured to the lateral aspect of the elbow joint. The output of the goniometer was recorded, displayed on a monitor, and stored on a personal computer. An inertial load equivalent to 20% MVC force was suspended from the subject’s wrist at the same location that contacted the force transducer during the force task. In the vertical forearm posture, the inertial load was applied via a line-and-pulley system from the subject’s wrist (27). Although the pulley had minimal friction, it was not zero and would have dampened the fluctuations during the position task when the forearm was vertical. Two uniaxial accelerometers (Endevco 7265A-HS, San Juan Capistrano, CA) were mounted on the orthosis to measure acceleration in the frontal and sagittal planes.

EMG signals were recorded with bipolar surface electrodes (Ag-AgCl, 8-mm diameter; 20-mm distance between electrodes) that were placed over the short and long heads of biceps brachii, brachioradialis, triceps brachii, and anterior and posterior heads of the deltoid muscle. The electrodes were attached distal to the innervation zone for each muscle (21, 22). The EMG of the supraspinatus, infraspinatus, and teres minor were measured with intramuscular bipolar electrodes, which consisted of two stainless steel wires (100-μm diameter) that were insulated with Formvar (California Fine Wire, Grover Beach, CA). One wire in each pair had ~2 mm of insulation removed to increase the recording volume of the electrode. The EMG signal was amplified (×2,000), band-pass filtered (13–1,000 Hz; Coulbourn Instruments, Allentown, PA), and recorded on a personal computer. The needle placement for the infraspinatus and supraspinatus was one-third of the distance from the proximal tendon and 1 in. from the scapular border inferiorly and superiorly, respectively. The needle insertion for the teres minor was one-third of the distance from the distal tendon at the middle of the muscle belly. The needle placement for each of the three rotator cuff muscles was verified using ultrasound recordings to determine the appropriate location for each muscle. The force, position, and acceleration signals were digitized at 200 samples/s, whereas the EMG signals were digitized at 2,000 samples/s.

HR and blood pressure were recorded at 200 samples/s during the sustained, submaximal contractions 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 right hand, and the relaxed arm was positioned with the hand at heart level. Additionally, the rating of perceived exertion (RPE) was measured with the modified Borg 10-point scale (1). The subjects were instructed to focus the assessment of effort on the arm and shoulder muscles performing the task. The scale was anchored so that 0 represented the resting state and 10 corresponded to the strongest effort that arm and shoulder muscles could perform.

**Experimental protocol.** All four tasks included measurements of the MVC force and EMG for the elbow flexor and extensor muscles, anterior and posterior deltoid, supraspinatus, infraspinatus, and teres minor, and a sustained submaximal contraction to task failure. The order of the fatiguing contractions was counterbalanced across sessions. Subjects were not informed of the times to task failure until completion of all four sessions.

MVC force. A modified wrist-hand-thumb orthosis was rigidly attached to a force transducer. The MVC task comprised a 3-s increase in force from zero to maximum, and the maximal force was held for 2–3 s, while the subjects were verbally encouraged to achieve maximal force (6). There was a 60- to 90-s rest between trials. Additional trials were performed when the peak forces from two of the three trials

![Fig. 1. Experimental arrangement. Subjects were seated upright in an adjustable chair with the nondominant (left) forearm in a horizontal (A) or vertical (B) posture. The left hand and the forearm were placed in a modified wrist-hand-thumb orthosis. The position task involved supporting an inertial load that was suspended from the wrist (A). The force task involved pulling against a force transducer (B). Measurements were made with an accelerometer (a), electromyogram (EMG) electrodes (b), a goniometer (c), and an elbow force transducer (d).](http://jap.physiology.org/Downloadedfrom)
differed by >5%. The greatest force achieved by each subject was taken as the MVC force and used as the reference value to calculate the target force for the fatiguing contraction.

Fatiguing contraction. Subjects were required to sustain each submaximal contraction until failure. The criteria for task termination for the force task were 1) an inability to sustain the force within 5% of the target force for >5 s, and 2) elevation of the elbow off the pad or away from the elbow force transducer for >5 s without correction, despite strong verbal encouragement. The criteria for ending the position task included 1) an inability to maintain the elbow angle within 0.2 rad of the target for >5 s, and 2) displacement of the left forearm from the neutral position for >5 s without correction, despite the urging of the investigators. The required arm postures were monitored by visual observation, and feedback was provided to the subject by the same investigator for all experiments. The elbow force and joint angle signals were monitored using Labview (version 7.1 with PCI-6052E, National Instruments, Austin, TX), and an acoustic signal was sounded when the signals departed from the target values for >5 s.

Data analysis. All data were analyzed off-line using the Spike2 data analysis system (Cambridge Electronic Design, Cambridge, UK). HR and MAP during the fatiguing contractions were quantified as 15-s averages at 10% increments of task duration. The blood pressure signal was analyzed in 15-s intervals for mean systolic blood pressure (SBP), mean diastolic blood pressure (DBP), and the number of pulses per second to determine HR. MAP was calculated as MAP = DBP + 1/3 (SBP − DBP). MAP, HR, and RPE scores were plotted as a function of absolute time for each fatiguing contraction. The rate of change in aEMG of each muscle during the fatiguing contractions was quantified by averaging the rectified aEMG for the rotator cuff muscles was greater (10.9%). An interaction between arm posture and time indicated that the aEMG across tasks was greater during the horizontal posture (20.5 ± 3.0, 25.1 ± 3.3, and 32.6 ± 4.1 N in the horizontal and vertical postures, respectively, P < 0.001). MVC force was similar in the force and position tasks in the horizontal posture (309 ± 45 and 307 ± 43 N) and in the vertical posture (264 ± 55 and 259 ± 41 N, P > 0.5).

The target force was 62 ± 9 N in the horizontal posture and 52 ± 10 N in the vertical posture (P < 0.001). The time to task failure was longer for the force task than for the position task when the forearm was horizontal (8.8 ± 3.6 and 5.2 ± 2.6 min, P = 0.003) but not when the forearm was vertical (7.9 ± 4.1 and 7.8 ± 4.5 min, P = 0.99). The associations between MVC force and time to failure were not significant for any of the four tasks (P > 0.116).

EMG amplitude. The EMG activity for both the rotator cuff muscles and the elbow flexor muscles increased during the fatiguing contractions, as indicated by the representative data shown in Fig. 2. The amplitude of the aEMG increased with time (time main effect; P < 0.001) for supraspinatus (10.7 ± 7.3 to 29.7 ± 20.8% MVC), infraspinatus (14.2 ± 9.8 to 32.6 ± 21.1% MVC), and teres minor (13.4 ± 8.8 to 34 ± 22.4% MVC) during the force and position tasks in the two arm postures (Fig. 3). A main effect for task (P < 0.007) indicated that the aEMG across tasks was greater during the position task compared with the force task for supraspinatus (20 ± 15.3 vs. 14.8 ± 10.4%), teres minor (26.2 ± 16.9 vs. 17.5 ± 13.7%), and infraspinatus (27.0 ± 17.8 vs. 15.3 ± 10.9%). An interaction between arm posture and time indicated that the aEMG for the rotator cuff muscles was greater (P < 0.001) in the horizontal forearm position at all six time points. As quantified by the exponential coefficient eα, the interaction between task and posture was due to a greater rate of increase in EMG activity for the supraspinatus (P = 0.05), infraspinatus (P = 0.004), and teres minor (P = 0.002) during the position task with the forearm in the horizontal posture compared with the force task (Table 1).

The amplitude of the aEMG for all elbow flexor muscles increased with time (10.4 ± 6.3 to 21.4 ± 11.5% MVC; time main effect; P < 0.001). A main effect for posture indicated that the EMG activity averaged across all elbow flexor muscles was greater during the horizontal posture (15.3 ± 9.7% MVC) compared with the vertical posture (14.5 ± 8.8% MVC, P = 0.01). There were no task differences in EMG activity of the elbow flexor muscles (P = 0.5), and there was no interaction between task and posture (P = 0.114). The rate of increase in the short and long heads of biceps brachii, brachioradialis, triceps brachii, anterior and posterior deltoid, supraspinatus, infraspinatus, and teres minor during the submaximal contraction.

Slopes derived from aEMG and MAP were plotted as a function of time for each fatiguing contraction and used for all statistical comparisons involving rates of increase in the dependent variable of interest. Paired t-tests (independent and dependent) with Bonferroni corrections were used as post hoc analyses to test differences among pairs of means when appropriate. Bivariate linear regression analyses were performed between rate of increase in aEMG of each muscle and the rate of increase in MAP and MVC force and time to failure during each task. A significance level for all statistical tests was set at P < 0.05, except when modified by the Bonferroni correction. Data are reported as means ± SD within the text, and they are displayed as means ± SE in Figs. 3 and 4.

RESULTS

An interaction between task and arm posture indicated that the MVC force was greater when the forearm was horizontal (308 ± 43 N) than when it was vertical (261 ± 47 N, P < 0.001). MVC force was similar in the force and position tasks in the horizontal posture (309 ± 45 and 307 ± 43 N) and in the vertical posture (264 ± 55 and 259 ± 41 N, P > 0.5).

The results were analyzed off-line using the Spike2 data analysis system (Cambridge Electronic Design, Cambridge, UK). HR and MAP during the fatiguing contractions were quantified as 15-s averages at 10% increments of task duration. The blood pressure signal was analyzed in 15-s intervals for mean systolic blood pressure (SBP), mean diastolic blood pressure (DBP), and the number of pulses per second to determine HR. MAP was calculated as MAP = DBP + 1/3 (SBP − DBP). MAP, HR, and RPE scores were plotted as a function of absolute time for each fatiguing contraction. The rate of change in each of these variables was quantified by the slope of a linear fit to the data for individual trials.

The maximal EMG for each muscle was calculated as the average value over a 0.5-s interval about the peak MVC force. The EMG activity of the elbow flexors, elbow extensors, the anterior and posterior deltoid, supraspinatus, infraspinatus, and teres minor during the fatiguing contractions was quantified by averaging the rectified EMG over the first and last 30 s of task time and over 30-s intervals centered around the 20, 40, 60, and 80% time points. EMG values were normalized to the aEMG obtained during the MVC. The EMGs of the anterior and posterior deltoid were normalized to the maximal EMG obtained when the seated subject performed either a maximal shoulder flexion or extension. The EMGs of supraspinatus, infraspinatus, and teres minor were normalized to the values recorded during a maximal external rotation of the shoulder joint in a seated position.

The maximal EMGs recorded for both horizontal and vertical forearm postures. The rate of change in aEMG of each muscle during each task was quantified by the slope of an exponential fit to the data for individual trials. The coefficient eα was used as an indicator of the rate of increase.

The fluctuations in motor output were characterized as the average SD of the resultant force during the force task and the resultant acceleration during the position task derived from the measurement of force and acceleration in the forward-backward (sagittal plane) and side-to-side (frontal plane) directions. The average values obtained during the first and last 30 s and for 30-s time intervals around the 20, 40, 60, and 80% time points were used for analysis. The force and acceleration fluctuations were expressed as the percent change relative to the values obtained at the beginning of each task.

Statistical analysis. The independent variables were HR, MAP, RPE, target force, SD of limb acceleration and force, and aEMG activity. The times to task failure, MVC forces, and rates of increases in aEMG, MAP, HR, and fluctuations were compared with a two-factor, repeated-measures ANOVA (arm posture × task). A three-factor (task × arm posture × time) ANOVA with repeated measures on task, arm posture, and time was used to compare the SD of acceleration and force, HR, MAP, and RPE. A four-factor (task × arm posture × time × muscle) ANOVA with repeated measures on task, arm posture, time, and muscle was used to compare the aEMG of the...
EMG activity for the elbow flexor muscles was similar for force and position tasks in the two forearm postures (task × posture; $P > 0.34$). When the forearm was horizontal, however, the aEMG for the elbow flexor muscles at the end of the contraction (last 40%) was greater for the force task (23.1 ± 11%) compared with the position task (17.2 ± 6.4%, $P = 0.0007$).

The aEMG of the triceps brachii increased with time (6.5 ± 6.6 to 12.4 ± 11.1% MVC; time main effect; $P < 0.001$) and did not differ between tasks and arm postures (task, $P = 0.415$; posture, $P = 0.07$; task × arm posture, $P = 0.217$).

The amplitude of the aEMG for anterior and posterior deltoid increased with time (5.1 ± 5 to 14.3 ± 12.2% and 3.4 ± 5.8 to 16.4 ± 15.8% MVC, respectively; time main effect, $P < 0.001$). There were no differences in the aEMG of the anterior and posterior deltoid during the force and position tasks in the two arm postures (task × arm posture; $P = 0.163$). However, the rate of increase in the aEMG for posterior deltoid was greater during the position task with the forearm in the horizontal posture compared with the vertical posture (task × arm posture; $P = 0.008$).

**MAP, HR, and RPE.** MAP increased during the submaximal contractions (time main effect, $P < 0.001$), beginning and ending with similar values ($P > 0.05$) for all four fatiguing contractions. An interaction between task and posture ($P = 0.039$) indicated that MAP increased at a greater rate during the position task with the forearm in the horizontal posture (Fig. 4A). Bivariate regression analysis indicated that the rate of increase in MAP was associated with the rates of increase in EMG activity for the rotator cuff ($r^2 = 0.42$, $P = 0.002$) and the posterior deltoid ($r^2 = 0.37$, $P = 0.004$) muscles during the position task when the forearm was horizontal. The association between the rates of change in MAP and EMG activity was not significant for any of the other three tasks.

HR was similar at the start of the contraction for the position and force tasks with the forearm in horizontal and vertical postures (89 ± 12 and 82 ± 15 beats/min; $P > 0.05$), but it was greater at the end of the force and position tasks when the forearm was horizontal compared with the vertical posture (114 ± 18 and 105 ± 13 beats/min; $P = 0.037$) (Fig. 4B).

There were no differences in RPE for the force and position tasks in the two arm postures (task × arm posture × time; $P = 0.904$) (Fig. 4C). RPE began at a similar value for all four fatiguing contractions, but it increased at a greater rate when the forearm was horizontal (posture main effect; $P = 0.003$).

**Fluctuations in force and acceleration.** The amplitude of the fluctuations in acceleration and force increased progressively during all four tasks (time main effect; $P < 0.001$). The initial fluctuations of limb acceleration during the position task when the forearm was in the horizontal and vertical arm postures were 0.18 ± 0.11 and 0.2 ± 0.12 m/s², respectively. The initial force fluctuations during the force task in the horizontal and vertical arm postures were 3.2 ± 2 and 2.5 ± 1.9 N, respectively. The relative increase in the acceleration fluctuations during the position task in horizontal and vertical forearm postures (mean increase 467 ± 343% at end) was greater than the relative increase in the force fluctuations during the two force tasks (mean increase 208 ± 148% at end; task main effect; $P = 0.008$).

**DISCUSSION**

The main finding of this study was that the briefer time to failure for the position task with the forearm horizontal was accompanied by more rapid rates of increase in EMG activity of accessory muscles and MAP compared with the force task and the two tasks with the forearm vertical. In contrast, the rate of increase in EMG activity of the elbow flexor muscles was similar across the tasks. These results suggest that the involvement of more muscles during the position task when the forearm was horizontal enhanced the pressor response and reduced time to task failure.

The present results confirmed previous studies, which demonstrated differences in time to failure for the position and force tasks when the arm was in the two postures. As with previous studies, the time to failure of a sustained submaximal contraction when the forearm was horizontal and in a neutral position was longer when the wrist pushed against a rigid restraint (force task) compared with when the subject exerted...
the same net muscle torque to maintain limb position (position task) (10). There was no difference in time to failure, however, when the forearm was in a vertical and neutral posture (26). The time to failure of a sustained, submaximal contraction can be influenced by the activity of synergist muscles and by the distribution of activation within a muscle (5, 16, 32, 34–36). Similar to previous studies (10, 24, 26), the rates of increase in aEMG were similar among the elbow flexor muscles for all four tasks and therefore could not explain the difference in time to failure for the two tasks when the forearm was horizontal. Furthermore, aEMG amplitude at the end of the position task when the forearm was horizontal was less than that for the force task, which suggests a difference in total motor unit activity at the end of the two tasks (10).

However, the briefer time to failure for the position task when the forearm was horizontal was accompanied by a more rapid rate of rise in MAP (10, 23, 24). These different adjustments during the two different arm-shoulder positions emphasize the significance of limb posture in influencing task performance. This finding is consistent with the observation of Palmerud et al. (25) that external factors, such as arm posture and hand load, influence the development of intramuscular pressure in the shoulder muscles, especially the rotator cuff muscles, and, consequently, lead to an increase in peripheral resistance to blood flow. Accordingly, the different rates of increase in MAP suggest that the involved muscle mass was greater when subjects performed the position task with the forearm in the horizontal posture (18, 30, 31, 33).

Previous observations demonstrated different EMG activity of accessory muscles in the two limb postures. The rate of increase in the EMG activity of anterior deltoid was greater during the position task compared with the force task when the forearm was horizontal (10) but not when the forearm was vertical (27). In the present study, the EMG activity of the accessory muscles (supraspinatus, infraspinatus, teres minor, posterior deltoid) increased more rapidly during the position task when the forearm was horizontal, whereas the rate of increase was similar for the two tasks when the forearm was vertical. These differences suggest that involvement of the accessory muscles was more substantial when the forearm was in the horizontal posture. The increased activity of the accessory muscles when the forearm was horizontal can be attributed to the external rotation torque that was required to maintain the position of the slightly abducted (~0.25 rad) arm in a sagittal plane when supporting the inertial load (position task) but not when restrained by the force transducer (force task). Similarly, Le Bozec and Bouisset (17) found that the capacity to perform bimanual pushes at 75% MVC force was limited by the activity of postural muscles that controlled the pelvic girdle.

Table 1. Rate of increase (exponential coefficient $e^a$) in EMG activity for the supraspinatus, infraspinatus, teres minor, and posterior deltoid during the four tasks with the forearm in vertical and horizontal postures

<table>
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<tr>
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<th>Vertical</th>
<th>Position</th>
<th>Horizontal</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supraspinatus</td>
<td>1.0032±0.0005</td>
<td>1.0039±0.0007</td>
<td>1.002±0.0004</td>
<td>1.0043±0.0006</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>1.0036±0.0006</td>
<td>1.0025±0.0003</td>
<td>1.0019±0.0003</td>
<td>1.0033±0.0005</td>
</tr>
<tr>
<td>Teres minor</td>
<td>1.0030±0.0006</td>
<td>1.0028±0.0004</td>
<td>1.0020±0.0005</td>
<td>1.0045±0.0005</td>
</tr>
<tr>
<td>Posterior deltoid</td>
<td>1.0044±0.0001</td>
<td>1.0054±0.0009</td>
<td>1.0045±0.0008</td>
<td>1.0092±0.0001</td>
</tr>
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Values are means ± SD. *$P < 0.05$ between force and position tasks.
There was a strong association between the rates of increase in MAP and aEMG of the accessory muscles (rotator cuff and posterior deltoid) during the position task when the forearm was horizontal but not for the other tasks. The increase in MAP (pressor response) to sustained muscular contraction is mainly attributed to metabolite stimulation of group III-IV afferents by biochemical agents (14, 15). Group III-IV afferent discharge has been shown to increase during fatiguing contractions and likely depend on various task-related variables, such as intensity of muscle contraction and amount of muscle mass involved (14, 15).

Presumably, the feedback delivered by group III-IV afferents paralleled the increase in MAP and was greatest during the position task when the forearm was horizontal (13–15). Although it is often assumed that feedback by group III-IV afferents during fatiguing contractions depresses the excitability of motor neuron pools (7, 8), Butler et al. (3) demonstrated that potentials evoked by cervicomedullary stimulation recovered within 15 s after the fatiguing contraction, despite the muscle being held ischemic, and, therefore, the recovery occurred in the presence of continued group III-IV feedback. In the present study, there was no difference in the rate of increase in aEMG for the elbow flexor muscles across tasks, which suggests that the presumed difference in group III-IV feedback did not evoke a significant effect on the motor neuron pools of the prime mover muscles. This interpretation, however, must be tempered by the inability of surface EMG recordings to reflect modest changes in motor unit activity. For example, Mottram et al. (24) found that greater changes in rate coding and the recruitment of additional motor units during the position task were accompanied by similar increases in aEMG during the force and position tasks. Consequently, the potential role of group III-IV feedback in contributing to the briefer duration for one task needs to be examined with single motor unit recordings.

One interpretation suggested by the present study is that the difference in the time to failure is not attributable to the type of load supported by the limb but rather is due to the demands imposed on the accessory muscles. However, observations of a difference in motor unit activity (24, 29) and a difference in the rate of increase in aEMG for a hand muscle (20) during the two tasks indicates that the control strategy used by the central nervous system differs for these two tasks. Taken together with the results of the present study, these findings suggest that the type to failure for sustained submaximal contractions can be limited by, at least, factors related to the type of load supported by the limb and the posture of the limb.

GRANTS
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Fig. 4. Mean arterial pressure (MAP), heart rate (HR), and ratings of perceived exertion (RPE) during the force and position tasks in vertical and horizontal forearm postures. A: the MAP was similar at the start of the contractions, but it increased at a greater rate (based on a slope analysis) during the position task with the forearm horizontal ($P = 0.039$). B: HR was similar at the start of the contractions, but it was greater at the end of the contraction when the forearm was horizontal compared with the vertical posture ($P = 0.037$). C: the RPE was similar at the start of the contractions but increased at a greater rate (based on a slope analysis) when the forearm was horizontal ($P = 0.003$). Values are indicated as means ± SE. Measurements were made at the beginning of each task and at increments of 20% of task duration. bpm, Beats/min.
REFERENCES