CHANGES IN SUBJECTIVE MUSCLE FATIGUE SENSATION AND BLOOD LACTATE AND THEIR RELATIONSHIPS WITH DECREASING FORCE DURING SUSTAINED HANDGRIPPING USING VARIOUS TARGET VALUES AND ITS RECOVERY STAGE

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The purpose of this study was to examine the relationship between the level of subjective muscle fatigue sensation (SMS) and the physiological responses to decreasing force during and after sustained and constant effort static gripping (SSG) at 50, 75 and 100\% of the maximal voluntary contraction (MVC). The subjects were 10 healthy males without upper extremity impairments. Each subject performed SSG for 6 min with three target forces. SMS of the forearm by Borg’s CR 10 scale was measured every 30 sec during and after the SSG. The blood lactate concentration (La) and MVC were measured before the SSG and at 0, 4 and 7 min after the SSG. There were no significant differences in the average grip force after 30 sec from the SSG onset between the target forces. The SMS for 75\% MVC during the SSG increased markedly, and was the highest at 30 sec after the onset (p < 0.05). Although the La at 4 min was higher than that before the SSG, the La recovered to 80\% at 7 min after the SSG, and the SMS recovered almost completely. The cross correlation coefficients between the increasing SMS and decreasing force during the SSG were very high in all conditions (\(r_{xy} = -0.819\) to \(-0.979\), \(-0.930\) to \(-0.988\), \(-0.789\) to \(-0.985\), for 50\%, 75\% and 100\%, respectively; all coefficients: lag = 0), but the relationships between the recovery ratio of the SMS and that of the maximal grip force at 4 and 7 min after the SSG were low. In addition, the relationships between the recovery ratio of the La and the maximal grip force for 75\% MVC were high at 0 and 4 min after the SSG (\(r = -0.814\), \(-0.744\), respectively). In the case of sustained muscle contraction for a long time, there were no significant differences between the target forces for the SMS, La and maximal grip force after SSG, and the degree of muscle fatigue was considered to be similar at each target force. However, the SMS during SSG, especially before the gripping force decreased to the almost steady state, may differ at each target force.

Key words: muscle endurance; fatigue; sustained force curve; blood lactate; subjective muscle fatigue

INTRODUCTION

When evaluating muscle endurance or muscle fatigue levels using sustained isometric muscle contraction, it is necessary to sufficiently consider measurement conditions such as exercise type, measurement time and intensity (Enoka and Stuart, 1992; Yamaji et al., 2002). Although muscle endurance is generally evaluated by sustained time or a decreased rate of exertion force, it is difficult to simply compare sustained muscle contraction reported in previous studies because measurement conditions differ considerably among researchers. The intensity level for sustained isometric contrac-
tion is an important factor for determining the physiological mechanism during sustained muscle contraction.

Many previous studies have used the intensity above 30% of the maximal voluntary contraction (MVC) to evaluate muscle endurance because intensities below 30% MVC require a long time until force decreases to a certain level. Force decrease during sustained muscle contraction above 30% MVC reaches an almost steady state (15-20% MVC) at about 3 min regardless of the intensity (target force) (Yamaji et al., 2000). That is, at any intensity, measuring force output until a steady state is reached may allow for the evaluation of muscle endurance because the degree of muscle fatigue after work is assumed to be almost the same. On the other hand, by increasing the intensity (above 60 ~ 70% MVC), blood flow is obstructed by an increase in the intra-muscular pressure, and the force exertion is sustained in an ischemic state. An ischemic state during muscle contraction causes hyperactivity of nervus sympathetic, then an increase of heart rate and blood pressure, and an upregulation of the production of blood lactate (Bonde-Patersent et al., 1975; Tanimoto and Ishii, 2006). In particular, the effect by ischemia is large in the upper extremity (Takarada et al., 2000; Koba et al., 2004).

Moreover, low intensity contraction has little of the above effects because it rarely results in ischemia. Therefore, physiological contributions to a decreasing force in the initial phase may differ largely by the used intensity (target value). That is, the production volumes of blood lactate which is a restriction factor of sustained muscle output may differ with or without the presence of ischemia. The presence of blood obstruction in the initial phase of sustained isometric exercise is considered to influence largely force decrease properties, and the above hyperactivity of nervus sympathetic by ischemia may also influence the latter phase during which blood flow resumes with a decrease in force. In addition, these effort levels impose a large burden on subjects because of blood pressure elevation caused by distal ischemia (Bonde-Patersen et al., 1975).

If muscle endurance can be evaluated equally at any intensity, the lower intensity should be selected. However, few studies have clarified the relationships and differences of force output, physiological responses and subjective muscle fatigue during sustained muscle contraction at each target. If the muscle fatigue level or the recovery process after work differs among target values, the evaluation of muscle endurance should be distinguished by the target force. Moreover, in order to improve working efficiency it will be necessary to clarify whether differences in work intensity during sustained isometric exertion in daily life affect pain sensation, subjective muscle fatigue state or accumulation of metabolites during force exertion and recovery period.

This study aimed to examine the relationship between the level of subjective muscle fatigue sensation (SMS) and the blood lactate concentration (La) during sustained and constant effort static gripping (SSG) and the recovery phase after gripping using various target values based on MVC (50%, 75% and 100% MVC).

METHODS

Subjects

The subjects were 10 healthy males [age 20.8 ± 1.3 yr, height 172.9 ± 4.6 cm, body mass 67.7 ± 5.7 kg] without upper extremity impairments. Their physical characteristics approximated the standard values for Japanese people within the same age range. Written informed consent was obtained from all subjects after a full explanation of the experimental purpose and protocol.

Materials

Grip strength was measured using a digital hand dynamometer with a load-cell sensor (EG-290, Sakai, Japan). Each signal during the SSG was sampled at 20 Hz by an analog-to-digital interface, and then sent to a personal computer. To increase the subject’s motivation during the SSG, the recorded digital data were immediately displayed on a screen as a sustained force curve to give feedback. La was measured by gathering blood from the tip of the gripping side forefinger using a meas-
uring instrument (Lactate Pro LT-1710, Arkray, Japan).

**Experimental design**

Each subject carried out the SSG for 6 min with three target effort levels (50%, 75% and 100% MVC). The experimental design selected the crossover design, namely each subject performed all target forces with an interval of one or two days. This was randomized in considering the effect of the measurement order.

**Experimental procedure**

All subjects performed the handgrip test with the dominant hand as judged by Oldfield’s Handedness Inventory (Oldfield, 1971), and the grip width was individually adjusted. Handgrip measurements were performed while seated in an adjustable ergometric chair. The arm, supported by an armrest, was in a sagittal and horizontal position, with the forearm vertical and the hand in a semi-prone position. These settings were kept consistent throughout all the measurements. The subjects performed the maximal grip test twice before the SSG, and the higher exertion value was determined as the MVC. The maximal grip tests were also carried out at 0, 4 and 7 min after the SSG. The subjects were instructed not to change the grip, or to break into a posture during the handgrip measurement. Furthermore, they were instructed to maintain a target force for 6 min, during which the target force line was displayed on a screen for encouragement. No verbal encouragement was given during the test. To assess the physiological response to the SSG, La was measured before SSG and at 0, 4 and 7 min after the SSG. Subjective muscle fatigue sensation of the forearm was measured by Borg’s CR 10 Scale (Borg, 1973) every 30 sec from the SSG onset to 7 min after the SSG (13 times during the SSG, 14 times after the SSG). The index for the SMS was a 12-grade scale from “not at all” to “absolute maximum (highest possible)”.

**Data analysis**

One way ANOVA was used to reveal the mean difference in average gripping force between the target forces for each period (every 30 sec). Two way ANOVA was used to reveal the mean differences in the changing ratio of grip strength, SMS, and La before/after SSG, and that of the SMS with time lapse. Multiple comparisons were performed using Tukey’s HSD. Pearson’s correlation coefficients were calculated to examine the relationships of the changing rate between sustained force parameters, SMS and La. A probability level of 0.05 was indicative of statistical significance.

**RESULTS**

Figure 1 shows the average decreasing force curve of each target force during the SSG. The average curve was made up by calculating the average values of all the subjects for each sampling time (20 Hz). A marked difference in force decrease between the target values was found after 30 s after the SSG onset. However, at any target force, the grip force reached an almost steady state (nearly 15-20% MVC) within about 150 sec, and the decreasing tendency after about 150 sec was similar. Table 1 shows the mean differences in the average decreasing force every 30 sec. There was a significant difference until 30 sec after the SSG onset between the target values. Moreover, there was no significant difference in the average decreasing force for the whole period (6 min) between the target values.

Figure 2 shows the average maximal grip strength before and after the SSG and in the recovery period. There was a significant decrease until about 40% before the SSG in any target force, but there were no significant differences between the target forces.

Figure 3 shows the average change in SMS during the SSG and the recovery phase for each target force, and the test results for mean differences with time lapses. The SMS increased with time lapse at any target force. It reached “strong” or “very strong” at about 90 sec at any target force, and
reached a peak at 3-4 min. The SMS during SSG for 100% and 50% MVC increased significantly until 180 sec, and that for 75% MVC increased significantly until 150 sec. The SMS for 75% MVC at 30 sec after the SSG onset was significantly higher than that for 100% MVC, and that at 60 sec was also high compared with those for 50% and 100% MVC. The SMS in the recovery period for any target force decreased significantly until 300 sec. The SMS for 100% MVC was significantly higher at any time than that for 50% MVC (see Figure 3). Cross correlation coefficients between time series data of the SMS and the mean gripping value for 30 sec at each target force were calculated (Table 2). The coefficients had a high value, over 0.9, in all target forces (100% MVC: \( r_{xy} = -0.969 \); 75% MVC: \( r_{xy} = -0.998 \); and 50% MVC: \( r_{xy} = -0.989 \); in all cases: lag = 0).

Figure 4 shows the average La before and after the SSG and in the recovery period. The La after the SSG was significantly increased compared with that before the SSG in any target force, and that for 75% MVC had the highest value despite no significant differences between the target forces.
Fig. 2. The average of maximum grip strength before/after SSG and recovery period.

Table 2. Cross correlation coefficients between average gripping force and SMS for each subject.

<table>
<thead>
<tr>
<th>Subject</th>
<th>100%</th>
<th>75%</th>
<th>50%</th>
</tr>
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<tbody>
<tr>
<td>Subject 1</td>
<td>-0.985</td>
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<td>-0.930</td>
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</tr>
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<td>Subject 6</td>
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<td>Subject 9</td>
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<tr>
<td>Subject 10</td>
<td>-0.986</td>
<td>-0.962</td>
<td>-0.911</td>
</tr>
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Fig. 3. The average change of SMS (Borg’s CR 10 scale) during SSG and recovery phase on each target value and the mean difference with time lapses.

↓: There is no significant difference about increasing SMS after this point at 75% MVC.
↓: There is no significant difference about increasing SMS after this point at 50% and 100%MVC.
La in the recovery period for any target force recovered about 20-30% at 4 min and about 30-40% at 7 min after the SSG, and these were significantly different. However, there were no significant differences between the target forces (see Figure 4). Moreover, the level at 4 min had a significantly high value of 20-30% compared with that before the SSG, but was not significantly different at 7 min (10-13%).

Table 3 shows the correlation coefficients between the changing rate of La and the maximum grip strength before and after the SSG. The changing rate after the SSG at 0 and 4 min in the 75% MVC showed a significantly high correlation. The maximum grip strength at 4 and 7 min after the SSG recovered at about 78-79% and 83-84% compared with that before the SSG, respectively, and the level at 7 min had a significantly higher value than that at 4 min. However, there were no significant differences between the target forces (Figure 2).

**DISCUSSION**

Force decreases during SSG for 75% MVC and 100% MVC were very similar and showed two phases consisting of a marked decrease and an almost steady state (see Figure 1). On the other hand,
for 50% MVC, the grip force maintained a target force for the first 35 sec and then decreased linearly until 150 sec. In addition, the grip force reached an almost steady state after about 150 sec in a similar manner to the other target forces. The gripping force up to 30 sec after the SSG onset for 50% MVC was lower than that for 75% or 100%, but there was no significant difference in the average decreasing forces over 1 min between the target values. In other words, the tendency of force decrease over about 35 sec, where it was impossible to maintain the target value, was similar at any target value. It is inferred that the difference of the decreasing tendency between 50% MVC and the other (be specific here) during the initial decreasing phase depends on the degree of blood flow obstruction with an increase in the intra-muscular pressure. Previous studies reported that blood flow obstruction during sustained muscle contraction was more marked at greater than 60-70% MVC (Bonde-Petersen et al., 1975; Gaffney et al., 1990; Kahn et al., 1998; Kimura et al., 1999). Moreover, Royce (1958) compared the force-decreasing curve between the conditions of occlusion and non-occlusion of arterial blood flow during the maximal SSG, and reported that both conditions showed similar curves until 1 min. Therefore, the SSGs for 75% and 100% MVC may be exerted under ischemic conditions in an initial decreasing phase.

An ischemic state during muscle contraction was reported to cause hyperactivity of nervus sympatheticus, increased heart rate and blood pressure, and upregulation of the production of blood lactate (Bonde-Patersent et al., 1975; Tanimoto and Ishii, 2006). In particular, the influence of ischemic state is strong in the upper extremities (Takarada et al., 2000; Koba et al., 2004). Blood lactate (La) was measured as the index of muscle fatigue in this study. The ATP reconstruction process by anaerobic glycolysis metabolism produces muscle metabolites, such as lactic acid or H+. Their accumulations cause a marked decay of intracellular pH and bicarbonate, and result in intramuscular acidification.

The maximal grip strength and La after 6 min SSG markedly decreased at all target forces, but there were no significant differences between the target forces. An increase of La did not correspond to a force decrease, and it may increase still further after the SSG. However, since there were no significant differences between target forces in La of the recovery stage, almost the same volume of La is produced in any target force. We hypothesized that an ischemic condition with rising intramuscular pressure by SIG promotes anaerobic glycolysis and produces more La. However, this study rejected this hypothesis.

The influence of ischemia in the initial phase may not have shown a difference because the reperfusion phase occupies a large part of SSG for 6 min. In the case of muscle contraction for a long time, the degree of muscle fatigue may be almost identical even if the target force differs.

Although there was no significant difference in the absolute value of the La and the maximal grip strength after the SSG between the target values, the relationship between the La and the maximal grip strength in the recovery period was highest for 75% MVC, and the recovery tendency of both parameters correlated.

The SMS reached the peak value for 3-4 min at any target force, the increasing ratio until reaching the peak was the highest in 75% MVC. Kilbom et al. (1983) reported that the SMS for 25% MVC is closely related to physiological responses (Kilbom et al., 1983). Nagasawa et al. (2000) reported that, in the case of SSG above 50% MVC, the physiological effects, such as decreasing force and blood flow, appeared at an early period, and rapidly reached the SMS peak. In addition, they reported that when using a target value below 50 % MVC, the force output could remain above the target value for a long time, and the individual differences in fatigue onset time and time to SMS peak were large. In this study, the SMS reached a peak value at any target force when force decrease reached an almost steady state. The relationships of the time-series changes between SMS and the average force every 30 sec were very high at any target force. However, the relationships between SMS and the integrated area every 30 sec were poor. It is inferred that a time-series change in the SMS has a highly corresponding relationship with force decrease, but an absolute value of SMS at the time did not reflect the gripping force, because the SMS depends on individual fatigue sensation.

The relationship between the time-series changes in SMS and the gripping force during SSG
was the highest at 75% MVC. Considering the above-stated relationship between La and the maximal grip strength after SSG, the decreasing force output during 75% MVC may be linked to the accumulation of metabolites by glycolysis and SMS.

There was no significant mean difference of La, average force output, and SMS among target values. However, force output during SSG at 75% MVC tended to show large individual differences after reaching an almost steady state (Table 1: SD after 240 sec), and the individual differences of La at 7 min in the recovery period also tended to be large. That is, muscle fatigue after SSG at 75% MVC may vary greatly on an individual basis. The SMS during SSG at 75% MVC, which was the highest target demand, increased markedly in the initial phase. The above may affect force output after reaching an almost steady state.

In conclusion, grip force decrease among the various target forces shows significant differences in the initial phase until about 1 min after onset of SSG, but not in the La and the maximal grip strength after the SSG and in the recovery state between the target forces. Namely, in the case of prolonged muscle contraction, which reaches an almost steady state, even if the target force differed with or without ischemia in the initial phase, the degree of muscle fatigue is almost the same. Although the SMS reached a peak value for 3-4 min at any target force, the increasing ratio for 75% MVC was the highest of all the target forces. At 75% MVC, the changes in the grip force during and after SSG are related to La after the SSG and the SMS during the SSG.

REFERENCES


