

Research article

Absence of gender differences in the fatigability of the forearm muscles during intermittent isometric handgrip exercise

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Abstract

Previous studies have reported women to have a greater resistance to fatigue than men during sustained handgrip exercise, however, observed gender differences in fatigue has been shown to be a function of contraction type. The purpose of the present study was to determine if gender differences exist in forearm muscle fatigue during intermittent handgrip contractions. Women [$n = 11$, 23.5 ± 1.5 (SE) yr] and men ($n = 11$, 24.1 ± 1.5 yr) performed intermittent isometric handgrip contractions at a target force of 50% of maximal voluntary contraction (MVC) for 5 s followed by 5 s rest until task failure. Rate of fatigue was calculated from MVCs taken every 2 min during exercise, and recovery of muscle strength was measured in 5 min increments until 45 min post-task failure. Forearm muscle strength was less for women than men (W: 341.5 ± 11.9 N; M: 480.2 ± 28.0 N; $p \leq 0.05$). No gender difference was present in time to task failure (W: 793.3 ± 92.5 s; M: 684.8 ± 76.3 s) or in the decrease in muscle force generating capacity at task failure (W: $-47.6 \pm 1.0\%$; M: $-49.9 \pm 1.3\%$). Rate of muscle fatigue was found to be similar between women and men (W: $-3.6 \pm 0.5 \%$ ·min⁻¹; M: $-4.3 \pm 0.6 \%$ ·min⁻¹) and no gender difference was found in the recovery of muscle strength following task failure. In summary, no gender difference was found in the fatigability of the forearm muscles during intermittent submaximal handgrip contractions, independent of muscle strength.

Key words: Muscle fatigue, gender differences, handgrip.

Introduction

The underlying events leading to muscle fatigue, defined as a decrease in the maximum force-generating capacity of muscle (Bigland-Ritchie et al., 1978), continue to be examined because of the limiting effect that muscle fatigue has on exercise tolerance in both health and disease. Previous studies have shown that gender differences exist in skeletal muscle fatigue (for review see Hicks et al., 2001), with a number of studies demonstrating untrained, healthy women to experience a lower decrement in muscle strength following an exercise task and/or perform the task for a longer period of time as compared to untrained, healthy men (Fulco et al., 1999; Hunter and Enoka, 2001; Hunter et al., 2004; Russ and Kent-Braun, 2003; West et al., 1995). This general finding has often been described as a greater relative resistance to muscle fatigue in women as compared to men, however, this is not a universal finding (Ditor and Hicks, 2000; Kent-Braun et al., 2002).

Handgrip contractions has been widely used in studies examining forearm muscle fatigue (Ettinger et al., 1996; Pitcher and Miles, 1997) and the forearm blood

flow response to exercise (Barnes, 1980; Kagaya and Ogita, 1992). The main forearm muscles involved in handgrip contractions are the flexor digitorum profundus, flexor digitorum superficialis, and the flexor and extensor carpi. Gender differences in the fatigability of the forearm muscles have been previously investigated during sustained isometric handgrip contractions. During this type of contraction it has been found that untrained women exhibit a longer endurance time than untrained men throughout a range of intensities (30-75% MVC) (Petrofsky et al., 1975; West et al., 1995). However, gender differences in the fatigability of the forearm muscles during intermittent handgrip exercise has not been examined, but would be of interest to the sports medicine specialist since intermittent handgrip contractions are utilized in physical activities such as sport climbing (Watts and Drobish, 1998) and racquet sports (Chow et al., 1999), and overuse of the forearm muscles has been previously described to result in musculoskeletal disorders (Bilic et al., 2001).

The observed gender difference in forearm muscle fatigue following sustained isometric handgrip exercise can be attributed to limited blood flow by intramuscular pressure in stronger men contracting at a greater absolute force but similar relative contraction intensity as weaker women. Reduced blood flow contributes to muscle fatigue by means of decreased delivery of oxygen and glucose, and also by insufficient removal of metabolic byproducts (H^+ , P_i , H_2PO_4) associated with muscle fatigue (Fitts, 1994). In contrast, the hyperemic response that occurs between intermittent handgrip contractions minimizes the effect of mechanical compression on limiting forearm muscle blood flow, thus a different mechanism is responsible for the gender difference in muscle fatigue that has been reported during intermittent isometric exercise (Fulco et al., 1999; Gonzales and Scheuermann, 2006; Hunter et al., 2004). Using the fatigue protocol described by Lewis and Fulco (1998), we have recently shown untrained women have a slower rate of inspiratory muscle fatigue than untrained men during intermittent isometric exercise (Gonzales and Scheuermann, 2006), consistent with findings in the adductor pollicis muscle (Fulco et al., 1999). Since the activation of muscle is largely dependent on the task and has been shown to vary between muscles that contribute to a functional load (Clark et al., 2003; Hunter et al., 2003), we postulated that gender differences in forearm muscle fatigue from intermittent handgrip exercise may be different than skeletal muscle groups comprised of a single muscle like the adductor pollicis muscle (Fulco et al., 1999) or the diaphragm (Gonzales

and Scheuermann, 2006). To investigate this hypothesis, we recruited the same subjects recently examined during an inspiratory muscle fatigue study (Gonzales and Scheuermann, 2006) and followed the same protocol during intermittent isometric handgrip exercise to determine if women will demonstrate a slower rate of forearm muscle fatigue and/or a longer duration to task failure than men as previously reported (Fulco et al., 1999; Gonzales and Scheuermann, 2006).

Methods

Subjects

Twenty-two healthy, untrained women ($n = 11$) and men ($n = 11$) provided written informed consent after being explained all experimental procedures, the exercise protocol, and possible risks associated with participation in the study. Women subjects were interviewed by the investigator and menstrual cycle history was determined. All testing occurred during the early follicular phase (between days 1-5) of their menstrual cycle, when both estradiol and progesterone levels are believed to be lowest. The experimental protocol was approved by the Human Subjects Research and Review Committee at the University of Toledo and is in accordance with guidelines set forth by the Declaration of Helsinki.

Separate analyses were performed retrospectively in a subgroup of women ($n = 5$) and men ($n = 5$) that were matched for resting forearm muscle MVC force (i.e. absolute strength). Previous studies have found absolute strength to be an independent factor contributing to skeletal muscle fatigue during isometric muscle contractions (Hunter and Enoka, 2001). Therefore, a strength-matched gender comparison would determine if any gender difference found in the fatigability of the forearm muscles was due to differences in absolute strength.

Experimental protocol

Subjects reported to the Cardiopulmonary and Metabolism Research Laboratory at the University of Toledo on two separate occasions with no less than 48 h between testing sessions. Each subject was instructed to consume only a light meal, and to abstain from vigorous exercise and caffeinated beverages for ≥ 12 h prior to arriving for testing. Exercise testing was performed at approximately the same time of the day for each subject.

Preliminary exercise testing was performed to both familiarize the subject with the testing procedures and for the determination of their achieved maximal aerobic capacity ($VO_{2,peak}$) which we used as an indicator of overall fitness level. The highest mean oxygen uptake averaged over a 30 s interval was defined as $VO_{2,peak}$. Cardiopulmonary testing was performed on an electrically braked cycle ergometer (Excalibur Sport, Lode, The Netherlands). The maximal exercise test involved 5 min of low intensity (20 W) cycling followed by a progressive increase in exercise intensity to volitional fatigue. The work rate was increased as a ramp function at a rate of 20 and 25 $W \cdot min^{-1}$ for women and men, respectively. Subjects were instructed to maintain a constant pedal cadence selected by the subject and were aided by both visual feedback and verbal encouragement. Following a cool

down period, subjects were instructed on the testing protocol to be conducted during the second study session, and were allowed sufficient time to practice all tasks. During the second study session, subjects performed submaximal intermittent handgrip exercise to task failure.

Pulmonary gas exchange

Pulmonary gas exchange and expired ventilation were measured using an automated open-circuit metabolic measurement system (Jaeger, Oxycon Alpha, Germany). Expired gas flows were measured using a turbine. The flow signal was integrated to yield a volume signal that was calibrated with a syringe of known volume (3.0 L). Prior to each exercise test, the O_2 and CO_2 analyzers were calibrated using gases of known concentrations. Corrections for ambient temperature and water vapor were made for conditions measured near the mouth.

Forearm muscle strength and fatigue

Prior to the exercise protocol, subjects performed two maximal voluntary contractions (MVC), separated by 2 min of rest, using a handgrip dynamometer for the determination of maximal forearm strength in kilograms (Takei, Japan). Following 5 min of rest, the subjects performed two additional MVCs, separated by 2 min of rest, using a handgrip dynamometer connected to a data acquisition system (ADInstruments, MCT 300/D, Grand Junction, CO) that allowed for the force displacement to be shown on-screen for subject viewing. For test-retest reliability of MVC force, an intraclass correlation coefficient of 0.98 was obtained (CI = 0.96-0.99). The highest force displacement was scaled so that the peak force was 100% and the target force for the fatigue protocol (i.e. 50% MVC) was clearly indicated on the monitor.

Handgrip exercise performed by the dominant arm was utilized to elicit forearm muscle fatigue using an approach previously described by Lewis and Fulco (1998). While seated with the elbow at approximately a 90° angle, subjects performed repeated contractions at 50% of their relative MVC for 5 s followed by 5 s of relaxation with the forearm in the neutral position. The handgrip dynamometer used in the present study did not allow adjustment for different hand sizes with a grip span of 5 cm. We do not believe this influenced the results of the present study since fatigue of the forearm muscle flexor digitorum superficialis, as inferred from EMG frequency shifts, has been shown not to change as a function of grip size (Blackwell et al., 1999). Subjects visually monitored force generation during the protocol and were aided by verbal encouragement. Subjects were asked to perform a single maximal effort every 2 min in order to record the decline in maximal force production. Task failure was determined as the time at which the subject was unable to produce a MVC greater than 50% of their resting MVC during each maximal effort or was unable to reach 50% of their MVC during three consecutive contractions during intermittent exercise. Upon reaching task failure, the subjects were instructed to perform two MVCs immediately and at 5 min increments up to 30 min post-task failure with the last measurement taken at 45 min post-task failure in order to monitor recovery of forearm muscle strength.

Table 1. Subject characteristics. Values are means (\pm SE).

Variable	UNMATCHED		MATCHED	
	Women (n=11)	Men (n=11)	Women (n=5)	Men (n=5)
Age (yrs)	23.1 (2.0)	24.0 (2.0)	22.4 (2.0)	24.6 (1.0)
Height (m)	1.69 (.02) *	1.76 (.02)	1.71 (.03)	173.7 (2.4)
Weight (kg)	65.8 (3.6) *	78.1 (4.4)	74.0 (6.3)	71.2 (4.6)
Body surface area (m ²)	1.7 (.1) *	1.9 (.1)	1.9 (.1)	1.8 (.1)
VO _{2,peak} (ml·kg ⁻¹ ·min ⁻¹)	34.8 (1.6) *	41.2 (2.5)	34.6 (3.4)	39.8 (1.3)
Resting MVC force (N)	341.5 (11.9) *	488.5 (31.3)	376.6 (10.6)	407.8 (27.3)
MVC force (N) at task failure	179.7 (7.6) *#	242.7 (12.8) #	199.0 (8.1) #	208.7 (16.0) #
Time to task failure (s)	793.3 \pm 92.5	684.8 (76.2)	706.6 (117.0)	831.8 (118.7)

* significant gender difference within each respective group ($p < 0.05$).

significant difference between resting MVC force and respective value at task failure ($p < 0.05$).

Statistical analysis

The rate of muscle fatigue (i.e. slope) in Newtons per minute was determined for each subject by linear regression using the maximal force measurements that were obtained every 2 min during the fatiguing task. The individual slopes were averaged to provide group mean values for each gender. Comparison between gender in demographic information, time to task failure, and rate of fatigue were performed by Student *t*-tests. Bivariate correlations were performed to evaluate relationships between variables. Gender differences in forearm muscle force were analyzed using a repeated measures ANOVA design with gender and time as the main effects. All values are reported as Mean \pm SE and significance was set a priori at $p \leq 0.05$.

Results

Subjects

The physical characteristics of the subjects are reported in Table 1. No attempt was made to recruit women and men with similar forearm muscle strength in the present study. Therefore, the mean age of women and men subjects was similar, but on average, women were shorter, had a lower body mass and VO_{2,peak} compared to men. Subjects reported to be sedentary or involved in regular recreational activity, but none were considered to be highly trained ($< 42 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$).

Forearm muscle fatigue

The maximal isometric force generated by women at rest was less than men (F: $341.5 \pm 11.9 \text{ N}$; M: $488.5 \pm 31.3 \text{ N}$; $p \leq 0.05$) indicating that men had significantly greater forearm muscle strength than women. Body surface area, as calculated by the Mosteller formula $[\text{Height (cm)} \times \text{Weight (kg)} / 3600]^{1/2}$, was significantly correlated with resting MVC force for men and also when data from women and men were pooled together (F: $r = 0.11$, $p \geq 0.05$; M: $r = 0.82$, pooled: $r = 0.75$, $p \leq 0.01$). The greater absolute force for men persisted throughout the handgrip exercise protocol (Figure 1a).

Early fatigue of the forearm muscles was assessed after 2 min of intermittent handgrip exercise. The initial decline in maximal force generation was similar between women and men ($19.5 \pm 2.4\%$ and $18.6 \pm 2.5\%$ decrease from resting MVC force for women and men, respectively) (Figure 2a). The rate of forearm muscle fatigue, determined by the slope of the change in MVC force during handgrip exercise, was slower in women than men (F: $-12.2 \pm 1.8 \text{ N}\cdot\text{min}^{-1}$, M: $-21.8 \pm 4.4 \text{ N}\cdot\text{min}^{-1}$, $p \leq 0.05$), and was significantly correlated with resting forearm muscle strength (pooled: $r = 0.62$, $p \leq 0.01$). However, when the rate of forearm muscle fatigue was expressed relative to resting MVC force, thereby correcting for differences in absolute force, the relative rate of fatigue was similar between genders (F: $-3.6 \pm 0.5 \%$ decrease from resting MVC force per min; M: $-4.3 \pm 0.6 \%$ decrease from resting MVC force per min) (Figure 3).

As expected from the fatigue protocol, the decrease in maximal force development at task failure was similar between women and men (F: $47.6 \pm 1.0 \%$ decrease from resting MVC force; M: $49.9 \pm 1.3 \%$ decrease from resting MVC force). Time to task failure was not significantly different between the genders (F: $793.3 \pm 92.5 \text{ s}$; M: $684.8 \pm 76.2 \text{ s}$) and was highly correlated with the

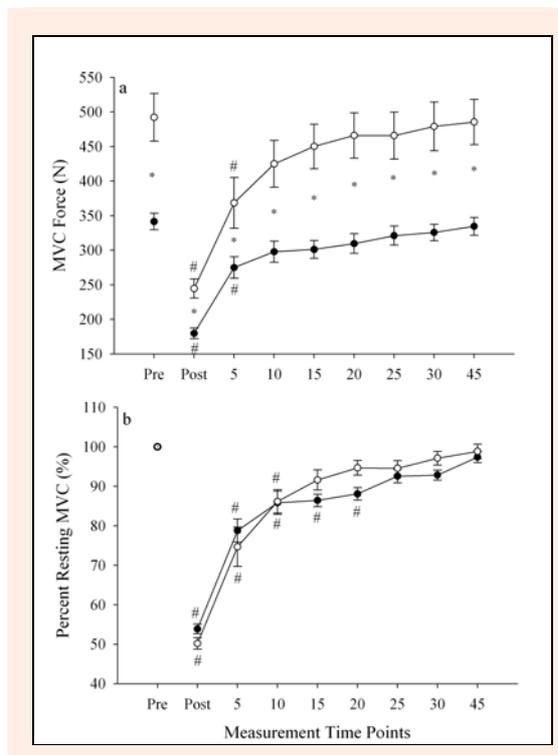


Figure 1. Change in forearm muscle force at rest (Pre), at task failure (Post), and during recovery from intermittent exercise (5-45 min) between women (●) and men (○). a) Men generated greater forearm muscle force than women across time. Both genders returned to resting maximal voluntary contraction (MVC) force within 10 min following task failure. b) No gender difference was found in the percent of resting MVC force across time. * significant gender difference ($p \leq 0.05$). # significantly different from Pre ($p \leq 0.05$).

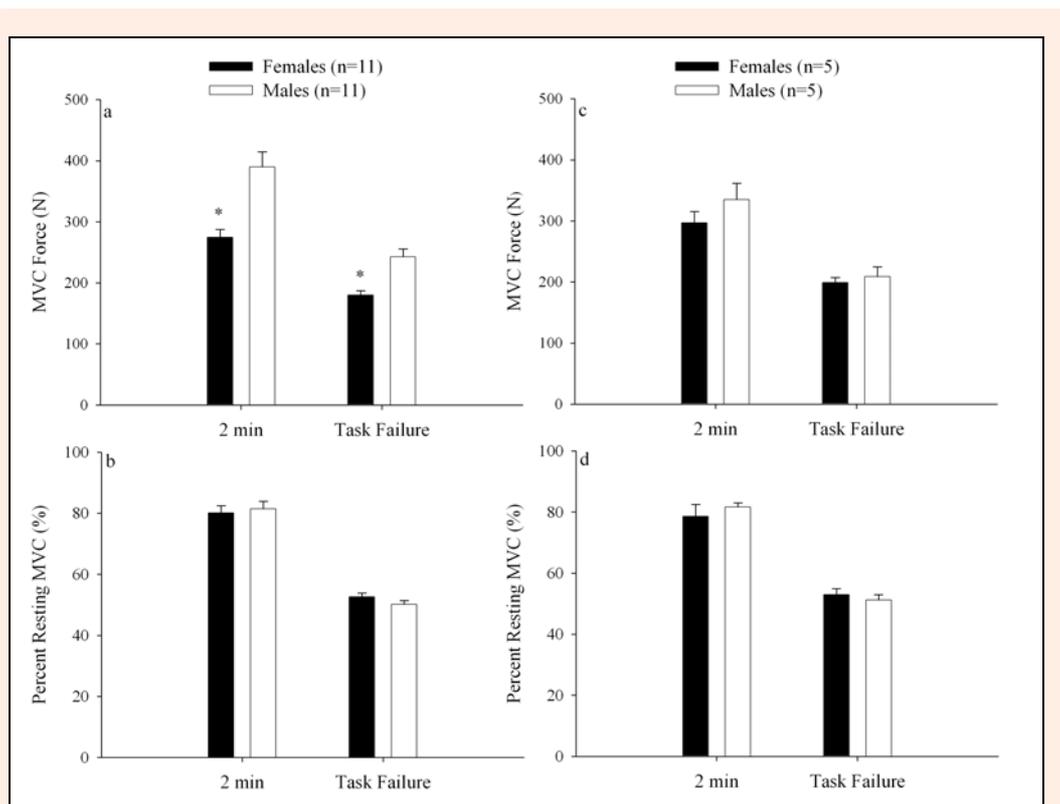


Figure 2. Change in forearm muscle force after 2 min of intermittent handgrip contractions and at task failure. a) Absolute MVC force was higher in men than women at 2 min and at task failure. b) No gender difference was present in forearm muscle force expressed relative to resting MVC force. The strength-matched gender comparison showed similar changes in muscle force production at 2 min and task failure when expressed in c) absolute or d) relative terms. * significant gender difference ($p \leq 0.05$).

absolute change in the rate of muscle fatigue (F: $r = 0.85$, M: $r = 0.84$, pooled: $r = 0.74$, $p \leq 0.01$). The relationship between time to task failure and pooled data for the absolute and relative changes in the rate of fatigue was well described by an exponential decay (absolute: $r = 0.87$, $y = 7.7 + 181.3^{-0.005x}$; relative: $r = 0.96$, $y = 1.8 + 20.7^{-0.0037x}$) with women and men demonstrating a similar response (Figure 4).

Recovery of maximal force generating capacity was similar between women and men (10 min) when absolute changes in force were analyzed (Figure 1a). When expressed relative to resting MVC force, a 2-way ANOVA found no main effect for gender or an interaction between gender and time. A one-way ANOVA analyzed for time within each gender found women and men to return to maximal force generating capacity at 25 min and 15 min post-task failure, respectively (Figure 1b).

Gender comparison when matched for strength

Women and men matched for resting MVC force had similar physical characteristics (see Table 1). Resting MVC force was 376.6 ± 10.6 N and 407.8 ± 27.3 N for women and men, respectively ($p \geq 0.05$). After 2 min of handgrip exercise, women and men resulted in a similar decrease in forearm muscle strength (F: 21.4 ± 3.9 % drop from resting MVC force; M: 18.2 ± 1.3 % drop from resting MVC force) (Figure 2b). The rate of forearm muscle fatigue during handgrip exercise was similar for

women and men when analyzed for both absolute (F: -15.0 ± 3.1 N \cdot min $^{-1}$; M: -14.3 ± 3.3 N \cdot min $^{-1}$) and relative (F: -3.9 ± 0.8 % drop from resting MVC force per min; M: -3.4 ± 0.7 % drop from resting MVC force per min) changes (Figure 3). At task failure, both women and men demonstrated forearm muscle fatigue in accordance with the exercise protocol (F: 47.1 ± 2.0 % decrease from resting MVC force; M: 48.8 ± 1.7 % decrease from resting MVC force) (Figure 2b). Time to task failure was similar between the strength-matched genders (F: 706.6 ± 117.0 s; M: 831.8 ± 118.7 s), and lastly, recovery of maximal force generating capacity returned to resting MVC force within 5 min following task failure in both women and strength-matched men.

Discussion

To our knowledge, this is the first study to compare the fatigability of the forearm muscles during repeated sub-maximal handgrip contractions between women and men. Based on previous gender-based comparisons involving intermittent isometric contractions performed by other skeletal muscles (Fulco et al., 1999; Gonzales and Scheuermann, 2006; Hunter et al., 2004), we hypothesized that women would exhibit a slower rate of forearm muscle fatigue and result in a longer time to task failure than men (i.e. a greater fatigue resistance). In contrast to our hypotheses, the present study found time to task

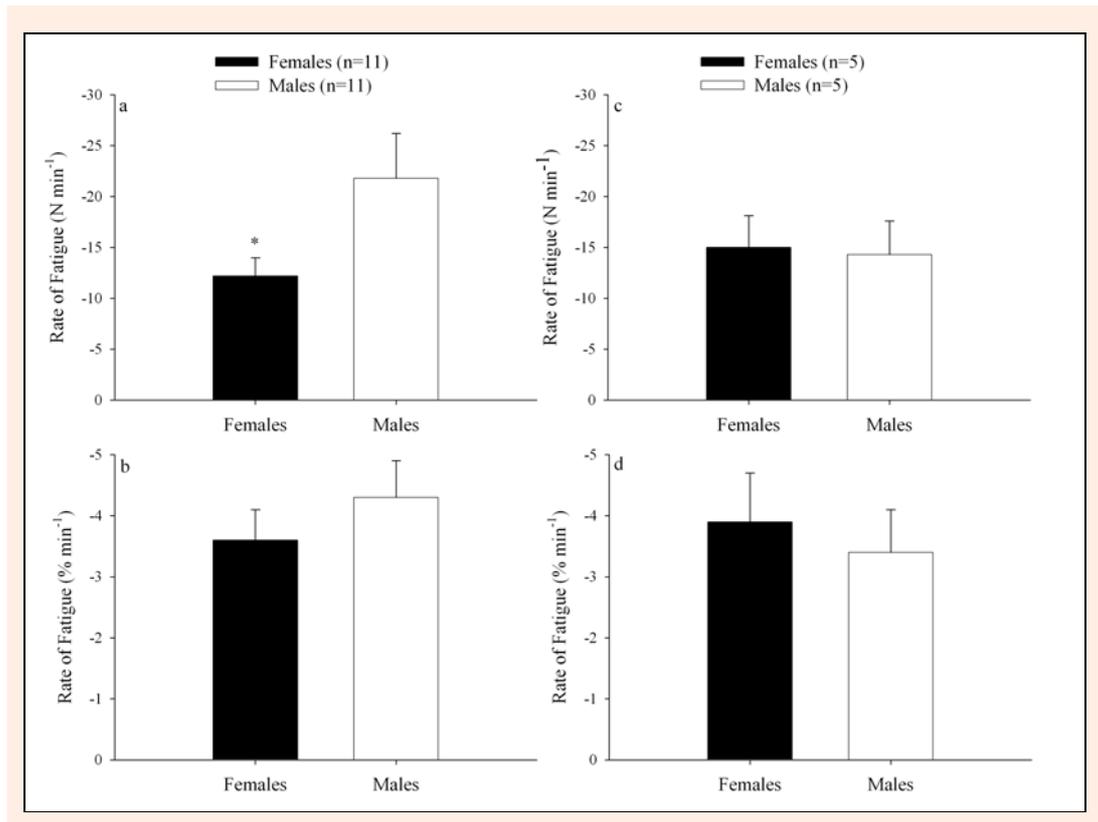


Figure 3. Comparison of forearm muscle fatigue rates between women and men during intermittent handgrip contractions. a) The absolute rate of fatigue was slower for women than men, b) but no gender difference was present for the rate of fatigue relative to resting MVC force. The strength-matched gender comparison showed similar c) absolute and d) relative changes in the rate of forearm muscle fatigue. * significant gender difference ($p \leq 0.05$).

failure and rate of forearm muscle fatigue to be similar between genders, in both unmatched and matched for strength comparisons. These results suggest that a similar fatigue process occurs for women and men during repeated isometric contractions performed by the forearm muscles.

The forearm muscles are a highly recruited muscle group utilized in physical activities such as tennis (Chow et al., 1999) and sport climbing (Watts and Drobish, 1998). Moreover, the forearm muscles are used frequently in daily functional activities such that handgrip strength is used as an indicator of overall muscle strength and has been reported to highly predict disability with ageing (Rantanen et al., 1999). The frequent use of the forearm muscles may result in a different neuromuscular activation pattern than those used by other skeletal muscles. In addition, the activation pattern within a muscle group has been shown to vary between muscles that comprise the functional group. Hunter et al. (2003) has demonstrated that activation among the elbow flexor muscles differ across time during a fatiguing contraction and also within the same muscle during different tasks. Chow et al. (1999) has also demonstrated greater activation of the extensor carpi radialis than the flexor carpi radialis in the handgrip contraction used during tennis volleys. It is therefore reasonable to suspect that the forearm muscles would demonstrate various activation patterns within single muscles or at the synergistic level of the muscle group that may result in a different fatigue process than other muscle groups. Although speculative, the similar

rate of fatigue found between women and men in the present study suggests that neuromuscular activation pattern may have been similar between genders during intermittent forearm exercise.

Differences in muscle morphology and hence substrate utilization is a mechanism that partly explains the inconsistent findings between the present study and those found by others examining the adductor pollicis (Fulco et al., 1999) and inspiratory muscles (Gonzales and Scheuermann, 2006). The adductor pollicis and inspiratory muscles are both highly oxidative muscles comprised of a large proportion of fatigue resistant Type I fibers. On the other hand, the forearm muscles (flexor digitorum muscles) have a generally equal proportion of Type I and II fibers (Johnson et al., 1973). Since women have been shown to have a greater potential for oxidative phosphorylation relative to glycolysis than men (Simoneau et al., 1985), it reasons that women would experience a slower rate of fatigue than men during exercise performed by an oxidative muscle. In contrast, the even distribution of fiber types in the forearm muscles would suggest that one metabolic pathway would not be relied heavily upon for ATP production throughout exercise. This is supported by calculations from ³¹P magnetic spectroscopy measurements taken from the flexor digitorum superficialis muscle that showed equal relative total contributions of PCr hydrolysis, glycolysis, and oxidative phosphorylation to ATP production between women and men during 3 min of intermittent finger flexion exercise (Mattei et al., 1999).

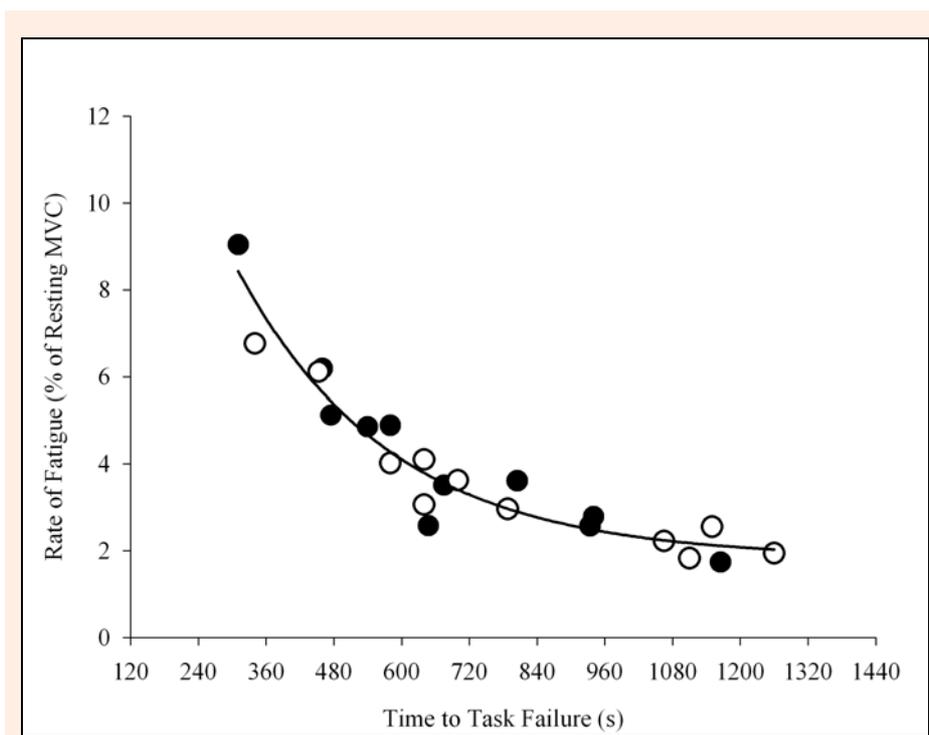


Figure 4. Relationship between rate of forearm muscle fatigue and time to task failure during intermittent handgrip contractions. The similar fatigue response between women (●) and men (○) unmatched for muscle strength was well described by an exponential decay ($y = 1.8 + 20.7^{-0.0037x}$, $r = 0.96$).

In the present study relative forearm muscle force fell by a similar magnitude between women and men during the first 2 min of intermittent handgrip exercise. Mattei et al. (1999) has provided evidence from ^{31}P magnetic spectroscopy measurements to indicate that forearm muscle activity has a preference for anaerobic pathways during the first minute of intermittent forearm muscle contractions in both women and men. In addition, Pitcher and Miles (Pitcher and Miles, 1997) have shown similar decreases in forearm muscle force during the first 2 min of intermittent handgrip exercise between ischemic and free-flow circulation conditions suggesting the primary use of anaerobic metabolic energy pathways. Taken together, these findings indicate that the similar decrease in forearm muscle force between women and men after 2 min of intermittent exercise was due to similar metabolic pathways utilized by each gender, which were likely anaerobic in nature.

Interruption of muscle blood flow by means of significant intramuscular pressure has been extensively studied during sustained isometric muscle contractions, many of which have been performed using handgrip exercise (Barnes, 1980; Kagaya and Homma, 1997). Limited muscle blood flow contributes to muscle fatigue by decreased delivery of oxygen and glucose and also the removal of metabolic byproducts (H^+ , P_i , H_2PO_4) associated with muscle fatigue (Fitts, 1994). This fatigue mechanism has been attributed to be a cause of the reduced time to task failure seen in men during sustained handgrip exercise when blood flow is thought to be limited (Petrofsky et al., 1975; West et al., 1995). In the present study, men generated greater absolute forearm muscle force than women, and thereby, likely generated more metabolic by-products

than women (Ettinger et al., 1996). However, women and men showed a similar relative rate of forearm muscle fatigue during intermittent forearm muscle contractions, with no gender difference observed in the absolute change in rate of fatigue when matched for absolute force. This suggests that forearm muscle blood flow was sufficient to prevent the local accumulation of metabolic byproducts during intermittent isometric handgrip exercise. The hyperemic response shown to occur between intermittent handgrip contractions likely minimizes the effect of mechanical compression on forearm muscle blood flow (Kagaya and Ogita, 1992), which may prevent a significant reduction in forearm blood flow.

Although forearm muscle mass was not measured in the present study, men were on average taller and heavier (i.e. 10% larger body surface area) than women. Although this does not completely explain the 25% greater forearm muscle strength in men as compared to women, a significant correlation between body surface area and resting MVC force was observed (pooled: $r = 0.75$, $p < 0.01$). Thus, it is likely that men also had a larger forearm muscle mass than women in order to generate the greater forearm muscle force. In spite of this, women and men had a similar relative rate of decline in forearm muscle strength and resulted in a similar time to task failure during repeated handgrip exercise. This is consistent with the report by West et al. (1995) that found low correlations between resting MVC force and endurance time during sustained isometric handgrip exercise in women and men of different forearm strength. The present study extends this finding to intermittent handgrip exercise in that time to task failure was not correlated with forearm muscle strength (pooled data, $r = 0.08$). These results are consis-

tent with the view that absolute force is not a primary factor influencing forearm muscle fatigability during handgrip exercise.

Following task failure, both women and men returned to resting MVC force within 10 min. When strength measurements were analyzed relative to resting MVC force, no difference in recovery was found between women and men. However, analysis within each gender showed women and men to return to resting MVC force within 25 min and 15 min following task failure, respectively. Although this could be interpreted as a greater forearm muscle fatigue for women as compared to men, the fact that each gender resulted in a similar relative rate of forearm muscle fatigue and time to task failure suggests that muscle fatigue was equal between women and men. The prolonged recovery exhibited by women could be due to a number of factors. For instance, women in the present study had a 15% lower VO_{2peak} (i.e. aerobic capacity) than men which may have translated to a reduced ability to restore MVC force (Hakkinen and Myllyla, 1990). Nevertheless, it is important to recognize that women and men matched for resting MVC force showed a similar recovery of forearm muscle strength following task failure, confirming that there was no gender difference in the magnitude of forearm muscle fatigue during intermittent handgrip exercise. We cannot, however, speak to the initial recovery (1-3 min) of MVC force which may have been different between women and men as been reported in other skeletal muscles during intermittent contractions (Fulco et al., 1999; Kent-Braun et al., 2002).

Conclusion

In conclusion, women do not exhibit a greater ability to resist forearm muscle fatigue than men during submaximal intermittent handgrip exercise. Instead, the present study found women and men to exhibit a similar exercise tolerance during repeated forearm muscle contractions. This finding was irrespective of absolute force, indicating that maximal handgrip strength had no influence on forearm muscle fatigability during handgrip exercise. These findings indicate that maximal handgrip strength is not a key determinant of exercise tolerance during relative isometric forearm exercise. Indeed, Mermier et al. (Mermier et al., 2000) recently reported similar static (50% MVC) handgrip endurance times between trained women and men sport climbers in spite of the men climbers having greater maximum handgrip strength than the women climbers. The precise mechanisms that cause the similar fatigue process for women and men during repeated isometric handgrip contractions has yet to be elucidated, but would be of great interest considering the gender differences in muscle fatigue observed in other skeletal muscles.

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Key points

- The aim of the present study was to determine if gender differences exist in forearm muscle fatigue during intermittent isometric handgrip contractions.
- Both unmatched and matched for strength gender comparisons found women and men to exhibit a similar exercise tolerance, rate of fatigue, and recovery of handgrip force following repeated forearm muscle contractions.
- These results indicate that maximal handgrip strength is not a key determinant of exercise tolerance during intermittent isometric forearm exercise performed at a moderate relative contraction intensity.

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