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The Influence of Different Target Values and Measurement Times on the Decreasing Force Curve during Sustained Static Gripping Work

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Abstract The purposes of this study were to clarify the decreasing properties of, and to examine useful measurement times for evaluating muscle endurance in a comparison among various parameters using measurement times of 1, 3 and 6 mins and target values of 50, 75 and 100% MVC. Fifteen males and 15 females participated in this study. All subjects carried out sustained isometric gripping under nine conditions of measurement times and target forces, (1, 3 and 6 mins vs. 50, 75 and 100% MVC) with an interval of one or two days. The property of decreasing force in the initial phase (marked decreasing phase) differed among the target values, and the decreasing speed of the gripping force was highest for 100% MVC. However, the decreasing property after about 60 sec, in which the force decreased to about 30% MVC from the onset of grip, was similar among all target values, and then the gripping force reached an almost steady state phase at about 150–180 sec. In other words, the difference of the decreasing property during the initial phase with different target values was considered not to influence the property in the later phase, in which the force decreases to about 30% MVC. When muscle endurance is evaluated from the phase until reaching the steady state, it may be possible to evaluate the same property of the decreasing phase at 6 min as the measurement at 3 min. The measurement for 1 min at 50% MVC was not valid as an evaluation time because the grip force did not decrease enough. The integrated area in the initial phase was considered to depend on the magnitude of the target value, and the integrated area for 30 sec or 60 sec at 75% MVC was larger than that at 100% MVC. It was inferred that higher pain at 100% MVC resulted in a greater decrease in the speed of the force. *J Physiol Anthropol 25(1): 23–28, 2006*
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Introduction

The degree of muscle fatigue caused by sustained muscle contraction depends on the measurement conditions, such as exercise type, measurement time, and intensity (Enoka and Stuart, 1992). A force that decreases with elapsed time during sustained muscle contraction differs considerably with measurement conditions. Muscle endurance, which is defined as the ability to sustain a certain muscle contraction level, has been examined from various viewpoints. Previous studies, generally used time series data with relative intensity (20–100%) based on the maximal voluntary contraction (MVC) of each individual to evaluate quantitatively decreases in the force exerted during sustained muscle contraction (Walamies and Turjanmaa, 1993; Yamaji et al., 2002, 2004). However, it is difficult to compare the study findings regarding sustained muscle contraction in previous studies simply, because the measurement conditions differed for different researchers. It will be necessary to clarify the property, similarities or differences in the decreasing force while controlling the above-stated measurement conditions.

Sustained muscle contractions with higher contraction levels impose greater pain on subjects, and the influence of psychological factors on the decreasing force or sustained time becomes larger (Nagasawa et al., 2000). With muscle contraction levels over 50% MVC, the force-decreasing curve showed a markedly decreasing phase just after the onset of muscle exertion (initial phase) and a small decreasing phase (steady state phase) (Nagasawa et al., 2000; Yamaji et al., 2000). Moreover, in the initial phase using 60–70% MVC as the target force, blood flow is obstructed with an increase of an intra-muscular pressure (Kahn et al., 1998). These contraction levels are required to exert a force in a state of ischemic hypoxia. In addition, it was reported that these intensities make blood pressure increase by a blood flow obstruction in a peripheral part (Bemben et al., 1996). Therefore, muscle endurance tests with higher contraction levels may be unsuitable for the elderly from a safety viewpoint. Moreover, the property of decreasing force is considered to differ in not only the initial phase of the blood flow obstruction, but also the latter phase by whether a blood flow obstruction has occurred or not. However, there are few studies to compare the decreasing property among different contraction levels, and useful evaluation parameters, which consider the decreasing property of each contraction level, have not been established.

Furthermore, Walamies and Tujanmaa (1993) used 1 min as the measurement time because the motivation decrease caused by long measurement times affects the exertion force. A subject may unconsciously affect the muscle contraction by psychological reaction to the pain. Therefore, selecting proper measurement conditions (time and contraction level) in order to ensure the subject exerts the maximal force is important for evaluating muscle endurance.

The purposes of this study were to clarify the force-decreasing property during sustained static grip (SSG), and to examine useful measurement times for evaluating muscle endurance from a comparison among various parameters using measurement times of 1, 3 and 6 mins, and target values of 50, 75 and 100% MVC.

Method

Subjects

Subjects were 15 healthy males [age 20.8±1.3 yr, height 172.9±4.6 cm, body mass 67.7±5.7 kg] and 15 healthy females [age 21.1±1.3 yr, height 160.9±5.4 cm, body mass 55.9±5.4 kg] without upper extremity impairments. Their physical characteristics approximated average values for Japanese people within the same age range (Lab Physical Edu Tokyo Met Univ, 2000). Written informed consent was obtained from all subjects after a full explanation of the experimental purpose and protocol was given.

Materials

Grip strength was measured using a digital hand dynamometer with a load-cell sensor (EG-290, Sakai, Japan). Each signal during SSG was sampled at 20 Hz with an analog-to-digital interface, and then relayed to a personal computer. To increase the subject's motivation during SSG, the recorded digital data was immediately displayed on a screen as a sustained force curve to give feedback.

Experimental design

Each subject carried out the nine SSG tests for 1, 3 and 6 mins with three target forces (50, 75 and 100% MVC). The experimental design selected was a cross over design, such that each subject performed all target forces with an interval of one or two days. This was randomized to eliminate the effect of measurement order.

Experimental procedure

All subjects performed the handgrip test with the dominant hand judged by Oldfield's Handedness Inventory (Oldfield, 1971), with the grip width being individually adjusted. Handgrip measurements were performed while seated in an adjustable ergonomic chair. The arm, supported by an armrest, was in a sagittal and horizontal position, the upper arm being vertical and with the hand in a semi-prone position. These settings were kept consistent through all measurements. The subjects performed the maximal grip test twice before the SSG test, and the higher exertion value was used as the target value (50, 75 and 100% MVC) of the test. Before the test, subjects rehearsed SSG. They were instructed not to change the grip, and not to change their posture during the handgrip measurement. Furthermore, the subjects were instructed to maintain a target force for the measurement times (1, 3 and 6 min), during which the target value line was displayed on a screen for encouragement. No verbal encouragement was given during the test.

Force-decreasing parameters

The integrated area of the decreasing curves required to decrease to 20, 30,40, 50, 60, 70 and 80% MVC, and the average integrated area during 30, 60, 120, 180 and 360 sec were selected as parameters.

Data analysis

Pearson's correlation coefficients were calculated to examine the relationships among the measurement times for each parameter. A two-way ANOVA (target value×gender, measurement time×gender) was used to examine the mean differences. Multiple comparison tests used Tukey's HSD method. The probability level of 0.05 was used as indicative of statistical significance.

Results

Figure 1 shows the average sustained force curve and standard deviations of each exertion value during 6-min SSG. The average curve was constructed by calculating the average of each sampling time (20 Hz) for each subject. For the target values of 75 and 100% MVC, the grip force decreased markedly until 60 sec after SSG onset, then it decreased slowly and reached nearly 20% MVC at about 2–3 min. On the other hand, for 50% MVC, the grip force maintained a target value for the first minute, then decreased markedly until 100 sec and reached nearly 20% MVC after about 2–3 min. For any target value, the grip force reached an almost steady state (nearly 15–20% MVC) within about 150 sec.

Table 1 shows the correlation coefficients between measurement times for each parameter. The relationships among measurement times for force-decreasing parameters tended to be higher in males than in females. They tended to be the lowest between 1 and 6 min, and the highest between 3 and 6 min. The decreasing speed of the gripping force was marked during the initial phase. This decrease was highest for 100% MVC, and lowest for 50% MVC.

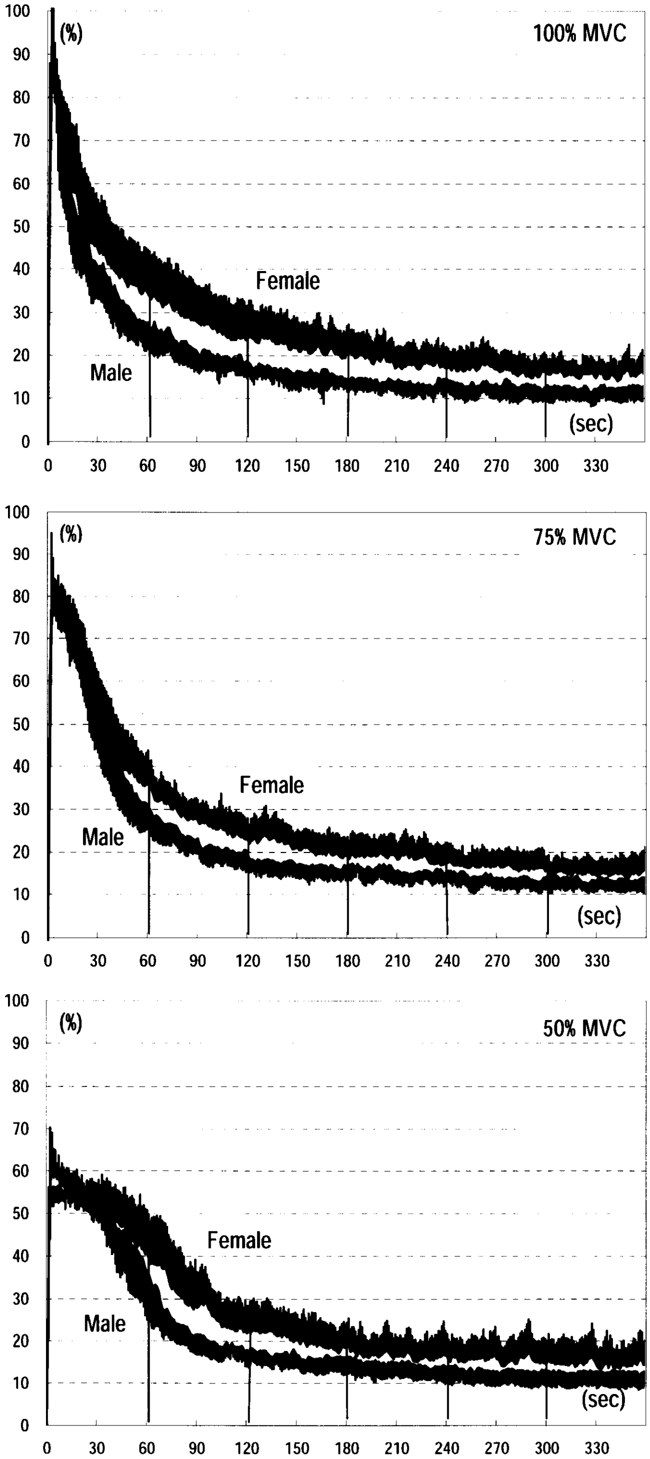

Fig. 1 Average force-time curve for each target value measured 6 min by gender.
Note) The mean value and standard diviations for all subjects calculated every sampling data.

Table 2 shows the results of the mean difference test for each parameter among the target values. There were significant differences for integrated areas for 30 and 60 sec and decreasing time until 40% MVC among the target values.

Table 3 shows the results of the mean difference test for each parameter among the measurement times. There were significant gender differences from decreasing time to 40% MVC. In males, the integrated areas except for 30 sec in 50% MVC were significantly larger at 1 min than at 3 and 6 min. In contrast, the decreasing times to 20 and 30% MVC were larger at 3 and 6 min than at 1 min.

Discussion

The decreasing force for three target values for 6 min showed two phases consisting of a marked decrease and an almost steady state. However, after a decreasing force for 50% MVC maintained a target value for 30–60 sec, it decreased markedly until about 100 sec. At a muscle contraction level over 60–70% MVC, there is a blood flow obstruction with an increase of intra-muscular pressure in the initial phase (Kahn and Monod, 1989). Muscle contraction is maintained in a state of little oxygenation of the activated muscle. The physiological factors related to a decreasing force at the target values of 75 and 100% MVC are considered to be similar. Therefore, a decreasing tendency of the gripping force for both target values was similar, although the former's decrease was somewhat slower than the latter's.

The integrated area is considered to increase with increasing contraction level, but for 30 and 60 secs at the target value of 75% MVC it was larger than that of 100% MVC. A decreasing force at 100% MVC may become faster due to the psychological factor of the pain of sustaining high contraction levels. It is inferred that the difference in the decreasing property in the initial phase does not reflect the latter phase, because any parameter evaluating the latter phase shows an insignificant difference at any contraction level. Therefore, similar grip strengths irrespective of contraction level during the initial phase may be exerted in the latter phase which reached an almost steady state decrement of 15–20% MVC. The differences of force-decreasing property among target values occur in the markedly decreasing phase. The physiological factor related to sustained muscle contraction in this phase was considered to differ (Yamaji et al., 2004). The energy supply system (oxygenation supply by blood) and economical efficiency of force output (muscle fiber type ratio) is intricately-intertwined with sustained muscle contraction as a physiological factor (Kahn and Monod, 1998). The physiological significance of muscle endurance measurement using each target value by the examination of the relationship between force-decreasing property and physiological factors during the marked decreasing phase may be made clear by further study.

The relationships between 1 and 6 min for force-decreasing parameters at 50% MVC and 75% MVC were not fair ($r<0.7$) in males and females. Measurement times in females were poor as compared with males. It has been reported that muscle endurance based on relative intensity has a gender difference, with females being superior to males (Maughan et al., 1986). In the present study, there was also a significant gender difference in the gradually decreasing phase, i.e. from decreasing to 40% MVC (Table 3). Moreover, the individual

Table 1 Correlation coefficients between the measurement time for each parameter

	100% MVC						75% MVC						50% MVC					
	male			female			male			female			male			female		
	1 vs. 3	1 vs. 6	3 vs. 6	1 vs. 3	1 vs. 6	3 vs. 6	1 vs. 3	1 vs. 6	3 vs. 6	1 vs. 3	1 vs. 6	3 vs. 6	1 vs. 3	1 vs. 6	3 vs. 6	1 vs. 3	1 vs. 6	3 vs. 6
Decreasing time																		
80%	.733	.590	.698	.350	–.028	.154												
70%	.790	.747	.749	.208	–.114	.285	.633	.575	.744	.135	.150	.850						
60%	.862	.739	.796	–.293	–.089	.342	.538	.513	.778	.195	.249	.656						
50%	.619	.748	.858	–.088	–.027	.283	.604	.481	.748	.553	.399	.604						
40%	.443	.765	.675	.132	.023	.268	.725	.515	.714	.493	.351	.316	.088	–.197	.818	.453	.177	.436
30%	–.129	.472	.477	.311	.093	.354	.425	.288	.605	.490	.349	.632	.223	.148	.756	.244	.311	.595
20%	.351	–.257	.037	.057	–.081	.516	.119	.021	.421	.103	–.203	.620	.368	.249	.650	.036	.258	.731
Average integrated area																		
30s	.824	.773	.823	–.017	–.004	.278	–.647	.681	.772	.449	.403	.711	.597	.508	.443	.439	.292	.121
60s	.712	.814	.773	–.115	–.061	.356	.698	.568	.665	.470	.318	.618	.513	.284	.767	.733	.173	.192
120s			.628			.374			.646			.517			.788			.522
180s			.474			.381			.597			.583			.738			.590

Note) Shadow portion indicates the significant coefficients ($p<0.05$). "1 vs. 3" means the correlation coefficients between 1 and 3 min for each parameter.

difference of force output over 180 sec almost reaching the steady state phase was larger in females than in males. Therefore, the individual difference of force output in a gradually decreasing phase in females may influence a poor relation among measurement times for force-decreasing parameters.

The decreasing force during maximal sustained static gripping (SSG) showed a similar decreasing tendency in males and females, which was the same result as that reported by Yamaji at al. (2000). The gripping force for all subjects markedly decreased to 40% MVC from the SSG onset to 30–60 sec, and then gradually decreased to 20% MVC during the next 120–150 sec. The gripping force reached an almost steady state when it decreased to about 20% MVC, and decreased until 11–18% MVC in males and 12–20% MVC in females at just finishing for 6 min. This result is similar to that in previous studies which examined the tendency of the decreasing grip force during SSG (Maughan et al., 1986; Pertrofsky and Lind, 1975; Walamies and Turjanmaa, 1993, West et al., 1995; Yamaji et al., 2000, 2002, 2004), and the steady state level (15–20% MVC) is considered to be almost the same, even though the SSG test was measured over 6 min. The gripping force value may decrease little after 3 min, because the value decreased only by about 5% (about 1.5–2.5 kg) of MVC. The gripping force during SSG for 3 min almost reaches a steady state. Furthermore, the relationship between all parameters between 3 and 6 min, except the time decreasing to 80%, was fair. Yamaji et al. (2004) reported that blood reflow occurs in the steady state phase, and this phase keeps a balance between supply and demand oxygenation. On the other hand, force output during this phase does not recover even if there is a sufficient oxygenation supply, because nuromuscluar transmission impairment and the frequency of impulse discharge decrease occur (Petrofsky and Lind, 1975). The physiological significance of individual differences of force output during the steady state phase reaching state of muscle fatigue has not been elucidated. There is, therefore, room for further study about the availability of this phase as an evaluation phase for muscle endurance. However, when trying to evaluate muscle endurance from the individual difference of force output during the phase until a reaching muscle fatigue state, the 3 min measurement can sufficiently estimate the decreasing tendency of the grip force after 3 min.

Muscle endurance tests need a longer measurement time compared with maximal strength tests or muscle power tests, and are accompanied by greater anguish and fatigue. With longer measurement times, a subject may unconsciously affect the force exertion because of the anguish. A motivational decrease caused by the long measurement time would affect the gripping force. Yamaji et al. (2002) reported that the integrated areas for the first 60 sec during sustained maximal static gripping for 3 and 6 min were lower than those for 1 min, and suggested that in the case of 6 min, the subjects unconsciously restrained maximal gripping because of the considerable pain associated with greater force exertion. On the other hand, there were no significant differences among the measurement times for the target value of 50% MVC in this study. Moreover, the decreasing time until 20, 30 and 40% MVC in measurement times of 3 and 6 min was longer than that for 1 min. Most subjects were considered not to decrease lower below 40% MVC within 1 min.

The gender difference was larger from the gradually decreasing phase (120–80 sec after gripping onset). Since the individual difference of force output in this phase was larger in females than in males, the relationships between 1 and 6 min for force-decreasing parameters may be weak. However, those relations between 3 and 6 min were good. In addition, because the force output reached an almost steady state phase after 3 min in males and females, it is possible to evaluate muscle endurance after 3 min instead of 6 min.

The contribution of physiological factors involving

Table 2 The results of two-way ANOVA (gender vs. target value) for each measurement time

	6 min					3 min					1 min				
	two-way ANOVA			post-hoc		two-way ANOVA			post-hoc		two-way ANOVA			post-hoc	
	F value gender	F value target value	F value interaction	gender	target vaule	F value gender	F value target value	F value interaction	gender	target vaule	F value gender	F value target value	F value interaction	gender	target vaule
Decreasing time															
40%	2.62	7.58*	1.06		M: 50>100	7.46*	14.01*	1.46	100, 50: F>M	F: 50>100, 75	0.00	13.44*	0.60		M: 50>75, 100
30%	9.52*	0.97	0.16	100, 75, 50: F>M		14.43*	2.33	0.29	100, 75, 50: F>M		0.14	2.71	0.17		
20%	13.10*	0.65	0.33	100, 75, 50: F>M		15.07*	1.10	1.63	100, 75, 50: F>M		0.03	0.53	0.39		
Integrated area															
30s	0.60	23.49*	1.71		M: 75>100, 50 F: 75>100	0.40	24.18*	3.38*		M, F: 100, 75>50	0.67	63.48*	0.37		M: 75>100>50 F: 75, 100>50
60s	0.05	7.33*	1.21		M: 100>75	1.80	0.70	2.16			0.17	6.58*	0.38		M, F: 75>100, 50
120s	3.43	2.86	0.80			9.19*	0.19	2.38	100, 50: F>M						
180s	6.38*	1.78	0.73	100, 50: F>M		1.14	84.73*	79.31*		M: 50>100,75					

note: *: $p<0.05$, M: male, F: female, 50, 75 and 100 mean 50% MVC, 75% MVC, and 100% MVC, respectively

Table 3 The results of two-way ANOVA (gender vs measurement time) for each target value

	100%					75%					50%				
	two-way ANOVA			post-hoc		two-way ANOVA			post-hoc		two-way ANOVA			post-hoc	
	F value gender	F value time	F value interaction	gender	time	F value gender	F value time	F value interaction	gender	time	F value gender	F value time	F value interaction	gender	time
Decreasing time															
80%	0.01	1.12	3.13												
70%	0.10	1.02	2.71			3.63	3.06	0.04							
60%	1.16	2.42	1.91			1.91	5.28*	0.03		M: 1 min>3, 6 min					
50%	3.35	3.71*	1.30		M: 1 min>3,6 min	0.48	8.58*	0.28		M: 1 min>3, 6 min					
40%	4.45*	1.25	1.41	3 min: F>M		0.86	4.51*	1.82		M: 1 min>3, 6 min	4.29*	2.65	5.12*	3 min: F>M	F: 3 min>1 min
30%	8.73*	5.36*	3.90*	3 min: F>M	F: 3 min>1 min	8.95*	7.14*	6.03*		F: 3,6 min>1 min	10.48*	13.14*	6.89*	3, 6 min: F>M	F: 3,6 min>1min
20%	20.42*	50.93*	8.70*	3, 6 min: F>M	M, F: 3,6 min>1 min	8.39*	59.49*	5.09*	6 min: F>M	M, F: 3, 6 min>1 min	7.07*	47.97*	4.94*	6 min: F>M	M,F: 3, 6min>1 min
Integrated area															
30s	0.31	4.67*	1.88		M: 1 min>6 min	4.03	7.55*	0.42		M: 1 min>3, 6 min	1.30	3.15	0.69		
60s	1.36	6.58*	1.49		M: 1 min>6 min	0.50	9.76*	0.27		M: 1 min>3, 6 min	0.77	12.50*	1.10		M: 1 min>3,6 min

Note) *: $p<0.05$, M: male, F: female

sustained maximal static force exertion changes over time (Kahn and Monod, 1989; Yamaji et al., 2004). In further studies, therefore, it will be, necessary to examine the relationships between the physiological response and the decreasing force by measuring simultaneously the muscle oxygenation kinetics, EMG, and subjective fatigue using various target values for selecting the useful parameters for evaluating muscle endurance.

Many previous studies evaluated muscle endurance using time-series data of the force-decreasing relation (Bemben et al.; 1996, Maughan et al., 1986; Nagasawa et al., 2000; Walamies and Turjanmaa, 1993; West et al., 1995; Yamaji et al., 2000, 2002, 2004). The force-decreasing parameters in their studies used other parameters such as regression coefficients and decreasing rate. Since the present study aimed to evaluate each decreasing phase in stages, it used the decreasing time to a fixed force output and integrated area to a fixed time. Further study is necessary to examine the decreasing property including the other parameters.

In conclusion, the property of decreasing force in the initial phase (markedly decreasing phase) differs among the target values, and the decreasing speed of gripping force is highest for 100% MVC. However, the decreasing property after about 60 sec from gripping onset (force decreased until about 30% MVC) is similar among the target values. Gripping force reaches an almost steady state phase at about 150–180 sec. The difference in the initial phase based on target values does not affect the latter phase. When muscle endurance is evaluated from the large individual difference of force output until the steady state phase, it may be possible to use the 3 min measurement to estimate the property of the decreasing phase for 6 min. The measurement for 1 min at 50% MVC is not valid as an evaluating time because the grip force does not decrease enough. The integrated area in the initial phase is considered to depend on target values, and the integrated area of 75% MVC for 30 and 60 sec is larger than that of 100% MVC. It is inferred that the pain at the latter target value makes for a high decrease in speed.

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