Influence of grip types and intensities on force-decreasing curves and physiological responses during sustained muscle contractions

＜Original Article＞

Influence of Grip Types and Intensities on Force-decreasing Curves

and Physiological Responses During Sustained Muscle Contractions

Running Head: Influence of grip condition to decreasing force.

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Abstract

This study aimed to examine relationships between force outputs during sustained isometric grips (SIG) and intermittent repeated grips (IRG) with three relative target forces (50%, 75%, and 100% MVC), and subjective muscle-fatigue sensation (SMS) and blood lactate (La) during and after gripping tests. Ten young males performed sustained grip tests with 2 grip types and 3 target forces for 6 min. La and maximal grip strength were measured before, just after and 4 min and 7 min after each grip test. SMS of the forearm was measured every 30 s during and after each grip test. The relationships of average grip force in every 30 s between SIG and IRG were not good. The La value after IRG tests with 75% and 100% MVCs tended to be higher than that in the other conditions. The tendency for decline differs with grip type, intensity (target forces) and the force outputs among the conditions. The muscle fatigue level in the SIG and IRG may differ largely even when using the same target force. Although the SIG imposes a larger burden on subjects than the IRG, La after gripping work is lower.

Key words: muscle endurance, fatigue, blood lactate, subjective muscle-fatigue sensation, recovery

Introduction

Muscle endurance, defined as the maximal capacity to sustain a fixed force output [1], is closely related to muscle fatigue produced during sustained contractions. The measured values cannot be simply compared because muscle fatigue differs considerably with measurement conditions such as exercise type, sustained time, and intensity [2].

Static muscle endurance has, generally, been evaluated by sustained isometric or intermittent repeated muscle contraction using relative intensity based on each individual's maximal strength [3-7]. In the case of sustained isometric contractions above 50% MVC, the force output decreases markedly in the initial phase and reaches an almost steady state at 15-20% MVC within 150-180 s [4, 6-9] With intermittent repeated muscle contractions, the force output is largely influenced by an exertion interval as well as sustained time [10] because of repeated muscle contraction and relaxation. Summarizing previous findings on the exertion interval, a repeated contraction with a 2 s interval using high intensity reaches an almost steady state within about 180 s, but not until at 6 min with over a 2 s interval [3, 4, 10]. In addition, it has been reported that a steady state of force outputs appears at higher %MVC levels in intermittent repeated muscle contractions than in sustained isometric contractions [3, 4, 10].

Until now, the measurement of muscle endurance has been considered to be valid if force output during sustained contraction decreases to a certain level [5, 6, 11]. Even if measurement conditions (target value and exertion type) differ, muscle fatigue peaks when force output reaches an almost steady state. In short, muscle endurance may be able to be evaluated equivalently in all measurement conditions if measurement is continued until force outputs reach a steady state. However, it is unclear whether a steady state means equivalent muscle fatigue and whether the muscle endurance evaluated from the force-decreasing parameters using various measurement conditions can be compared simply.

Although there are some reports of the relationships between sustained force outputs and physiological responses or subjective muscle-fatigue sensation (SMS) [12], the above relationships during sustained isometric and intermittent repeated contractions with various target forces have been little examined. The total force impulse (sum of force output) is larger in sustained isometric contraction with a long contraction time. Since oxygen supply to muscles differs by target force levels [7, 10], the contribution of the energy supply system also has different possibilities. It is, therefore, hypothesized that the differences of sustained contraction types and target force levels reflect SMS and blood lactate (La) during and just after each grip test and their recovery process.

However, as stated above, since it is assumed that the contribution of physiological factors to each sustained muscle contraction differs considerably with measurement conditions, they should be considered when measuring static muscle endurance.

The purpose of this study was to examine relationships between force outputs during SIG and IRG tests with three relative target forces (50%, 75%, and 100% MVC) and SMS or La during and after each sustained grip test.

Materials and 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. Written informed consent was obtained from all subjects after a full explanation of the experimental purpose and protocol. This experimental protocol was approved by the Kanazawa University Health and Science Ethics Committee.

Experimental design

We selected sustained isometric grips (SIG) and intermittent repeated grips (IRG) with 2 s intervals (1 s contraction and 1 s relaxation) as grip exertion types and intensities of 50%, 75%, and 100% MVC based on each subject’s maximal grip strength. Sustained time used 6 min in all conditions. The experimental design was a within-subject group design in which all subjects participate in all conditions and the experimental order is completely randomized considering an influence of bias. Each subject performed all sustained grip tests within 3 weeks with only one test in a day, and the others with an interval of 1 or 2 days to eliminate the influence of muscle fatigue.

Materials

Grip strength was measured using a digital hand dynamometer with a load-cell sensor (EG-290, Sakai, Japan). Each signal during sustained gripping was sampled at 20 Hz by an analog-to-digital interface, and then relayed to a personal computer. To increase the subject's motivation during sustained gripping, 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 measuring instrument (Lactate Pro LT-1710, Arkray, JAPAN).

Experimental procedure

After determining the dominant hand using Oldfield's Handedness Inventory [13], each subject sat in an adjustable ergonomic chair, and put their dominant arm in a sagittal and horizontal position on an armrest, and the hand in a semi-pronation position. The grip width was individually adjusted to achieve a 90° angle with the subject's proximal-middle phalanges [6, 7, 9, 10]. These settings were kept consistent throughout all the measurements.

The subjects were instructed not to exercise before the test, and kept quiet in a chair for 1 hour before each grip test. All grip tests were carried out within the same time (10:00 a.m. or 2:00 p.m.) for all subjects throughout the experiment. The subjects were instructed not to change the grip, or to break into a posture during the test for 6 min in addition to maintaining a target force displayed on a screen for encouragement. No verbal encouragement was given during the test.

La and maximal grip strength were measured 4 times (before and 0, 4, and 7 min after each grip test). SMS of the forearm was measured by Borg's CR-10 Scale [14] every 30 s from the test onset to 7 min after the test (13 times during the test and 14 times after the test). The index for SMS was a 13-grade scale from

“Nothing at all” to “maximal (highest possible)”.

Data analysis

The average grip forces every 30 s were calculated to evaluate the force output at each time point. Repeated two-way ANOVA (2 grip types × 3 target forces) was used to reveal mean differences in the average grip forces, SMS, La, and maximal grip. Multiple comparisons were performed using Tukey’s HSD. Pearson’s correlation coefficients were calculated to examine relationships of the average grip forces among the measurement conditions. A probability level of 0.05 was indicative of a statistical significance.

Results

Figs. 1 and 2 show the average decreasing force curve for each target force during SIG and IRG tests. The former curves were made by calculating the average sampling time (20 data/s) of all subjects and the latter curves by their average peak values every 2 s.

Table 1 shows the results of two-way ANOVA for average grip forces every 30 s. In the SIG tests, the average grip forces for the first 0-30 s were significantly higher at 75% and 100% MVC than at 50% MVC. From 150-210 s onward, all target forces decreased until 15-20% MVC and reached an almost steady state. In the IRG tests, there were significant differences among target forces in all 30 s periods except for 150-210 s and the average grip forces were lower at 50% MVC than at 75% or 100% MVC until 150 s after the grip onset but were higher at 50% MVC than at 100% MVC over 210 s. At 50% MVC, 7 of 10 subjects (70%) could maintain a force output over 50% MVC for 6 min, and the average peak values every 30 s were almost constant. In contrast, the force outputs at 75% and 100% MVC tended to decrease until 45-50% MVC and reached an almost steady state at 150-210 s (Fig. 1). All average forces for every 30 s period were significantly higher in the IRG tests than in the SIG tests except for the first 0-30 s (Table 1).

Table 2 shows the Pearson’s correlation coefficients for the average grip force in each interval among measurement conditions. There were no significant correlations over 120 s among target values in SIG grip.

The average force outputs in the IRG for 75% MVC correlated significantly with that for 50% MVC and 100% MVC in nearly all intervals. In addition, there were significant correlations over 120 s between 75% MVC in both grip types.

Fig. 3 shows the average change of SMS based on Borg's scale during both grip types. In all target forces of SIG tests, all subjects' SMS increased to "5: Strong"–"7: Very strong" at over 90 s after the grip onset, and reached "9" – "Maximal" at over 180 s. In IRG tests as compared with SIG tests, the SMS increased gently and did not reach "Maximal" in all subjects. The SMS at 75% and 100% MVC exceeded "7: Very strong" at over 150-180 s after the grip onset, but only at 50% increased to "5: Strong" or "6" for 6 min. The recovery tendency of SMS after each grip test differed little, and SMS in all conditions recovered to "2: Weak" at 7 min after the grip test.

Fig. 4 shows the changing tendency of an average La before and after each grip test and the results of two-way ANOVA. LA after IRG tests with 75% and 100% MVC tended to be higher than that in the other conditions~~,~~ and was significantly higher at both of the above MVCs than at 50% MVC at just after and 4 min after the test. In addition, the La of 75% MVC after 4 min was significantly higher in the IRG test than the SIG test.

Table 3 shows the results of two-way ANOVA for maximal grip strength at each measurement point. It was significantly larger just after the IRG test with 50% MVC than the other test conditions and at 4 min after the grip test recovered to about 80% in all conditions.

Discussion

The force output during sustained muscle contractions with moderate or high intensity decreases with time lapses, and reaches an almost steady state [6-9, 15]. The present force decreasing property agreed with those in the previous reports except for an IRG test with 50% MVC, in which almost all subjects could maintain greater than target force with little decrease.

When comparing the decreasing properties of force outputs among grip conditions (grip types and target forces) other than IRG with 50% MVC, the times to reach an almost steady state were almost the same as 150-210 s after grip onset. However, the force output of a steady state was higher in the IRG test than the SIG test. In addition, although the average grip force in IRG with 75% MVC tended to correlate significantly with that with 50% and 100% MVC and that in SIG with 75% MVC over 120 s, the relationships of average grip force in every 30 s between SIG and IRG were not good. Since the present experimental design was a within subject group design, the difference of this tendency for decline in both grip types may mainly depend on the different contribution of physiological or psychological factors within subjects to sustained muscle contraction.

The decreasing phenomenon of force output by a sustained muscle contraction is defined as muscle fatigue, and many physiological factors relate intricately to it [16, 17]. Muscle fatigue is classified roughly into central and peripheral fatigue in origin [16, 17]. The former occurs with excitation input to motor areas, excitation transfer to motor neurons, or excitation level of motor neurons. The latter occurs with nuromuscluar transmission, muscle cell membranes (excitation level), excitation-contraction coupling, sliding filaments, or ATP supply and reconstruction.

Many researchers (18-20) reported that peripheral fatigue strongly affects the decay of force output in sustained isometric contractions. Jones et al. [21] and Moritani et al. [19] revealed that muscle fatigue during sustained maximal isometric muscle contraction is caused by transmission impairment based on the accumulation of K^+ (Na^+ depletion) out of the sarcolemma by high frequency depolarization. In addition, Moritani et al. [20] reported that motor unit mobilization, amplitude of impulse, and frequency of impulse discharge decrease gradually during sustained isometric elbow flexion with 50% and 100% MVC. They interpreted the decrease of the latter two factors as a control operation to avoid muscle rigor by transmission impairment in local systems and ATP depletion. In particular, since the maintenance of the excitation level in muscle cell membranes relates closely to ATP reconstruction and supply, it is inferred that ATP reconstruction during SIG without a relaxation period is harder than that during IRG [16, 20]. The SIG may, therefore, produce a more marked force decrease and lower forces in a steady state phase than the IRG.

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. Metabolic acidosis in muscles largely inhibits phospho-fructokinase (PFK) activation, it being a rate-determining enzyme in glycolysis metabolism, and produces a decrease of ATP production required for excitation-contraction coupling. In SIG using high target forces, blood supply into active muscles is checked by rising intramuscular pressure. The intensity level induced the ischemic condition, although it differs by the region of muscle used, was reported as 50-75% MVC [22, 23]. We hypothesized that IRG with a blood supply during relaxation period promotes aerobic metabolism, in other words, it facilitates lactic acid rejection in ATP reconstruction. In contrast, we also hypothesized that an ischemic condition with rising intramuscular pressure by SIG promotes anaerobic glycolysis metabolism activity, and produces more lactic acid. However, these hypotheses were rejected in this study.

The maximal grip strength after the SIG tests tended to be lower than that after the IRG tests, and the SMS during the former tests was significantly higher. Therefore, the muscle fatigue level during the SIG tests is considered to be higher. As opposed to the above results, La after the IRG tests with 75% and 100% MVC tended to be higher than that after the SIG tests.

This may be the result of differences in muscle fatigue origin as stated above. In the SIGs, neuromuscular transmission and the excitation level in muscle cell membranes are impaired [19]. In addition, the amplitude of impulse and frequency of impulse discharge also decreases [20]. Force outputs would be, therefore, lower due to these muscle fatigue factors in addition to the defect of ATP reconstruction volume to the demand in muscles. Although the above-stated muscle fatigue mechanism affects force outputs during IRG, the contribution of these factors may be smaller as compared with that during SIG because the relaxation period is with 1 s. Moreover, the influence of a blood supply limit into muscles is kept during SIG because there is no relaxation period [7]. On the other hand, although the blood (oxygen) supply may be unsatisfactory for the shift to aerobic metabolism during an IRG within a 2 s relaxation period, blood reflow occurs early as compared with SIG [10]. Therefore, the contribution of anaerobic glycolysis metabolism for ATP reconstruction may be high.

In addition, La after an IRG at 50% MVC was lower than that at 75% and 100% MVC. Because lactic acid is metabolized by oxidation in aerobic metabolism, La during 50% MVC is considered to apply in aerobic metabolism, and may have low values after the grip test as compared with that with 75% and 100% MVC. Meanwhile, there was no significant difference in La after SIG among target forces. It is also suggested that a difference of muscle fatigue level in each target force cannot be evenly interpreted in both grip types. It may be necessary to examine the different contributions of muscle fatigue factors between both grip types in further studies.

The relationships between SMS and average force output during each grip test were very good. Kilbom et al. [24] reported that SMS for 25% MVC is closely related to physiological responses. Nagasawa et al. [12] reported that, with SIG greater than 50% MVC, the physiological effects such as decreased force and blood flow appeared at the early period and rapidly reached the SMS peak. There were significant differences of absolute SMS values between both grip types. Although various physiological fatigue factors relate intricately to SMS, their contribution may depend on the difference of SMS values.

We followed the recovery phase after each grip test for La, SMS, and maximal grip strength in all conditions. Although the difference of absolute values among target forces just after grip tests reflects a recovery phase, there were no significant differences of the recovery speed (rate of change) in all conditions. Metabolite elimination, such as La, by exercise hyperemia is considered to act similarly in all conditions.

Perspective

The tendency for decline differs with grip type, intensity (target forces) and the force outputs among the conditions. The muscle fatigue level in SIG and IRG may differ largely even with the same target force, because the difference of SMS and La during and after the test with 50% and over 75% MVCs differ in both grip types. Although SIG as compared with IRG imposes a larger burden (higher intensity) on subjects, La after gripping work is lower. Even though both tests evaluate the same static muscle endurance, physiological factors related to force outputs exerted by the above grip tests and their contributions may differ. The difference of the conditions may be hard to compare simply the evaluation of the muscle endurance.

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Figure captions

Fig. 1 Average force-decreasing curve of each target value during SIG for 6 min.

Fig. 2 Average force-decreasing curve of each target value during IRG for 6 min.

Fig. 3. Average change of SMS during gripping and recovery phase on each target value. The circle and square markers indicate SMS during SIG (circle) and IRG (square). Black, white, and gray markers indicate the target value of 100%, 75% and 50% MVC, respectively.

Fig. 4. Average La before and after grip and recovery periods. The mean difference is based on two-way ANOVA (2 grip conditions v.s. 3 target values). The circle and square markers indicate SMS during sustained isometric (circle) and rhythmic repeated grip (square). Black, white, and gray markers indicate the target value of 100%, 75% and 50% MVC, respectively. IRG: rhythmic repeated grip, SIG: sustained isometric grip.

Table 1 Results of two way ANOVA (conditions × target values) for the average grip force in each interval.

		Sustained isometric grip			Intermittent repeated grip			Conditions	Target	Interaction	Multiple comparisons	
		50%	75%	100%	50%	75%	100%	F	F	F	Conditions	Target
0–30 sec	mean	51.2	66.1	67.2	54.5	78.6	84.0	28.66	123.32	14.47	75, 100%	S, I
	SD	6.0	8.1	7.4	5.7	6.7	6.1	*	*	*	I > S	100, 75>50
30–60 sec	mean	45.9	45.6	43.6	53.2	74.5	71.7	52.90	17.37	29.29	50, 75, 100%	I
	SD	7.7	12.2	11.1	4.7	6.7	6.6	*	*	*	I > S	100, 75>50
60–90 sec	mean	38.5	34.2	34.6	53.2	67.3	63.2	96.56	2.86	12.12	50, 75, 100%	I
	SD	10.1	8.2	8.2	4.9	11.3	8.7	*		*	I > S	100, 75>50
90–120 sec	mean	29.3	27.1	27.6	52.8	63.5	58.3	158.30	2.23	9.60	50, 75, 100%	I
	SD	8.1	5.1	5.7	4.3	11.5	9.6	*		*	I > S	75>50
120–150 sec	mean	23.9	23.3	22.5	53.4	60.3	53.2	262.05	3.88	4.53	50, 75, 100%	I
	SD	4.6	3.3	4.2	4.6	10.8	9.7	*	*	*	I > S	75>50
150–180 sec	mean	21.9	20.7	19.5	53.1	55.4	49.3	226.83	3.41	2.29	50, 75, 100%	
	SD	3.2	3.1	3.5	4.8	11.4	9.7	*			I > S	
180–210 sec	mean	19.7	19.2	17.8	53.2	51.6	48.0	190.34	2.76	0.56	50, 75, 100%	
	SD	2.3	2.4	3.9	4.9	11.8	11.0	*			I > S	
210–240 sec	mean	17.6	17.8	16.5	51.9	50.0	45.7	151.34	4.01	1.77	50, 75, 100%	I
	SD	3.5	3.3	3.2	8.1	11.2	11.8	*	*		I > S	50 > 100
240–270 sec	mean	17.8	16.5	16.0	51.1	50.2	44.7	232.61	4.74	1.96	50, 75, 100%	I
	SD	4.4	3.0	2.5	9.3	8.3	9.2	*	*		I > S	50 > 100
270–300 sec	mean	15.6	16.7	15.0	52.3	48.3	44.0	347.08	5.37	4.91	50, 75, 100%	I
	SD	2.9	3.9	2.1	6.6	9.1	7.3	*	*	*	I > S	50 > 100
300–330 sec	mean	15.4	15.9	14.7	51.1	47.2	43.6	255.26	4.53	3.00	50, 75, 100%	I
	SD	2.7	3.8	1.9	8.3	10.4	8.2	*	*		I > S	50 > 100
330–360 sec	mean	15.4	15.7	14.8	50.6	46.8	43.3	187.91	5.17	3.83	50, 75, 100%	I
	SD	2.2	2.9	2.1	9.4	9.5	8.6	*	*	*	I > S	50 > 100

Note: "Conditions" means the grip conditions (Sustained isometric or Intermittent repeated). "Target" means the target values (50%, 75%, and 100% MVC).

I: Intermittent repeated gripping. S: sustained isometric gripping. *: $P < 0.05$.

Table 2 Correlation coefficients for the average grip force in each interval among measurement conditions.

30 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	**.76**				
100%	.44	.42			
IRG					
50%	**.73**	**.74**	.25		
75%	.63	.42	−.02	**.77**	
100%	.17	.05	.06	.57	**.74**

60 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	.53				
100%	**.79**	.58			
IRG					
50%	.27	.43	.30		
75%	.13	.34	.05	**.88**	
100%	.07	.47	.28	**.77**	**.76**

90 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	.26				
100%	.55	**.65**			
IRG					
50%	.17	.41	.46		
75%	.11	.41	.47	**.76**	
100%	.03	.55	.36	.53	**.72**

120 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	.11				
100%	.55	.56			
IRG					
50%	.28	.36	.40		
75%	.16	**.65**	.49	**.78**	
100%	−.09	.46	.41	.53	**.82**

150 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	.23				
100%	.61	.50			
IRG					
50%	.42	**.68**	.48		
75%	.44	**.71**	**.70**	**.78**	
100%	.24	.39	.49	.52	**.84**

180 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	.42				
100%	.39	.52			
IRG					
50%	.27	**.75**	.29		
75%	.28	**.90**	**.65**	**.64**	
100%	.23	**.81**	.52	.62	**.92**

210 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	.42				
100%	.60	.33			
IRG					
50%	.47	.50	.09		
75%	**.66**	**.79**	.50	.54	
100%	.24	**.78**	.21	.56	**.79**

240 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	.60				
100%	.57	.27			
IRG					
50%	**.67**	.61	.41		
75%	**.69**	**.69**	.55	**.74**	
100%	.45	.61	.33	.51	**.85**

270 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	.45				
100%	.38	.18			
IRG					
50%	.33	.56	.61		
75%	.50	**.75**	.29	**.64**	
100%	.42	.48	.30	.59	**.80**

300 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	.11				
100%	.59	.01			
IRG					
50%	.36	**.67**	.19		
75%	.34	**.66**	.20	**.67**	
100%	.59	.47	.28	.35	**.77**

330 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	.28				
100%	.53	.40			
IRG					
50%	.46	**.65**	.59		
75%	.51	**.66**	.61	.61	
100%	**.80**	.57	.55	.53	**.82**

360 s	SIG			IRG	
SIG	50%	75%	100%	50%	75%
50%					
75%	.04				
100%	−.01	.36			
IRG					
50%	.25	.50	.50		
75%	.43	**.82**	.54	**.71**	
100%	**.67**	**.64**	.47	.58	**.93**

Note: Shaped portion indicated a significant correlations ($p<0.05$).

Table 3 Results of two-way ANOVA (2 grip conditions v.s. 3 target values) for the average of maximal grip strength before and after grip and recovery period

		Sustained isometric grip			Intermittent repeated grip			ANOVA			Multiple comparisons	
								Condition	Target	Interaction	Conditions	Target
		50%	75%	100%	50%	75%	100%					
Rest	mean	51.1	50.4	51.4	51.8	50.1	50.0	0.282	0.759	0.332		
	SD	4.8	5.8	4.1	4.8	4.8	3.7					
Immediately after the grip	mean	22.5	21.3	20.4	36.0	28.0	26.1	34.631	10.157	2.925	50%	IRG
	SD	6.4	6.1	6.3	9.7	6.0	5.0	*	*		IRG > SIG	50 > 75, 100
After 4 min	mean	40.6	39.8	40.0	43.5	39.4	36.7	0.195	4.260	2.791		IRG
	SD	5.1	4.8	3.5	4.5	6.1	5.1		*			50 > 75
After 7 min	mean	42.9	42.6	42.6	44.5	41.3	41.1	0.362	1.423	0.571		
	SD	4.2	5.4	4.3	4.5	4.5	4.0					

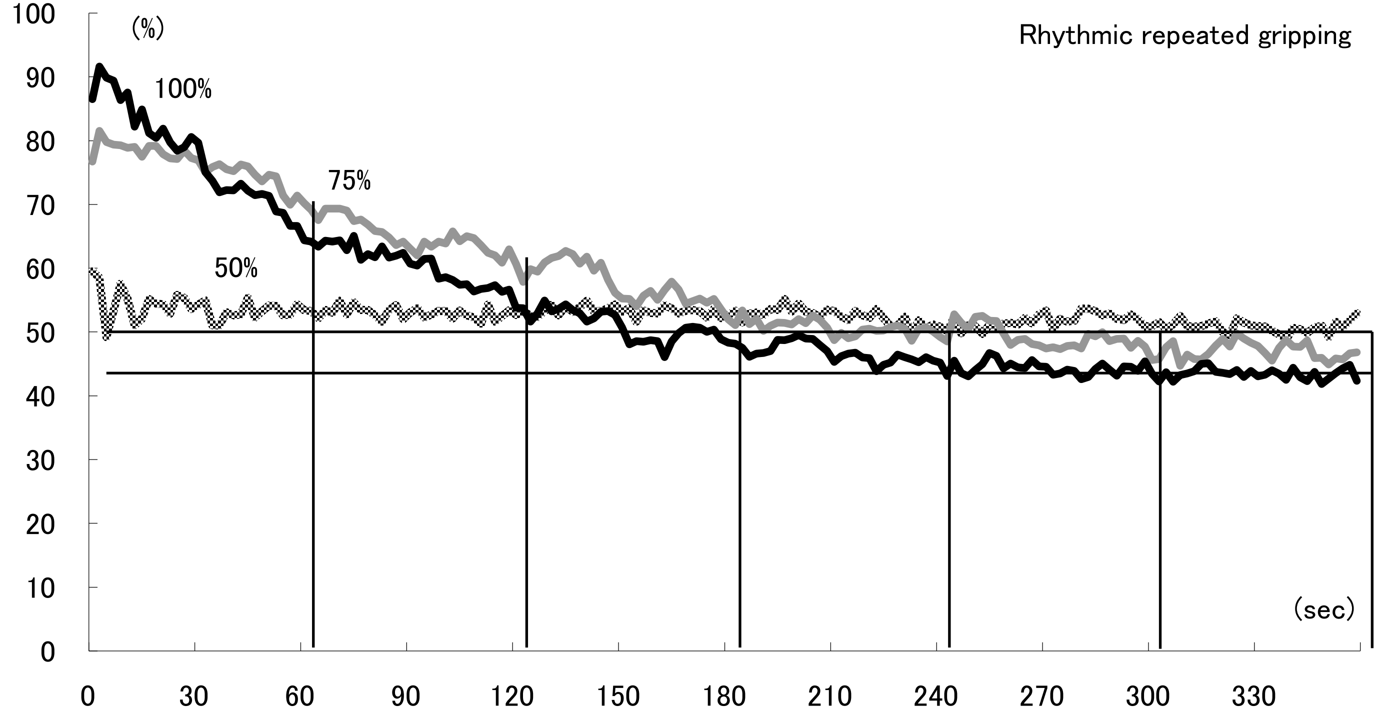

Fig. 2 Average force-decreasing curve of each target value during rhythmic repeated gripping for 6 min.

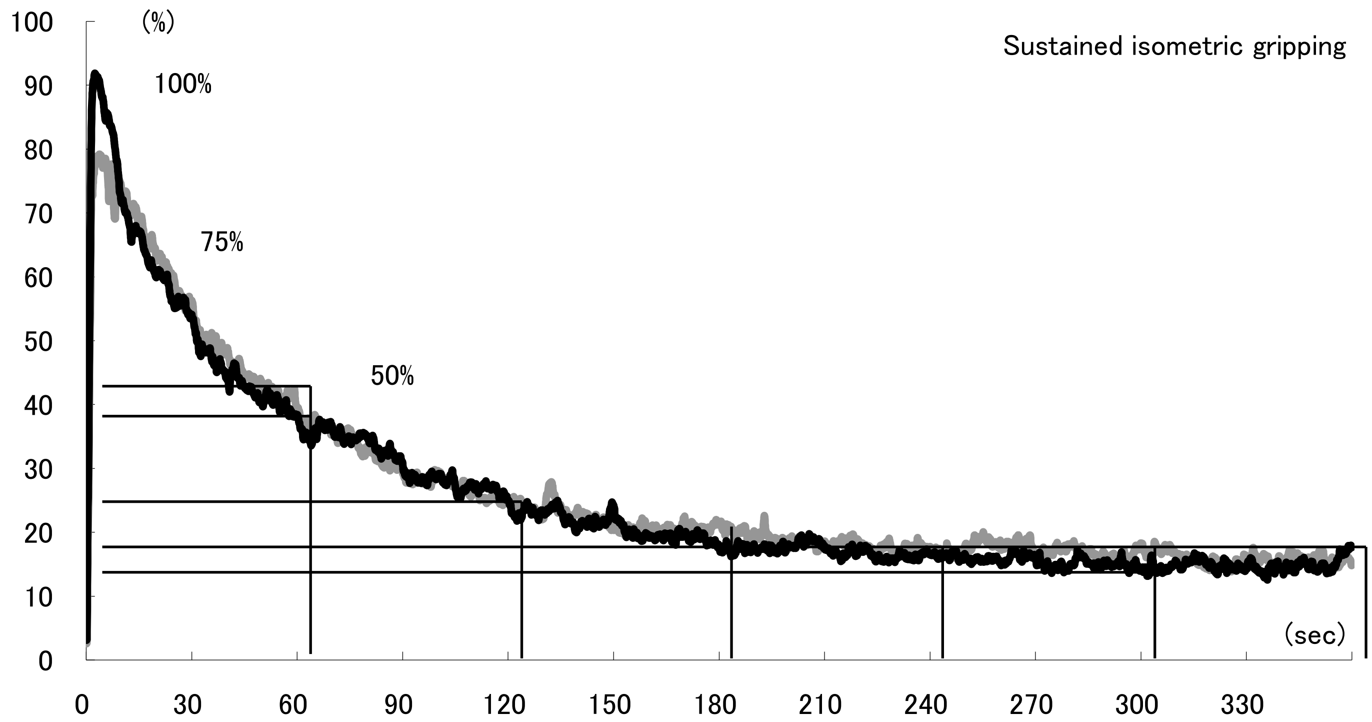

Fig. 1. Average force-decreasing curve of each target value during sustained isometric gripping for 6 min.

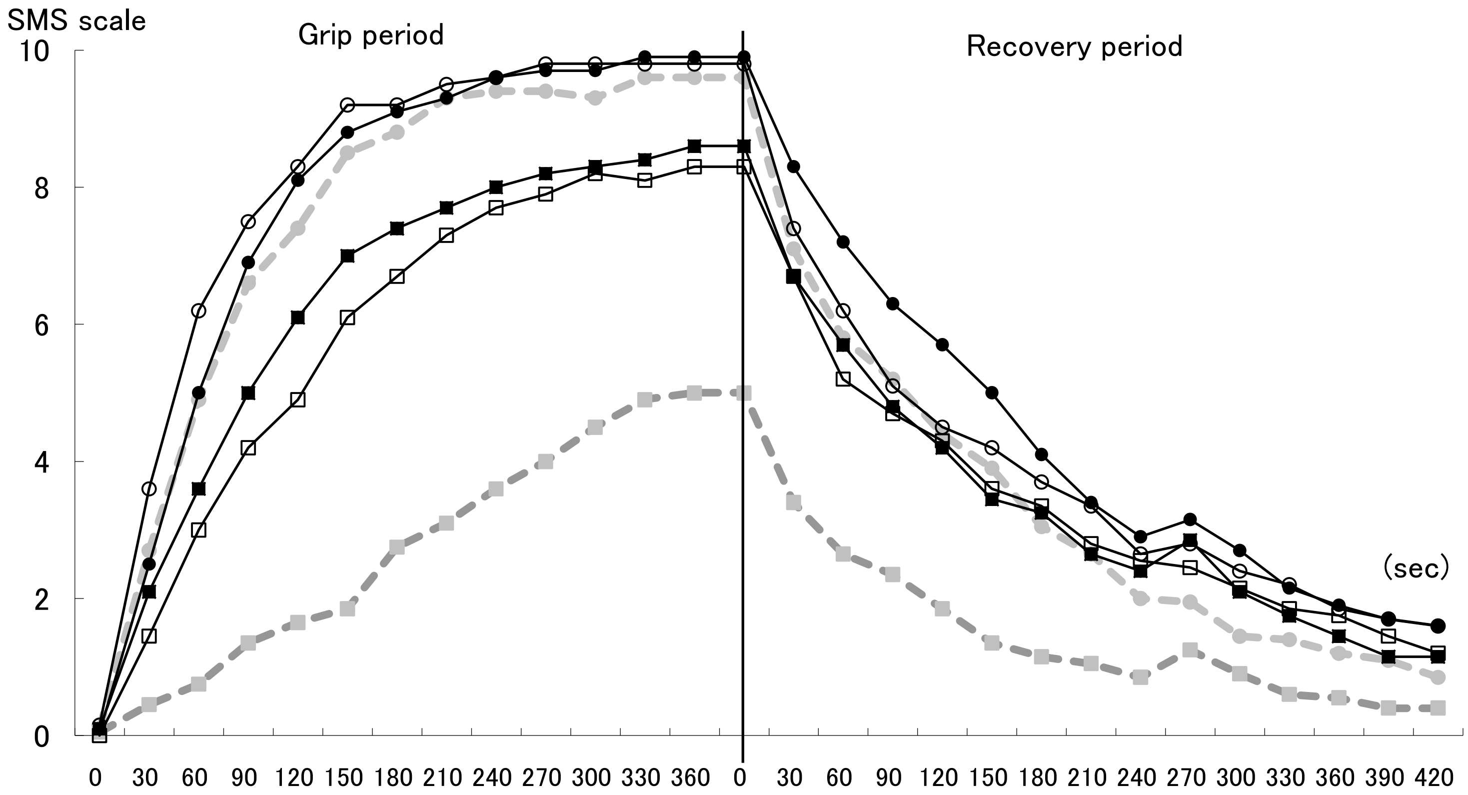

Fig. 3. Average change of SMS during gripping and recovery phase on each target value. The circle and square markers indicate SMS during sustained isometric (circle) and rhythmic repeated grip (square). Black, white, and gray markers indicate the target value of 100%, 75%

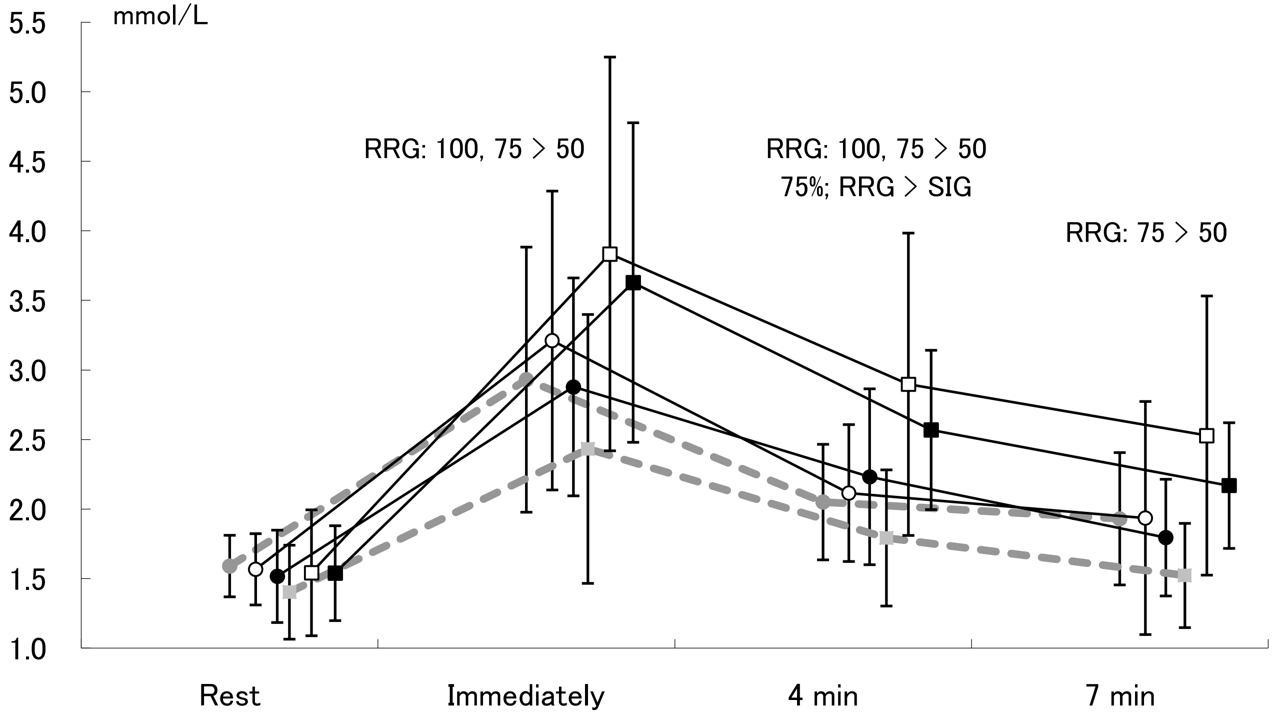

Fig. 4. Average La before and after grip and recovery periods. The mean difference is based on two-way ANOVA (2 grip conditions v.s. 3 target value). The circle and square markers indicate SMS during sustained isometric (circle) and rhythmic repeated grip (square). Black, white, and gray markers indicate the target value of 100%, 75% and 50% MVC, respectively. RRG: rhythmic repeated grip, SIG: sustained isometric grip.