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Gender Difference in Subjective Muscle-fatigue Sensation during Sustained Muscle Force Exertion

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Muscle endurance is one of the important composite factors to health-related physical fitness. However, previous measurement techniques for evaluation of isometric muscle endurance have been problematic, including rapid increase of blood pressure and heart rate. The progressive workload method which gradually increases the load can reduce subject's physical and mental burden and is safe even for the elderly. This study aims to examine the relationship between exerted force and subjective muscle-fatigue sensation (SMS) of the antebrachial region as well as differences with respect to gender during sustained static gripping. Subjects consisted of 12 males (age 20.8 ± 1.6 years) and 15 females (age 20.5 ± 1.3 years) with no history of neuromuscular disorders. They performed sustained static gripping, in which the demand values are gradually increased: 10 sec for 20% maximal voluntary contraction (MVC), 20 sec each for 30, 40, 50, 60, and 70% MVC, and 10 sec for 80% MVC. Demand values (each %MVC) were determined based on each subject's MVC. The forces exerted during at the demand values of 70-80% MVC were significantly lower in males than in females. A gender difference in SMS between male and female subjects occurred at demand values of 40-60% MVC. In short, even when maintaining the same exertion force during demand values of 40-60% MVC, males may experience greater physical fatigue than females. ——— subjective muscle-fatigue sensation; gender difference; progressive workload.
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Muscle endurance is one of the most important composite factors to health-related physical fitness (Pate 1983) and has been used as a test item of physical fitness. Muscle endurance, until now, has been mainly evaluated by sustaining time or decreasing rate using fixed, relative load intensities (Maughan et al. 1986; Laforest et al. 1990; Clarke et al. 1992; Huczel et al. 1992; Larsson et al. 2003). When using very large loads, the exerted force decreases markedly just after initiating force exertion, blood pressure and heart rate increase, and also the sensation of muscle pain increases (Petrofsky and Hendershot 1984). On the other hand, when using light loads, the measurement time becomes long, and subject's fatigue and feeling of discomfort

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increase (Nagasawa et al. 2000). Particularly in the case of the elderly, the above traditional measurement methods have an associated large risk because of the above-stated rapid physiological changes (Petrofsky and Hendershot 1984; Nagasawa et al. 2000; Nakada et al. 2004).

A progressive workload has been used to measure maximal oxygen uptake (Fitchett 1985; Okura et al. 1998) and can yield more exact values than the method of using fixed workloads (Fitchett 1985). Muscle blood volume obstruction increases blood pressure and heart rate and also produces muscle-fatigue and pain (Petrofsky and Hendershot 1984). When this pain sensation occurs in an early phase, sustained force exertion becomes very difficult. The progressive workload gradually increases the relative load, with consideration of the physiological response, and is safe because it can prevent a rapid increase in heart rate and blood pressure, thus reducing the subject's physical burden. Hence, when applying this method to measure muscle endurance, the above-stated problem may be resolved. However, because the forces exerted during the progressive workload may largely differ from those used in a fixed workload, it is necessary to confirm the validity of this methodology.

In addition, after the force value in any workload reaches a steady state at 15-20% MVC, it decreases very little (Yoshimura et al. 1996; Nagasawa et al. 2000; Yamaji et al. 2000; Yamaji et al. 2004). Also, the differences among individuals (Yamaji et al. 2002; Yamaji et al. 2004) and between genders (Maughan et al. 1986; Laforest et al. 1990) increase during a large decrease in force, until reaching a steady state. However, because measurement of muscle endurance using a progressive workload is without precedent, the effect of decreasing force is not entirely clear. Meanwhile, SMS increases with physiological muscle fatigue when exerting sustained forces with large loads (Saito and Mano 1989; Nagasawa et al. 2000), with several reports on the relationship between these two (Kilbom et al. 1983; West et al. 1995; Nagasawa et al. 2000). It is possible that a relationship between the exerted force and the corresponding muscle fatigue sensation in the progressive workload case differs from that in the constant workload, and the fatigue sensation in the progressive workload case may be reduced.

This study aimed to examine the reproducibility and gender differences of exerted force values and SMS during sustained hand gripping over progressive workloads.

Methods

Subjects

Written informed consent was obtained from 20 males and 20 females after a full explanation of the experimental purpose and protocol. Twelve males (height 173.3 ± 6.1 cm, body weight 67.8 ± 13.1 kg, and age 20.8 ± 1.6 years) and 15 females (height 160.9 ± 5.5 cm, body weight 53.3 ± 5.3 kg, and age 20.5 ± 1.3 years) who were able to participate in the present experiment, based on schedule adjustment, were selected as subjects.

Materials

Grip strength was measured using a digital hand dynamometer with a load-cell sensor (EG-100, Sakai, Japan). Each signal was sampled at 20 Hz through an analog-to-digital interface, and then relayed to a personal computer. The changes of force values on the computer display were shown as a time-series graph on the horizontal scale, with relative force values on the vertical scale. The scale marks were drawn with increasing loads as subjects tried to exert the best gripping and observe the demand value visually.

Subjective Muscle-fatigue Sensation

A Category-Ratio Scale based on Borg's RPE was used to evaluate Subjective Muscle-fatigue Sensation (SMS) (Saito and Mano 1989). This scale consists of 12 points ("Nothing at all (0)" to "Maximal (limit) (10)". The SMS was measured from the sensation of fatigue in the antebrachial region.

Setting of progressive workloads and measurement time

Two males and three females participated in an exploratory experiment to decide upon the setting of load intensity and measurement time. It was reported that the persistence time of sustained gripping is very short at levels above 75% MVC, with little difference among individuals (West et al. 1995; Nagasawa et al. 2000), while the load that could be maintained under sustained gripping without a force decrease is 15% MVC (Yamaji et al. 2002). Therefore, the maximum and minimum loads were considered to be 70-80% MVC and 10-20% MVC in the progressive workload. Considering the result of the pre-experiment and the influence of psychological factors (Bowei et al. 1971; Nakada et al. 2005), the authors selected a measurement time of 2 min, with a progressive workload of between 20-80% MVC.

Experimental procedure

Maximal grip strength was measured twice in a sitting position, and the larger value (MVC: maximal voluntary contraction) was used as the target value for sustained static gripping using a progressive workload. The intraclass correlation coefficient between two trials of maximal grip value was 0.991. After measuring maximal grip force, each subject performed sustained static gripping with progressive workloads at 7 relative demand values (20% to 80% MVC) using their dominant hand, based on Oldfield's handedness inventory (1971). The persistence time of demand values was 10 sec when exerting 20% and 80% MVC and 20 sec when exerting 30, 40, 50, 60 and 70% MVC. The SMS of the antebrachial region was measured during a pre-experimental test and every 10 s during sustained static gripping (Fig. 1). To examine the reproducibility of exerted force values and SMS, subjects re-performed sustained static gripping with progressive workloads by the above-stated experimental procedure on another day.

Parameters

Referring to previous studies (Yamaji et al. 2000), the following force-time parameters were selected: (1) the peak of the force value (peak force), (2) the time of the peak force (peak time), (3) the persistence time of the demand value (persistence time), (4) the final force value (final force), and (5) the integrated area under the force-time curve is the average of all force values during the sustained static gripping using progressive workload for 2 min (average force). The final force value was the force exerted at 120 s. The average SMS and final SMS were selected as SMS-parameters.

Data analysis

Time-series data of the force and SMS during the sustained static gripping with the progressive workload was averaged for each subject, and the cross-correlation coefficient between two trial values was calculated to examine the reproducibility. A Student's t-test was used to examine the gender difference for force-parameters and SMS-parameters. A coefficient of variance (CV) was used to examine the individual difference in force-parameters. Two-way (gender x time) ANOVA was used to examine the change and gender differences of time-series force and SMS. Multiple comparisons used Tukey's HSD method. A probability level of 0.05 was used as indicative of statistical significance.

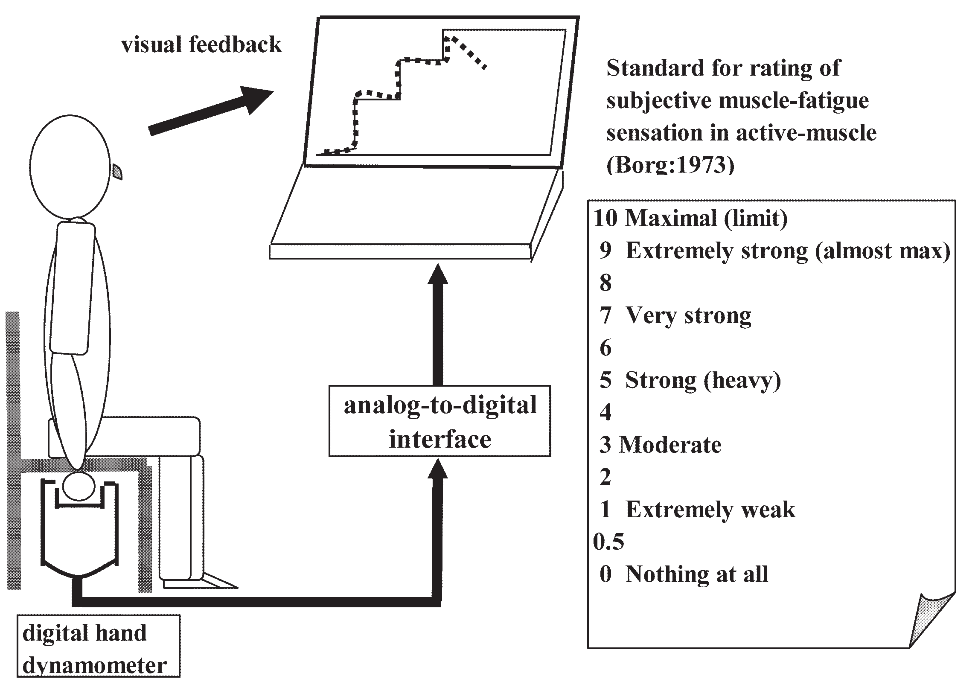

Fig. 1. Experimental system and standard for rating subjective muscle-fatigue sensation.

Results

Figs. 2 and 3 show the average curves of changes in time-series forces (Fig. 2) and SMS (Fig. 3) during sustained static gripping using the progressive workload. The peak force appeared at 75 s in both genders after the onset of gripping, corresponding to 60% MVC. Then, the force decreased until the end of 2 min measurement, and the final force was about 26% MVC in males and about 40% MVC in females. When both males and females could not maintain the demand

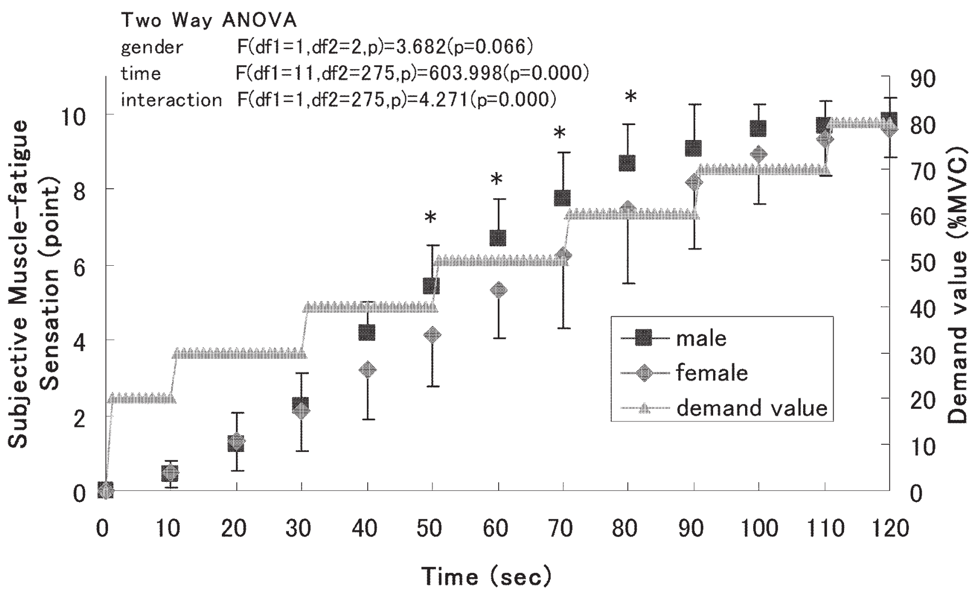

Fig. 2. Average curves of Subjective Muscle-fatigue Sensation during sustained static gripping using a progressive workload.
Note. Only gender difference (*$p < 0.05$).

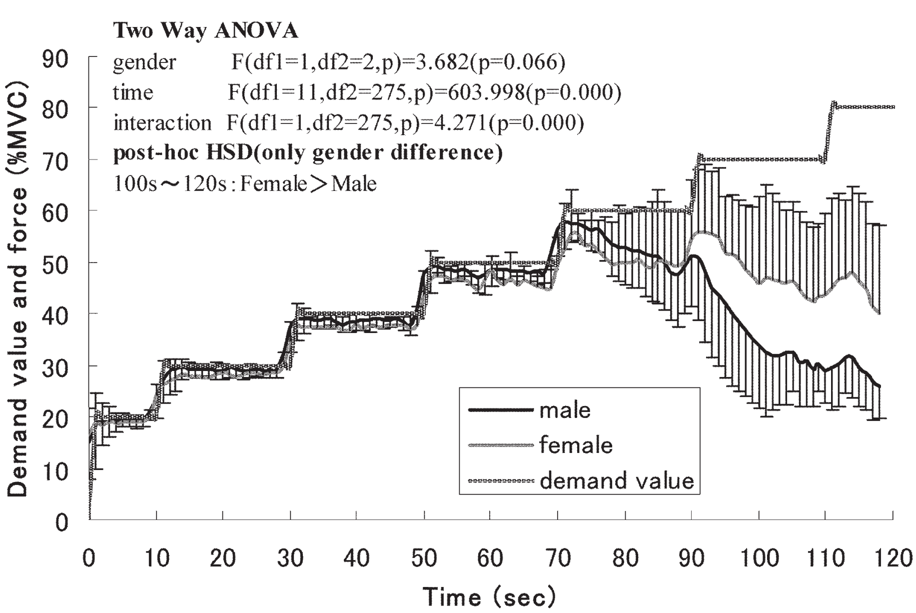

Fig. 3. Average curves of grip force during sustained static gripping using a progressive workload.

value, SMS was about 8 (7: very strong, 9: extremely strong). In SMS, the result of a two-way ANOVA showed a significant interaction effect. The result of multiple comparisons showed gender differences at 40-80 s (demand value: 40%-60% MVC), being higher in males. Also, the force showed a significant interaction effect. The multiple comparison test showed gender differences at 100-120 s, this time being higher in females.

Table 1 shows cross-correlations in average force and average SMS during sustained static gripping. The values were very high (rxy = 0.991-0.999) up until the peak force time and for the average over all measurement times. Table 2 shows the t-test, illustrating a gender difference in force-parameters and SMS-parameters. There were significant gender differences in peak force time and final force, being higher in females. However, there was not a significant gender difference in persisting time. The CVs of force-parameters were 6.6-41.7.

Table 1. The trial-to-trial cross correlation coefficients of grip force and.

	Force	SMS
Until peak force time	0.998	0.999
Whole measurement time (2 min)	0.991	0.999

Discussion

The present results show that the reproducibility of intra-individuals in exerted force and SMS is very high (rxy = 0.991-0.999). A high reproducibility was also reported in values of maximal leg extension (Larsson et al. 2003) and maximal, repeated, rhythmic grip (Nakada et al. 2005). Thus, the progressive workload appears to have a similarly high reproducibility as the constant workload.

SMS increases with physiological muscle fatigue during sustained muscle exertion, especially when using large loads (Saito and Mano 1989; Nagasawa et al. 2000). Nagasawa et al. (2000) examined relationships between persistence time and SMS in sustained static hand gripping with constant workload, and reported that the peak of SMS was at 53.3 ± 19.7 s (75% MVC) and 95.0 ± 36.3 s (50% MVC). Comparing these results to the present ones, even 50% MVC in the case of the above gripping causes SMS to reach a peak earlier, while after that, individual differences in forces increase, if allowed time. However, in the present sustained, static gripping using progressive workloads, an individual difference in force values increased in the region that SMS peaked and decreased markedly after that (i.e., force exertion time shortened). Hence, individual differences in muscle endurance may be measured by lightening the physical burden in the progres-

Table 2. The gender differences of Force-parameter and SMS-parameter during sustained static gripping.

	Unit	Male			Female			t-value
		Mean	SD	CV	Mean	SD	CV	
1 Peak force	%MVC	61.8	4.1	6.6	64.9	7.3	11.3	1.330
2 Peak force time	sec	79.0	9.8	12.4	90.9	14.0	15.4	2.496*
3 Persiting time	sec	76.1	12.1	16.0	82.6	18.8	22.8	1.038
4 Final Force	%MVC	25.9	6.6	25.6	39.9	16.7	41.7	2.750*
5 Average Force	%MVC	38.3	3.4	8.8	40.2	4.7	11.6	1.187
1 Mean SMS	point	6.2	0.7	11.3	5.5	1.1	19.8	1.919
2 Peak force time SMS	point	8.8	1.0	11.7	9.0	1.1	12.6	0.395
3 Persiting time SMS	point	8.4	1.2	13.8	8.0	1.4	17.0	0.841

Note: *($p < 0.05$)

sive workload, as compared to the constant workload.

Yamaji et al. (2002) examined the effect of psychological factors during sustained static gripping by maximal voluntary contraction at different measurement times (1, 3, and 6 min), and reported that the subjects tend to hold the force value for the first 1 min. He also noted the influence of psychological factors such as muscle pain and its association with force exertion is large. Kimura et al. (1998) reported that because the sustained, static gripping at 50% MVC restricts markedly muscular blood volume and diminishes oxygen supply, the persisting time becomes short, leading to large differences from the case of below 50% MVC. The peak force during sustained, static gripping using progressive workloads in this study corresponded to about 62-65% MVC. This intensity is considered to cause the obstruction of muscular blood volume. It was predicted that during sustained, static gripping using progressive workloads after the peak force was reached, intra-muscular pressure decreases as the force decreases and muscle-fatigue is relieved by the resumption of muscle blood flow. However, the present results suggest that the SMS increases with measurement time, even after the peak force was reached.

In addition, both males and females could not maintain the demand value of 60% MVC. At that point, the SMS was about 8. In short, it was confirmed that there is no gender difference in drop-out time and SMS. The coefficients of variance of force-parameters were 16.0-22.8 in persisting time, 25.6-41.7 in final force, and 8.8-11.6 in average force. According to the report of Nakada et al. (2004), using maximal, repeated rhythmic gripping, values of 33.8-46.6 in persisting time and 13.4 in average force were obtained. In sustained, static maximal gripping (Yamaji et al. 2000) value of 52.8-82.0 in persisting time, 35.4 in final force, and 18.9 in average force were obtained. Comparing those in previous studies using constant workload, it is believed that persistence time during sustained, static gripping using a progressive workload exhibits small individual differences, but the final force is similar (Yamaji et al. 2000).

In the present sustained, static gripping, peak force time and final force were larger in females, but there was not a gender difference in SMS. The male's SMS was higher at 40-80 s (demand value of 40-60% MVC). This time approximately agreed with peak force time (79.0 s) in males. Maughan et al. (1986) reported that muscle endurance was higher in females in loads below 70% MVC, but there is not a gender difference in loads above 80% MVC. Laforest et al. (1990) reported that there were not gender differences in force values during maximal work. Therefore, in the sustained force exertion of submaximal workload below 70% MVC, physical fatigue by force exertion may differ between males and females. Kent-Braun et al. (2002) reported that males compared with females, depend largely on nonoxidative sources during muscular contractions from metabolic responses to exercise. That is, even when maintaining the same force value of 40-60% MVC, males may experience greater physical fatigue than females. In addition, in the present sustained, static gripping, peak force and SMS did not show a gender difference, but peak force time was longer in females. Because males experience greater fatigue than females during force exertion at 40-60% MVC, the peak force time may appear earlier. The gender difference in muscle endurance is believed to be related to factors such as muscle mass, energy metabolism, and muscular tissue (Hicks et al. 2001). Hunter and Enoka (2001) suggested that because people with larger muscle strength must maintain larger, absolute muscle strength when using the fixed, relative demand value, they are judged to be inferior in muscle endurance. Even when performing work with the same relative intensity, males exert larger muscle forces than females. Bonde-Peterson et al. (1975) reported that an isometric contraction with high intensities over 60-70% MVC produces a blood flow obstruction to muscle activity, due to increasing the intra-muscular pressure, and the persistence time shortens markedly. That is, during the sustained static gripping using the progressive workload, after the peak force was reached, there is a point where the intra-muscular pressure decreases with a decrease of muscle strength and muscle blood flow resumes (Nakada et al. 2004). Because the degree of the resumption is stronger in females that have inferior, absolute muscle strength, individual differences in force values may increase. However, it was also reported that in loads below 70% MVC, people with inferior muscle strength excel in muscle endurance (Carlson 1969; Heyward 1975). It will be necessary to examine the dependence of maximum strength on gender differences in future studies.

This study used young adults because of the need to impose a large physical burden on the subjects. However, it is important to evaluate the muscle endurance of the elderly and middle aged people. Hence, the further study of these populations will be required.

Summary

In summary, the reproducibility of force value and SMS during sustained, static gripping using the progressive workload is very high (rxy = 0.991-0.999) in males and females. Peak force time and final force (% MVC) are higher in females than males during the above work. Force values show significant gender differences at 100-120 s, and the decrease is significant in males. This gender difference may largely originate in SMS differences at 40-80 s (demand value: 40%-60% MVC).

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