Men are more fatigable than strength-matched women when performing intermittent submaximal contractions

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Hunter, Sandra K., Ashley Critchlow, In-Sik Shin, and Roger M. Enoka. Men are more fatigable than strength-matched women when performing intermittent submaximal contractions. J Appl Physiol 96: 2125–2132, 2004. First published February 13, 2004; 10.1152/japplphysiol.01342.2003.—The purpose of this study was to compare the time to task failure for a series of intermittent submaximal contractions performed with the elbow flexor muscles by men and women who were matched for strength (n = 20, 18–34 yr). The fatigue task comprised isometric contractions at 50% of maximal voluntary contraction (MVC) torque (6-s contraction, 4-s rest). The MVC torque was similar for the men and women [64.8 ± 9.2 (SD) vs. 62.2 ± 7.9 N·m; P > 0.05]. However, the time to task failure was longer for the women (1,408 ± 1,133 vs. 513 ± 194 s; P < 0.05), despite the similar torque levels. The mean arterial pressure, heart rate, and rating of perceived exertion started and ended at similar values for the men and women, but the rate of increase was less for the women. The rate of increase in the average of the rectified electromyogram (AEMG; % peak MVC) for the elbow flexor muscles was less for the women: the AEMG was greater for the men compared with the women at task failure (72 ± 28 vs. 50 ± 21%; P < 0.05), despite similar AEMG values at the start of the fatiguing contraction (32 ± 9 vs. 36 ± 13%). These results indicate that for intermittent contractions performed with the elbow flexor muscles 1) the sex difference in time to task failure was not explained by the absolute strength of the men and women, but involved another mechanism that is present during perfused conditions, and 2) men required a more rapid increase in descending drive to maintain a similar torque.

A SEX DIFFERENCE IN THE TIME TO TASK FAILURE FOR A SUSTAINED, LOW-INTENSITY CONTRACTION PERFORMED WITH THE ELBOW FLEXOR MUSCLES IS OBSERVED WHEN YOUNG MEN ARE STRONGER THAN YOUNG WOMEN (22, 32, 35) BUT NOT WHEN MEN AND WOMEN ARE MATCHED FOR STRENGTH (21). WHEN THE TWO SEXES WERE NOT MATCHED FOR STRENGTH, THE LONGER DURATION THAT WOMEN COULD SUSTAIN A LOW-INTENSITY CONTRACTION WITH THE ELBOW FLEXOR MUSCLES WAS DUE TO A LESSER ABSOLUTE TARGET FORCE (21, 22). THESE FINDINGS WERE RELATED TO THE INCREASE IN MEAN ARTERIAL PRESSURE (MAP; PRESSOR RESPONSE) AND CONSISTENT WITH THE HYPOTHESIS THAT STRONGER MEN EXPERIENCE GREATER OCCULSION OF BLOOD FLOW DURING THE MORE FORCEFUL CONTRACTIONS (2), LEADING TO A GREATER ACCUMULATION OF METABOLITES, LESS OXYGEN SUPPLY, AND BRIEFER CONTRACTIONS.


A previous report indicated that the rate of increase in electromyogram (EMG) activity and the EMG amplitude at task failure for an isometric contraction sustained at a submaximal intensity were less for women compared with strength-matched men, despite a similar time to task failure (21). Therefore, a secondary purpose was to compare the EMG activity for the series of intermittent contractions performed with the elbow flexor muscles by strength-matched subjects. The results indicated that the time to task failure was longer in women compared with strength-matched men, and this was accompanied by a lesser rate of increase in MAP, heart rate, rating of perceived exertion (RPE), and torque fluctuations for the women. Furthermore, the EMG activity at task failure and the rate of increase in the EMG during the contraction were less in the women compared with the men. Preliminary accounts of these results have been presented in abstract form (10).

METHODOLOGY

Sixty-seven healthy young adults (18–34 yr) volunteered to participate in the study. Eleven men and 14 women were selected to complete the experimental protocol and 10 men and 10 women (21 ± 4 yr) were matched for strength on the basis of the torque exerted at the wrist during a maximal voluntary contraction (MVC). Each pair of subjects was matched within 5% of the maximal torque exerted by the elbow flexor muscles. When several subjects could be matched for strength within the 5% criterion, those who were most similar in their

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reported physical activity levels were selected as a pair. None of the subjects had any known neurological disorder or cardiovascular disease, and all were naive to the experimental protocol and procedures. Before participation in the study, all subjects gave informed consent, and the Human Subjects Committee at the University of Colorado approved the protocol.

The physical activity level for each subject was assessed by estimating the kilocalorie expenditure per week by using a modifiable activity questionnaire (28). The physical activity levels are reported as metabolic equivalents (MET)-h/wk. Arm dominance was determined by using the Edinburgh Handedness Inventory (31) and indicated that all subjects were right-handed. The day of the menstrual cycle on which each female participant performed the experimental protocol was recorded. The first day of menstruation was considered as day 1 of the cycle.

Mechanical Recording

Subjects were seated upright in an adjustable chair with the non-dominant arm abducted slightly and the elbow resting on a padded support. The elbow joint was flexed at 1.57 rad so that the forearm was horizontal to the ground and the force at the wrist was directed upward when the elbow flexor muscles were activated voluntarily. 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 oriented midway between pronation and supination. The forces exerted by the wrist in the vertical and horizontal (side-to-side) directions were measured with a force transducer (Force-Moment Sensor, JR-3, Woodland, CA) that was mounted on a custom-designed, adjustable support. The orthosis was rigidly attached to the force transducer. The forces detected by the transducer were recorded online by using a Power 1401 A-D converter and Spike2 software [Cambridge Electronics Design (CED), Cambridge, UK]. The force exerted in the vertical direction was displayed on a 17-in. monitor located 1.5 m in front of the subject.

Electrical Recordings

EMG signals were recorded with bipolar surface electrodes (Ag-AgCl, 8-mm diameter; 16-mm distance between electrodes) that were placed over the middle of the long head of biceps brachi, the short head of biceps brachi, and triceps brachi muscles, and 2 cm distal to the antecubital fossa for the brachioradialis. Reference electrodes were placed on a bony prominence at the elbow or shoulder. The EMG of the brachial muscle was measured with an intramuscular bipolar electrode consisting 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 the insulation removed at the tip for ~2 mm to increase the recording volume of the electrode. The electrode was inserted into the muscle 4–5 cm proximal to the antecubital fold with a hypodermic needle that was removed immediately after insertion. A surface electrode (8-mm diameter) placed on a bony prominence served as the reference electrode. The EMG signal was amplified (500–2,000 ×) and band-pass filtered (13–1,000 Hz for the surface and intramuscular EMGs) with Coulbourn modules (Coulbourn Instruments, Allentown, PA) before being recorded directly to computer by using the Power 1401 A-D converter (CED) 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 relaxed, dominant hand with the arm placed on a table adjacent to the subject at heart level. The blood pressure signal was recorded online by a computer.

Experimental Protocol

Before the experimental session, each subject visited the laboratory for an introductory session to become familiar with the equipment and procedures by performing several trials of the MVC task and practicing the timing of the intermittent contractions for the fatiguing task. All subjects were naive to the experimental protocol and procedures before the familiarization session. The protocol included an assessment of the MVC force for the elbow flexor and elbow extensor muscles, determination of the EMG at various contraction intensities for the elbow flexor muscles, performance of a fatigue task that comprised a series of intermittent isometric contractions preformed at 50% MVC (6 s of contraction followed by 4 s of rest) with an MVC once every minute, and measurement of the MVC force for the elbow flexor muscles at 1, 2, and 3 min after termination of the fatiguing task.

MVC torque. Each subject performed three MVC trials with the elbow flexor muscles, followed by three trials with the elbow extensor muscles. The MVC task consisted of a gradual increase in force from zero maximum over 3 s, with the maximal force held for 2–3 s. The force exerted by the wrist was displayed on a 17-in. 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 (17). If the peak forces from two of the three trials were not within 5% of each other, additional trials were performed until this was accomplished. The greatest force achieved by the subject was taken as the MVC force and used as the reference to calculate the 50% target level for the intermittent fatiguing contraction. The MVC torque was calculated as the MVC force multiplied by the distance between the elbow joint and the contact point of the wrist with the force transducer. The calculated torque was used to match the men and women for strength.

EMG activity. The EMG activity of the involved muscles was recorded in standardized tasks so that the EMG-torque relation could be compared between men and women in the nonfatigued state. 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 torque. The subject was given a 30-s rest between each contraction. The similarity of these relations for the two groups of subjects ensured that changes in EMG during the fatigue task represented physiological adjustments and were not due to differences in recording conditions.

Intermittent fatiguing contractions. The fatiguing contractions of the elbow flexor muscles were performed at a target value of 50% MVC torque. The subject was required to match the vertical target torque as displayed on the monitor and was verbally encouraged to sustain the torque during the intermittent contractions. The subject was cued by a metronome to perform repeated 6-s isometric contractions at 50% MVC torque followed by 4 s of rest (3) (Fig. 1). Once every minute, an MVC was performed during the 6-s contraction period with a gradual increase in force from zero to maximum for the first 3 s, and the maximal force was held for the remaining 3 s. The fatiguing task was terminated when the torque declined by 10% of the 50% target value for greater than ~5 s or when the subject lifted the elbow off the support for greater than ~5 s, despite strong verbal encouragement. Neither the subject nor the investigator who terminated the task knew the time during the task.

As an index of perceived effort, the RPE was assessed with the modified Borg 10-point scale (5). The subjects were instructed to focus on the assessment of effort of the arm muscles performing the task during the series of contractions. 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 fatigue task.

Data Analysis

All data collected during the experiments were recorded online using a Power 1401 A-D converter (CED) and analyzed offline using
the Spike2 data-analysis system (CED). The force and blood pressure signals were digitized at 500 samples/s, whereas the EMG signals were digitized at 2,000 samples/s.

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

The fluctuations in torque during the fatiguing contraction were quantified in the vertical and horizontal (side-to-side) directions as the SD of torque for a 3-s window during the first and last contractions and during the 50% MVC contractions closest in time to 25, 50, and 75% of task duration.

The EMG activity of the elbow flexor muscles and elbow extensor muscles during the fatiguing contraction was quantified as the averages of the rectified EMG (AEMG) over 3-s intervals during the first and last contractions and during contractions closest in time to 25, 50, and 75% of the task duration. The EMG was normalized to the peak EMG obtained during the MVC.

Heart rate and MAP recorded during the fatiguing contraction were analyzed by comparing ~6 s at 25% intervals throughout the fatiguing contraction. For each interval, the blood pressure signal was analyzed for the mean peaks [systolic blood pressure (SBP)], mean troughs [diastolic blood pressure (DBP)], and the number of pulses per second (multiplied by 60 to determine heart rate). MAP was calculated for each epoch with the following equation: MAP = DBP + 1/3(SBP − DBP).

Statistical Analysis

Data are reported as means ± SD within the text, and displayed as means ± SE in the figures. A one-way ANOVA (StatView, SAS Institute) was used to compare the time to task failure between the strength-matched men and women. Separate two-factor ANOVAs (sex × time) with repeated measures on time were used to compare the heart rate, MAP, RPE, percent decline in MVC torque, force under the elbow joint, and SD of torque in the vertical and side-to-side directions. A three-factor ANOVA (sex × intensity × muscle) with repeated measures on intensity was used to compare the EMG-torque relation for the 6-s constant-torque contractions. Separate three-factor ANOVAs (sex × time × muscle) with repeated measures on time were used to compare the AEMG during the fatiguing contraction. The average slope for the decline in the MVC torque that was recorded each minute during the task was quantified for the men and women by using regression analysis for each subject. Correlation analysis was used to determine the relation between day of menstrual cycle and the time to task failure. 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

Ten men (20.7 ± 4.2 yr, 65.7 ± 5.2 kg, and 176 ± 5 cm) and 10 women (21.5 ± 3.3 yr, 65.9 ± 9.9 kg, and 165 ± 9 cm) were matched for strength within 5% of maximal torque of the elbow flexor muscles (Fig. 2A). The physical activity levels were similar for the strength-matched men (137 ± 104 MET-h/wk) and women (115 ± 47 MET-h/wk; \( P > 0.05 \)).

MVC Torque

MVC torque performed before the fatiguing contraction was similar for the men (\( n = 10; \) 64.8 ± 9.2 N-m) and women (\( n = 10; \) 62.2 ± 7.9 N-m) who were matched for strength (\( P > 0.05 \); Fig. 2B). The MVC torque was recorded every minute during the fatiguing task. The men showed an average decline in MVC torque of 3.0 N-m/min and the women 0.97 N-m/min (\( P < 0.05 \)). Recovery of MVC torque was quantified each minute for 3 min after task failure. Women showed a trend for enhanced recovery compared with the men, despite a longer time to task failure (\( P = 0.08 \), moderate effect size of 0.42). After 1 min of recovery, the MVC torque for the men was 73 ± 7% and for the women was 79 ± 8% of the initial value. At minute 2 of recovery, the men and women were 72 ± 6 vs. 77 ± 5%, and at minute 3 of recovery 74 ± 6 vs. 77 ± 5%, of the initial value, respectively.

Time to Task Failure

Each subject exerted a torque of 50% MVC during the intermittent contractions. Because the MVC torque was similar

![Fig. 1. Records of a man performing an intermittent fatiguing contraction at 50% of maximal voluntary contraction (MVC) torque with the elbow flexor muscles. Repeated isometric contractions were sustained for 6 s followed by 4 s of rest. Once every 1 min, an MVC was performed. The interference electromyogram (EMG) of the elbow flexor muscles (top 4 traces) increased throughout the fatiguing task. The amplitude of the torque fluctuations increased progressively throughout the task.](http://jap.physiology.org/Downloadedfrom)
for the men and women, target torque maintained throughout the contraction was similar for the two sexes (31.4 ± 4.5 vs. 30.6 ± 4.2 N·m, respectively; P > 0.05). However, the time to task failure was longer for the women (1,408 ± 1,133 s) compared with the men (513 ± 194 s; P > 0.05). In seven of the 10 matched pairs, the women performed a longer time to task failure than the strength-matched men (Fig. 3). In the other three cases, the task duration was similar.

Neither the force exerted under the elbow during the fatigue task nor the phase of the menstrual cycle for the women influenced the time to task failure. Although the force under the elbow was variable between subjects, the average forces did not differ throughout the fatiguing contractions for the strength-matched men (94 ± 66 N) and women (95 ± 76 N; P > 0.05). Furthermore, there was no association between the time to task failure and the day of the menstrual cycle for the women (r² = 0.04, P > 0.05).

MAP and Heart Rate

MAP increased during the fatiguing contractions (P < 0.05) for the strength-matched men and women. The MAP began at 96 ± 11 mmHg for men and 95 ± 8 mmHg for women (P > 0.05) and ended at 134 ± 14 mmHg for the men and 139 ± 12 mmHg for the women (P > 0.05). Because the time to task failure was longer for the women compared with the men (P < 0.05), the rate of rise in MAP was less for the women compared with the men (Fig. 4A).

Similarly, heart rate increased during the fatiguing contraction (P < 0.05) for both the men and women (P > 0.05). Men and women had a similar heart rate at the start of the contraction (87 ± 11 vs. 82 ± 7 beats/min; P > 0.05) and at the time of task failure (109 ± 14 vs. 109 ± 18 beats/min; P > 0.05). Because time to task failure was longer for the women (P < 0.05), the rate of rise in heart rate was less for the women (Fig. 4B).

EMG-Torque Relation

The AEMG (% peak EMG) for the elbow flexor muscles was determined during isometric contractions held at 20, 40, and 60% MVC. AEMG increased with contraction intensity for all the elbow flexor muscles (P < 0.05) and was similar for the men and women (P > 0.05) at 20% (10.0 ± 5.6 vs. 10.8 ± 5.1%), 40% (25.8 ± 8.2% vs. 26.0 ± 8.5%), and 60% (47.2 ± 10.2% vs. 51.0 ± 14.0%) of MVC torque.

Fig. 2. MVC torque of the men and women who were matched for strength. A: MVC torque of the pairs of men (n = 10) and women (n = 10) who were matched for strength within 5%. The line of identity indicates a perfect match. B: MVC torques (mean ± SE) before and after the fatiguing task for the men and women. The average of the 3 values during recovery (minutes 1, 2, and 3) is shown because the MVC torque was similar at these times for each group.

Fig. 3. Time to task failure for the pairs of men and women who were matched for strength. Data points above the line of identity indicate that the time to task failure for the woman was longer than that of the man with whom she was matched for strength.

Fig. 4. Mean arterial pressure (MAP; A) and heart rate (B) at rest and during the fatiguing contraction for men and women who were matched for strength. Values are means (±SE) of 6-s intervals at 25% increments of the time to task failure for the men and women.
Task Failure and Intermittent Contractions

Adjustments in AEMG During the Intermittent Contractions

The amplitude of the AEMG (% peak MVC) for each elbow flexor muscle of the strength-matched subjects increased during the fatiguing contraction ($P < 0.05$) (Fig. 1). However, the women had a reduced rate of increase in AEMG compared with the men, as indicated by an interaction for sex and time ($P < 0.05$, Fig. 5A). At the start of the task (first contraction: mean of 3 s), the AEMG for all the elbow flexor muscles was $32 \pm 9\%$ for the men and $36 \pm 13\%$ for the women. At the end of the fatiguing task (last contraction), the AEMG of all the elbow flexor muscles was $72 \pm 28\%$ for men and $50 \pm 21\%$ for women ($P < 0.05$; Fig. 5A).

There was an interaction for muscle and time ($P < 0.05$) because of greater values for the AEMG of the biceps short head, long head, and brachioradialis compared with the brachialis muscle at task failure. This interaction was predominately because of the men: the men showed a trend for a greater rate of increase in AEMG of the short and long heads of biceps brachii and brachioradialis muscles compared with the women (interaction of time, muscle, and sex: $P = 0.07$ with a large effect size of 0.85) (Fig. 5, B and C).

The AEMG of triceps brachii during the fatiguing contractions was substantially less than that for the elbow flexor muscles (Fig. 5, B and C). There was a small but significant increase in AEMG of the triceps brachii during the intermittent contractions, but this increase was similar for the strength-matched men and women ($P > 0.05$). The triceps AEMG was similar for the men and women at the start of the contraction ($3.6 \pm 1.5$ vs. $4.7 \pm 1.8\%; P > 0.05$) and at task failure ($8.1 \pm 3.8$ vs. $7.6 \pm 3.6\%; P > 0.05$).

Fluctuations in Torque During the Intermittent Contraction

The amplitude of the fluctuations in torque (SD) in the vertical and side-to-side directions increased progressively during the intermittent task ($P < 0.05$, Fig. 6). The fluctuations increased by $177 \pm 94\%$ from the first 6-s contraction to the last 6-s contraction in the vertical direction, and it increased by $321 \pm 360\%$ in the side-to-side direction. Although there was no main effect for sex for the vertical fluctuations ($P > 0.05$), there was an interaction of sex and time because the fluctuations were greater for the men compared with the women at the end of the fatiguing task ($P < 0.05$). The SD of torque for the vertical fluctuations during the first contraction was $0.70 \pm 0.18$ N•m for men and $0.75 \pm 0.26$ N•m for women, and it increased to $2.22 \pm 0.72$ N•m for men and $1.61 \pm 0.47$ N•m for women during the last contraction. This difference in the increase in fluctuations between the strength-matched men and women at task failure was not observed in the side-to-side direction. The SD of torque for the side-to-side fluctuations was similar in the men and women throughout the task: there was no main effect for sex ($P > 0.05$) and no interaction for time and sex ($P > 0.05$). Because the women had a longer time...
to task failure, however, the rate of increase in the side-to-side torque fluctuations during the task was less for the women (Fig. 6B).

**RPE During the Intermittent Contraction**

RPE scores were similar for men and women at the beginning and end of the fatiguing contractions ($P > 0.05$). The RPE values progressed from initial values of $1.4 \pm 0.8$ and $1.4 \pm 1.0$ for the men and women, respectively, to $9.8 \pm 0.6$ and $9.9 \pm 0.3$ at the time to task failure. However, there was a trend ($P = 0.07$, moderate effect size of 0.64) for an interaction between time and sex. This was due to the women exhibiting a larger RPE at the same relative time points (25, 50, and 75% of time to task failure). However, because the women had a significantly longer time to task failure ($P < 0.05$), the rate of rise in RPE was less for the women compared with the men.

**DISCUSSION**

The purpose of this study was to compare the time to task failure for a series of intermittent contractions performed with the elbow flexor muscles for as long as possible by men and women who were matched for strength. The time to task failure was longer for women compared with the men, despite both sexes achieving a similar target torque. The rates of increase in MAP, heart rate, and RPE were less for the women compared with the strength-matched men, but they had similar values at task failure. In contrast, the AEMG amplitude of torque fluctuations differed between the men and women: the women had less AEMG for the elbow flexor muscles at the contractions and at task failure and lesser fluctuations in the vertical torque at task failure.

**Time to Task Failure was Longer for Women**

Women were able to perform a series of intermittent contractions at 50% of MVC torque with the elbow flexor muscles for a longer duration than strength-matched men. Consistent with this finding, the rate of decline in the MVC torque was threefold greater for the men compared with the women. These results are similar to those of Fulco et al. (16) for intermittent contractions (50% MVC force) performed by men and women who were matched for the strength of the adductor pollicis muscle: 1) women were capable of a longer time to task failure, 2) women had a reduced rate of decline in MVC force, and 3) women exhibited a more rapid rate of recovery of MVC force. In contrast, strength-matched men and women produced both a similar time to task failure and a similar pressor response for an isometric contraction that was sustained at 20% of MVC with the elbow flexor muscles (21) (Fig. 7). This previous study provided evidence that the sex difference in the time to task failure for a sustained contraction was associated with the absolute force and metaboreflex for a large muscle group. However, this association does not explain the longer performance of the women relative to the strength-matched men for intermittent contractions when muscle perfusion was less constrained. Furthermore, a sex difference in muscle fatigue during maximal intermittent contraction of the tibialis anterior muscle was not present when the muscle was ischemic, only when blood flow was possible (34). Comparison of these studies indicates that the mechanism responsible for the sex difference in muscle fatigability is task dependent but may not differ across muscle groups.

**Women Exhibited a Reduced Rate of Increase in the Pressor Response**

These observations raise the question: What mechanisms are responsible for the sex difference in time to task failure for intermittent isometric contractions performed at a submaximal intensity? Some insight was provided by the relative changes in MAP, heart rate, RPE, EMG activity, and torque fluctuations. The longer time to task failure for the women was associated with a reduced pressor response during the contractions. Although the men and women began and ended the contractions at similar levels of MAP, the women had a lower MAP than the men when compared at the same absolute time, despite a similar torque requirement. Thus the pressor response was independent of the torque exerted by men and women during the intermittent contractions.

The lower rate of increase in MAP for the women was due either to less feedback via the metaboreflex or to reduced feed-forward input to the cardiovascular centers (26, 30, 33). Because of the similar target torque for the men and women, feedback from the mechanoreceptors during the intermittent contractions was likely similar for the two sexes. The feedback provided by the metaboreflex, however, may have differed because of variation in the sensitivity of the sensory receptors, metabolite production, or metabolite clearance. Because metabolite production depends on the pathways that are used to provide the energy for a contraction, a preferential reliance on lipid metabolism by women during prolonged contractions could contribute to differences in metabolite production (6, 13, 37). Nonetheless, the reactive hyperemia that occurred in each 4-s rest period between contractions (4) likely attenuated the contribution of the metaboreflex in this study. Furthermore, the similar rate of increased MAP and increase in MAP during a sustained contraction for the men and women (21) suggests that the women may have had a more efficient clearance of metabolites during the rest period of the intermittent contractions that would diminish a contribution by the metaboreflex.

The feed-forward control of the MAP involves a descending drive to the ventral medulla, which is also the primary control signal for heart rate (1, 18, 30). The women had a reduced rate of increase in heart rate during the intermittent contractions compared with strength-matched men. Hence, the feed-forward
control of descending drive to the cardiovascular centers was less for the women during the intermittent contractions, despite the similar torque for the two sexes. Consequently, central cardiovascular adjustments occurred at a lesser rate for women during the intermittent fatiguing task, and this was associated with a longer time to task failure.

**Increased Descending Drive for the Strength-Matched Men**

The AEMG increased at a slower rate for the women compared with men during the intermittent contractions, despite beginning at similar levels in the first 6-s contraction of the task. At task failure, the men had reached 72% of maximal AEMG and the women achieved 50%. This difference in AEMG at task failure was not due to recording conditions because the men and women had similar EMG-force relations before the fatiguing task. Furthermore, a similar trend in the AEMG for strength-matched men and women was observed at task failure for an isometric contraction sustained at 20% of maximum (21). For the intermittent contractions, there was a difference during the task because the men had large increases in EMG activity for the short and long heads of biceps brachii and brachioradialis muscles compared with brachialis, whereas the women showed a similar rate of increase for all elbow flexor muscles. Differences in EMG activity among the elbow flexor muscles have been associated with variation in the time to task failure for a sustained contraction (23), but this involved greater activity for the brachialis muscle (23–25). Consequently, the subjects exhibited different activation strategies for the sustained and intermittent contractions.

The progressive increase in EMG activity during a submaximal contraction represents an increase in motor unit recruitment as the active motor units fatigue, with some modulation of discharge rate of the motor units (7, 14, 19). The greater rate of increase in AEMG for the men was probably attributable to an enhanced excitatory descending drive onto the motoneuron pool, as suggested by the more rapid increases in heart rate, RPE, and torque fluctuations (8, 18, 20, 29). Because the MAP represents an autonomic adjustment (feedback + feed forward) to provide the requisite blood flow, the greater rate of increase in MAP for the men suggests that the energetic demands within the muscles differed for men and women, presumably due to the recruitment of more motor units by the men. Nonetheless, it is not apparent why the men needed greater motor unit activity.

The difference in AEMG at task failure between men and women suggests that the men had a greater proportion of the motoneuron pool activated at task failure compared with the women. Alternatively, the difference may have been caused by the effect of task duration on amplitude cancellation in the EMG signal. Because of the summation of overlapping positive and negative phases of motor unit potentials, the EMG signal underestimates the output from the spinal cord (11, 15). The amount of cancellation (loss of content in the EMG signal) depends on the duration of the motor unit potentials (27). Because potential duration increases during prolonged contractions (12, 36), the longer performance by the women may have been associated with broader potentials and a greater amount of amplitude cancellation at task failure. This explanation, however, does not account for the reduced AEMG of the women during the fatiguing task unless the women had broader potentials than men at the same absolute time points.

In summary, women were able to perform a series of intermittent contractions at a moderate intensity for a longer duration than men who were matched for strength. The rate of increase in MAP and heart rate indicated that the men and women experienced different rates of increase in central cardiovascular adjustments during the contraction but reached similar values at task failure. The men had a more rapid increase in the EMG activity, RPE, and torque fluctuations than the women, despite a similar torque requirement. Furthermore, the EMG activity among the elbow flexor muscles differed for the strength-matched men and women. These findings indicate that 1) the absolute strength exerted during intermittent contractions does not account for the greater capacity of women compared with strength-matched men; and 2) men required a greater rate of descending drive to maintain a similar torque compared with strength-matched women during an intermittent fatiguing task.

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**REFERENCES**


