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Relationships between Force-Time Parameters and Muscle Oxygenation Kinetics during Maximal Sustained Isometric Grip and Maximal Repeated Rhythmic Grip with Different Contraction Frequencies

Shinichi Demura[1)], Masakatsu Nakada[2)], Shunsuke Yamaji[3)] and Yoshinori Nagasawa[4)]

1) Faculty of Education, Kanazawa University
2) National Defense Academy
3) University of Fukui
4) Akita Prefectual University

Abstract The purposes of this study were to examine the relationships between various force-time parameters and muscle oxygenation kinetics during maximal sustained isometric grip (SIG) and maximal repeated rhythmic grips (RRG) with different grip intervals (interval times: 5, 4, 3, and 2 s). Subjects were 10 healthy young males, aged 20–26 years (height 173.9±7.3 cm, body mass 71.5±11.2 kg). After measuring maximal grip force, each subject performed the SIG and RRG tests with a target frequency of 12, 15, 20, and 30 grips·min^{-1} (interval times: 5, 4, 3, and 2 s, respectively) for 6 min. The decreasing time until 80% MVC showed significant and high correlations with final force values in RRGs with over 3 s intervals (r=0.866–0.941), but not in the SIG and RRG with a 2 s interval. The time at the lowest Oxy-Hb/Mb value showed a significant and high correlation with the time at the highest Deoxy-Hb/Mb value only in the SIG and RRG with a 2 s interval (r=0.825–0.916). Oxy-Hb/Mb decreases markedly and deoxy-Hb/Mb increases after the onset of SIG due to the obstruction of blood flow caused by the increase in intramuscular pressure. A similar physiological response to that of SIG occurs also in RRG with a 2 s interval, but RRGs with intervals over 3 s achieve more resumption of blood flow in the muscular relaxation phase. Hence, in spite of the same RRGs, it was determined that RRGs with intervals over 3 s differ significantly in a changing pattern of grip force and muscle oxygen kinetics from RRGs with a 2 s interval. *J Physiol Anthropol 27(3): 161–168, 2008*
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Introduction

Various physiological factors such as recruitment of muscle fibers, muscle oxygenation, energy supply, etc. relate to force exerted during sustained muscle contraction (Kagaya, 1994; Boushel et al., 1998). Of them, the following parameters contribute largely the oxygen supply to activity muscles: the capillary density of muscle fibres of the muscle (Hulten et al., 1975), oxidation function depending on the myoglobin content, and blood flow volume to muscles. In addition, the oxygen supply to activity muscles also has a close relationship with muscle activity types (Yamaji et al., 2000). Isometric contraction with a high intensity over 60–70% of maximal voluntary contraction (MVC) produces a temporary blood flow obstruction to activity muscles due to increasing the intra-muscular pressure (Bonde-Peterson et al., 1975).

Royce (1958) compared the decreases of the grip force during sustained static maximal gripping with or without the occlusion of arterial blood flow, and found that both decreases in the initial phase were similar. That is, the initial phase of force exertion due to increasing the intra-muscular pressure may be a similar state to arteriovenous blood flow obstruction by a cuff. In addition, the restriction of blood volume by an intra-muscular pressure is also strongly affected by an interval of muscle contraction and relaxation in rhythmic repeated exertion (Kagaya, 1992). A decrease property of grip force in rhythmic repeated grip may differ fairly from that in sustained isometric grip without muscle relaxation.

We clarified that grip force in the initial phase during maximal repeated rhythmic grip (RRG) with a 2 s interval decreased markedly, but so did muscle oxygenation kinetics, i.e, they had specific corresponding relationships (Nakada et al., 2004). In addition, it has been considered that RRG with a

2 s interval is not enough time to produce a resumption of the blood flow. How much time is needed for that? Or how does a decrease property of force differ by the exertion interval? It is assumed that the RRGs with an interval relaxation over 3 sec exert less influence on the obstruction of the initial phase than that of SIG and RRG with a 2 s interval. Yamaji et al. (2000) suggested that there are two phases, which show remarkable decreasing force and an almost steady state, and that they depend on different physiological factors. Thus, muscle endurance should be evaluated considering the characteristics of both phases. In short, when estimating muscle endurance during maximal sustained static gripping, the phase of blood flow obstruction and the phase of blood flow reflux cannot be treated in the same way. How does the influence of blood flow obstruction differ by the exertion interval? By examining the above problems, a proper exertion interval in which to evaluate muscle endurance will be clarified.

The purpose of this study was to examine change properties of grip force and muscle oxygenation kinetics during SIG and RRG with different grip intervals (2–5 sec), and the relationships among the above-stated parameters.

Methods

Subjects

Subjects were ten healthy males aged 20–26 years [mean height 173.9 (SD 7.3) cm, mean body mass 71.5 (SD 11.2) kg] without upper extremity impairments. Their physical characteristics approximated the standard values for Japanese males of the same age level (Lab Physical Edu in Tokyo Met Univ., 2000). 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-100, Sakai, Japan). Each signal during the SIG and RRG was sampled at 20 Hz with an analog-to-digital interface, and then relayed to a personal computer. To increase subjects' motivation during the SIG and RRG, the recorded digital data was immediately displayed on a screen as a force-time curve to give feedback. Near infrared (NIR) spectroscopic measurements (PSA-IIIN, Biomedical Science, Japan) evaluated muscle oxygenation of the forearm during the SIG and RRG. A PSA-IIIN consists of a probe and a computerized control system. The probe contains a light source filtered at 700, 750 and 830 nm, and two optical detectors placed at 15 mm and 25 mm, respectively, from the light source. The transmitted light from the probe is then either absorbed or scattered within the tissue. Scattered light is delivered via two fiber-optic light detectors to a photomultiplier every 0.1 sec. PSA-IIIN analyzed absorbance of three-wavelengths based on the Lambert-Beer Law, and measured tissue oxygen saturation (StO_2) and total tissue hemoglobin (Total Hb) (Sakai and Saito, 1995). The mean depth of measurement in the tissue has been considered to be half of the distance between the light source and the detector (Hamaoka et al., 1992). The validity of this assumption has only been verified by a mathematical model and an experiment in vitro, and not in vivo. Pattern of light path detected from the input to the output does not always follow a banana shape in which the penetration depth into the tissue is approximately equal to half the distance between the light source and the detector. It is also reported that the distribution of the light intensity in the tissue corresponds to a semicircular shape (Nagashima et al., 2000). PSA-IIIN assumes a depth of 15–25 mm for supporting Nagashima et al.'s assumption. If Hamaoka et al.'s assumption is correct, the measured mean depth of PSA-IIIN is approximately 7–12.5 mm. A discussion on which is the validity of both assumptions is outside the scope of this study. PSA-IIIN can measure the oxygenation kinetics of tissue at depths greater than the paricipants' thicknesses (2–4 mm) with either assumption.

Experimental procedure

Each subject's dominant hand was judged using Oldfield's handedness inventory (1971). All subjects performed the handgrip test with the dominant hand while seated in an adjustable ergometric chair. The arm was in a sagittal and horizontal position and was supported by an armrest with the forearm vertical and the hand in a semi-prone position. Grip width was individually adjusted to achieve a 90-degree angle with the proximal-middle phalanges. After measuring maximal grip force, each subject performed SIG and RRGs with a target frequency of 12, 15, 20, and 30 grips $\cdot$ min^{-1} (interval times: 5, 4, 3, and 2 s, respectively) for 6 min. Each subject randomly performed each measurement above with an interval of one or two days. Muscle oxygenation kinetics was continuously monitored during a 2 min rest and the SIG or RRGs after a rest for 10 min. A near infrared spectroscopy probe was positioned over the first third of line connecting points of the epicondylus medialis humeri and processus styloideus radii of the dominant hand with palm up and forearm on the desk. It has been estimated that this position lies in the center of the flexor digitorum superficialis (Davis, 1959). Butler et al. (2005) reported that the flexor digitorum superficialis is recruited during active power gripping and that the flexor digitorum profundus is the primary contributor to unloaded finger flexion. Hence, the probe was positioned over the flexor digitorum superficialis.

Parameters

1. Force-time parameters

The force-time in RRG was obtained by plotting the peak force from every RRG. Referring to previous studies (Yamaji et al., 2000; Yamaji et al., 2004; Nakada et al., 2004), the following force-time parameters for this study were selected: (1) time to 80% MVC, (2) average integrated area, (3) final force value, (4) inflection time. Time to 80% MVC is the time when the force value decreased to 80% of MVC. The integrated area under the force-time curve is the average of all force values during SIG and RRG for 6 min. The final force value is the force at 360 sec. Nakada et al. (2004) reported that there is an inflection point of the decreasing speed in the force-time curve, distinguishing between a marked decreasing phase and an almost steady state phase during RRG. Kagaya (1994) reported that physiological factors (e.g. recruitment of muscle fibre, muscle oxygenation) related to force exertion differ in pre- and post-inflection points. This inflection point (time) was determined by the following conditions (Yamaji et al., 2004; Nakada et al., 2004; Nakada et al., 2005):

1) The time series sustained force data (180 data) were divided into the former and latter phases at all combinations (e.g. the former: the latter, 3: 177, 4: 176, ..., 176: 4, 177: 3), and respective regression lines were calculated.
2) The best-fit regression lines were determined by: the regression coefficients (a1) in the pre-inflection phase were significant and greater than the regression coefficients (a2) in any other post-inflection phase, and the sum of the determination coefficients of both regression equations was highest.
3) The inflection point was determined at the time from the best-fit regression lines in the combination of time series data.

2. Muscle oxygenation kinetics

Muscle oxygenation kinetics during SIG and RRG, with oxygenated, deoxygenated and total haemoglobins (Oxy-Hb/Mb, Deoxy-Hb/Mb, and Total Hb/Mb, respectively) as parameters, were examined using the following equations;

$$\text{Oxy-Hb/Mb} = \text{Total Hb/Mb} \times \text{Oxygen saturation } (StO_2) \quad (\text{cm} \cdot \text{g/l})$$

$$\text{Deoxy-Hb/Mb} = \text{Total Hb/Mb} - \text{Oxy-Hb/Mb} \quad (\text{cm} \cdot \text{g/l})$$

In this study, the normal value was a predetermined muscle oxygenation level in a resting state, and the muscle oxygenation kinetics measured by NIRS was only examined as a relative change to the resting state. The parameters for change of Oxy-Hb/Mb used the time to reach the lowest value during SIG and RRG. The parameters for change of Deoxy-Hb/Mb used the time to reach the highest value during SIG and RRG.

Data analysis

Time-series data of force and muscle oxygenation kinetics (Oxy-Hb/Mb, Deoxy-Hb/Mb, and Total-Hb/Mb) during SIG and RRG for 6 min were averaged for all subjects. Pearson's correlation coefficient was used to examine the relationship among force-time parameters and muscle oxygenation kinetics. A decrease property of grip force in the initial phase of SIG and RRGs was evaluated by calculating the curvilinear regression equation to estimate the force grip from time (sec), and testing the significance of the curvilinear regression coefficients. The probability level of 0.05 was taken as indicative of statistical significance.

Results

Figure 1 shows sample changes of grip force and muscle oxygenation kinetics (Oxy-Hb/Mb, Deoxy-Hb/Mb, and Total-Hb/Mb: 0–120 s and 240–360 s) during SIG, RRGs with 2 s, 3 s, 4 s and 5 s interval. Grip force in the SIG decreased rapidly for about 120 s, and then reached an almost steady state (about 20% MVC). Figure 2 shows the average curves of changes for grip force and muscle oxygenation kinetics (Total-Hb/Mb, Oxy-Hb/Mb, and Deoxy-Hb/Mb) during SIG and RRGs. In the RRG with a 2 s interval, grip force decreased rapidly until about 50% MVC for about 180 s, and then decreased slowly. Grip force in RRGs with over 3 s intervals decreased constantly throughout 6 min and reached about 55% MVC for a 3 s interval and about 70% MVC for 4 s and 5 s intervals. In particular, with the latter two RRGs, grip force decreased only about 5% MVC (4.8–7.0%) for the last half 3 min (180–360 s).

Oxy-Hb/Mb decreased linearly for about 20–40 s in the SIG after increasing markedly until about 120 s, and reached an almost steady state, but in the RRGs with over 3 s intervals, it decreased for about 10–20 s and then increased slowly. Deoxy-Hb/Mb increased for about 60 s in the SIG and then decreased slowly until the end. However, Deoxy-Hb/Mb in RRGs increased for about 40–50 s then RRG with a 2 s interval decreased slowly until the end, and RRGs with over 3 s intervals reached an almost steady state.

Table 1 shows results of a significance test of curvilinear regression equations during the initial phase (for 60 s) of SIG and RRGs. The curvilinear regression equation was significant only in the SIG and RRG with a 2 s interval.

Table 1 Results of a significance test of curvilinear regression equations during the initial phase (for 60 sec) of SIG and RRGs

Activity type	Curvilinear regression equation (Y: grip force, X: time)	Significance test of curvilinear regression Fr 1	Fr 2	Fr
SIG	Y=0.01938X–2.07282X+98.7	48.29 *	5.71 *	27.00 *
RRG (2 sec)	Y=0.00574X–0.70538X+97.2	75.43 *	4.88 *	40.15 *
RRG (3 sec)	Y=0.00196X–0.39299X+99.9	104.01 *	1.30 ns	52.65 *
RRG (4 sec)	Y=0.00093X–0.32423X+99.7	270.21 *	0.78 ns	135.50 *
RRG (5 sec)	Y=0.00040X–0.22550X+97.2	24.81 *	0.02 ns	12.42 *

Note) *: $p<0.05$, ns: not significant, Fr1: linear regression, Fr2: quadratic regression, Fr: all regression

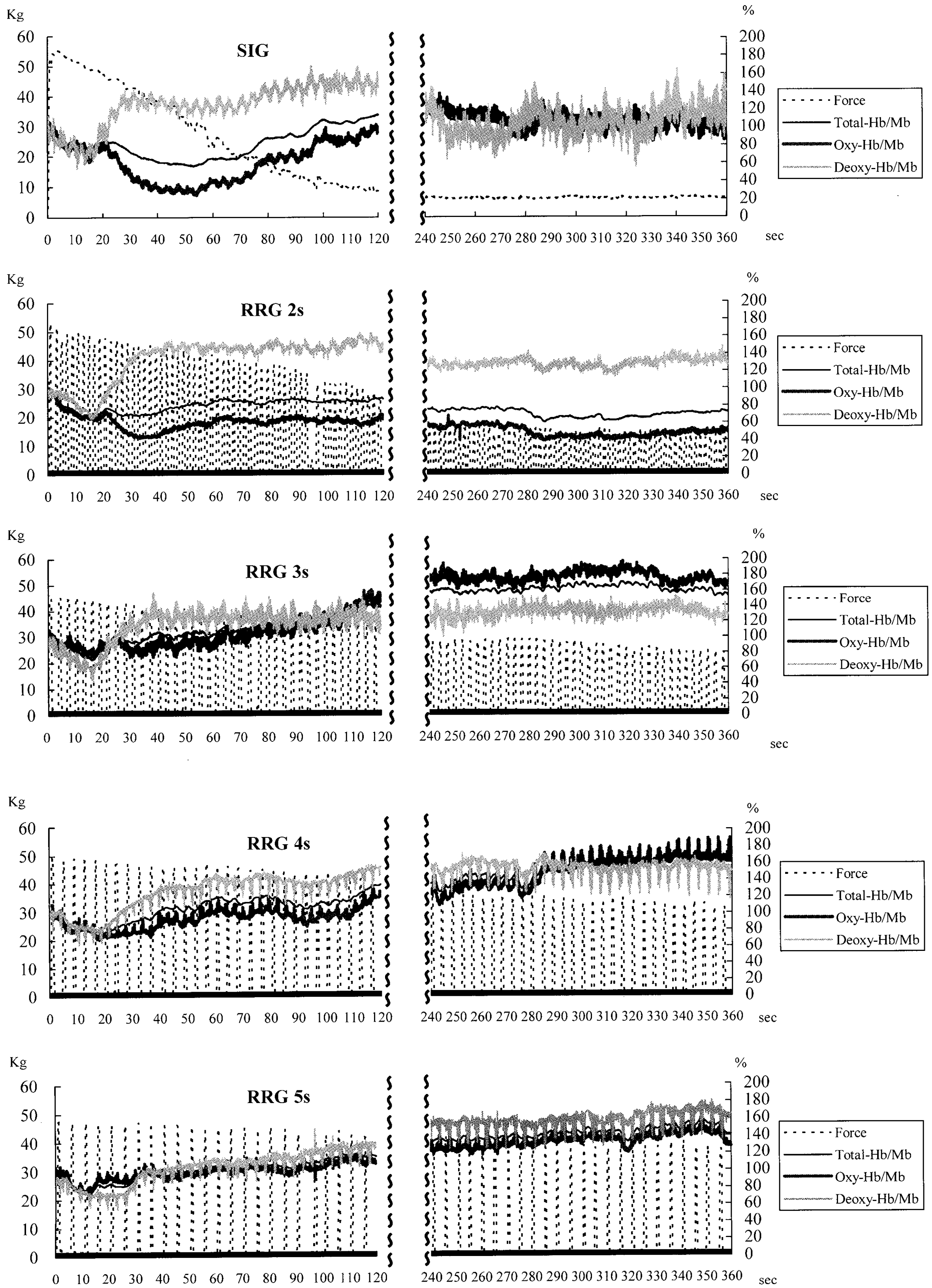

Fig. 1 Sample of changes in grip force and muscle oxygenation kinetics (Oxy-Hb/Mb, Deoxy-Hb/Mb, and Total-Hb/Mb) at phases in the first (0–120 s) and latter half (240–360 s) during SIG and RRGs in a typical subject.

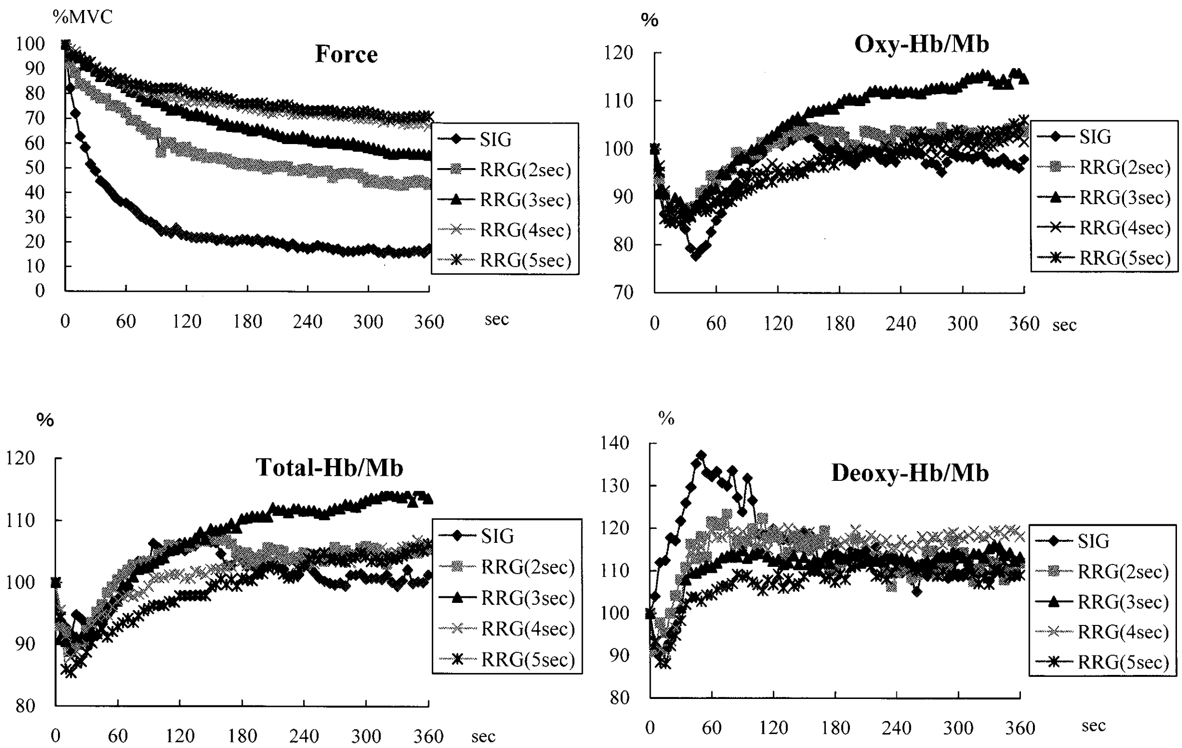

Fig. 2 Average curves of changes for grip force and muscle oxygenation kinetics (Oxy-Hb/Mb, Deoxy-Hb/Mb, and Total-Hb/Mb) during SIG and RRGs.

Table 2 Correlations between force-time parameters and muscle oxygenation kinetics parameters

Activity type	Parameter	Unit	Mean	SD	1	2	3	4	5
SIG	Time to 80% MVC	sec	6.0	3.5					
	Average integrated area	%	25.8	4.0	−0.010				
	Final force value	%	16.2	4.8	−0.171	**0.908**			
	Time to reach minimum Oxy-Hb/Mb	sec	30.4	15.1	0.208	−0.323	−0.454		
	Time to reach maximum Deoxy-Hb/Mb	sec	61.2	25.8	0.542	−0.494	−0.597	**0.825**	
	Inflection time	sec	41.6	29.4	0.420	−0.405	**−0.662**	0.424	0.576
RRG (2 sec)	Time to 80% MVC	sec	35.8	21.9					
	Average integrated area	%	56.6	8.3	**0.739**				
	Final force value	%	43.6	9.7	0.477	**0.874**			
	Time to reach minimum Oxy-Hb/Mb	sec	20.0	10.1	0.030	0.026	0.141		
	Time to reach maximum Deoxy-Hb/Mb	sec	80.2	29.4	0.014	−0.066	−0.042	**0.916**	
	Inflection time	sec	64.4	43.9	−0.328	**−0.765**	**−0.832**	−0.072	0.160
RRG (3 sec)	Time to 80% MVC	sec	90.9	53.4					
	Average integrated area	%	69.3	9.2	**0.919**				
	Final force value	%	55.5	10.5	**0.866**	**0.894**			
	Time to reach minimum Oxy-Hb/Mb	sec	21.9	13.8	−0.261	−0.208	−0.458		
	Time to reach maximum Deoxy-Hb/Mb	sec	116.1	61.3	−0.193	0.038	−0.039	−0.007	
RRG (4 sec)	Time to 80% MVC	sec	132.0	81.7					
	Average integrated area	%	76.5	7.6	**0.898**				
	Final force value	%	67.3	9.4	**0.877**	**0.911**			
	Time to reach minimum Oxy-Hb/Mb	sec	24.0	13.3	−0.181	0.008	0.103		
	Time to reach maximum Deoxy-Hb/Mb	sec	110.6	61.9	0.173	0.288	0.416	0.183	
RRG (5 sec)	Time to 80% MVC	sec	168.0	96.3					
	Average integrated area	%	78.3	6.4	**0.935**				
	Final force value	%	71.1	8.0	**0.941**	**0.925**			
	Time to reach minimum Oxy-Hb/Mb	sec	19.5	9.8	−0.139	−0.092	−0.220		
	Time to reach maximum Deoxy-Hb/Mb	sec	162.0	64.7	−0.116	0.137	−0.038	−0.391	

Note: Significant correlations ($p<0.05$) are shaded and in bold-faced type.

Table 2 shows the correlations between force-time parameters and muscle oxygenation kinetics parameters. Significant and high correlations (r=0.874–0.925) were found between average integrated area and final force values in all tests. Significant and high correlations (r=0.739–0.935) between time to 80% MVC and average integrated area were found in RRGs, but not in the SIG. Time to 80% MVC showed significant and high correlations (r=0.866–0.941) with final force values only in the RRGs with over 3 s intervals. An inflection time was 41.6 s in SIG and 64.4 s in RRG with a 2 s interval, which showed significant curvilinear regressions, and almost agreed with visual inflection time in Figs. 1a and 1b. Both inflection times showed significant correlations (r=−0.662 for SIG, r=−0.832 for RRG (2 sec)) with final force values. Significant and high correlations (r=0.825–0.916) between Oxy-Hb/Mb and Deoxy-Hb/Mb were found only in the SIG and RRGs with a 2 s interval.

Discussion

The SIG (Yamaji et al., 2004) and RRG with a 2 s interval (Nakada et al., 2004) produce the inflection point shifting from a marked force decrease phase to a slow force decrease phase during the initial phase. The present grip force reached an almost steady state (about 15–20% MVC) in SIG and (about 40–50% MVC) in RRG for 120–180 s. These results were consistent with those in previous studies (Yamaji et al., 2000; Nakada et al., 2004). The critical force that a subject can keep during a steady state may be 40–50% MVC. Grip force during a steady state was about three times higher in RRG with a 2 s interval than SIG, but both showed a similar curvilinear decrease and their inflection point significantly correlated with a final force value. In contrast, grip force in RRGs with over 3 s intervals showed a linear decrease, and also the final force values were very high. Grip force in RRGs with 4 s and 5 s intervals was over about 70% MVC for 6 min. The following is considered from the present results. Grip force having an inflection point in the gripping work without or with little muscle relaxation such as the SIG and RRG with a 2 s interval, decreases rapidly until the point, and reaches an almost steady state. Because the grip force at the inflection point is almost maintained, the inflection point has a high relationship with a final force value. With RRGs with over 3 s intervals, the inflection point does not occur and grip force decreases gradually. In particular, the grip force in RRGs with over 4 s intervals has a very small decrease for the last half 3 min, and is small in the steady state with a high force value even for 6 min. Although the RRG with a 2 s interval has a relaxation phase as well as RRGs with over 3 s intervals, the decrease properties of grip force are very similar to those in the SIG because of the very short relaxation time. Blood flow velocity in the muscle contraction and relaxation phases changes markedly in repeated grip work. With a change of blood flow velocity, a blood flow–dependent vasodilatory effect, in addition to a metabolic vasodilation, acts, and blood flow increases during the repeated work (Kagaya, 1993). The RRG and SIG are distinguished as a different work condition by whether or not a muscular relaxation phase (Kahn and Monod, 1989), but from the decrease properties of grip force in this study, the properties of the RRG with a 2 s interval may be similar to those in the SIG without relaxation. However, because the grip force during a steady state was about three times higher in the RRG with a 2 s interval than SIG, the RRG with muscle relaxation, even if it is very short, it may be possible to exert a larger force during a steady state than the SIG without a relaxation. The resumption time of blood flow becomes longer with longer muscular relaxation time, muscle fatigue is reduced, and a large grip force is kept. It is inferred that although a difference of exertion intervals between 2, 3, and 4 s is only about one second, decreasing properties of their grip force and blood flow changes around activity muscles differ considerably.

Total-Hb/Mb in SIG and all RRG decreases temporarily by the obstruction of blood flow. Hence, the marked decrease and increase of Oxy-Hb/Mb and Deoxy-Hb/Mb are confirmed due to increasing intramuscular oxygen consumption. However, the influence in the SIG is larger than that in the RRGs. Those in the SIG and RRG with a 2 s interval reached lately an almost steady state. The increase of Total-Hb/Mb is considered to depend on exercise high blood flow, but the influence is quick in the SIG and RRG with 2 s and 3 s interval. In short, these SIG and RRGs with the strong influence of blood flow obstruction are considered to show quick vasodepressor response. In the SIG and RRG with a 2 s interval, in spite of a quick resumption of the blood flow, the increase of Deoxy-Hb/Mb is high. Hence, their oxygen demand may be larger than that in the RRGs with 3–5 s intervals. Yamaji et al. (2002) reported that Oxy-Hb/Mb decreased markedly about 20 s (about 70% MVC) after the onset of SIG due to the obstruction of the blood flow caused by an increase of intramuscular pressure. Kimura et al. (1999) reported that because the obstruction of muscle blood flow restricts the oxygen supply to the active muscle, oxygen stored in muscles or blood may be consumed and Deoxy-Hb/Mb remain without circulation. An increase of Deoxy-Hb/Mb in the initial phase is due to the obstruction of the blood flow where the oxygen requirement is high and oxygen delivery is in a deficiency state (Nakada et al., 2004). The time at the lowest Oxy-Hb/Mb and the time at the highest Deoxy-Hb/Mb had close relationships in the SIG and RRG with a 2 s interval, but not in RRGs with over 3 s intervals. The time at the highest Deoxy-Hb/Mb was preceded by the time at the lowest Oxy-Hb/Mb. This time is the lasting time of the Deoxy-Hb/Mb increase even though Oxy-Hb/Mb begins to increase with a resumption of blood flow because of a high oxygen requirement by sustained gripping (Kahn et al., 1998; Nakada et al., 2004). Because the muscular relaxation phase in the RRG with a 2 s interval is very short, the resumption of blood flow is also not enough, resulting in an increase of Deoxy-Hb/Mb. However, it is inferred that because the grip force in RRGs with over 3 s intervals was exerted in the state with a long muscular relaxation duration and sufficient resumption of blood flow, subjects could exert a large grip force with low muscle fatigue.

From the above results, changes of muscle oxygenation kinetics in the RRG with a 2 s interval are similar to that in the SIG (Oxy-Hb/Mb decreases, and then increases and reaches a steady state), and differs from that in the RRG with a 3 s interval. Namely, it is inferred that although the RRG with a 2 s interval is repeated rhythmic gripping with muscle contraction and relaxation as well as RRGs with over 3 s intervals, the changes of muscle oxygenation kinetics are similar to those in SIG because of blood flow velocity restriction based on a short exertion interval.

On the other hand, when sustaining force exertion with maximal effort such as SIG oxygen deficiency occurs and anaerobic muscular exertion becomes mainstream because the oxygen supply to the active muscle is restricted in the initial phase. However, in the latter phase, although grip force decreases with developing muscle fatigue, blood flow resumes and results in a state with sufficient oxygen delivery (Yamaji et al., 2004; Nakada et al., 2004). Victor et al. (1995) reported that the central command increases muscle sympathetic nerve activity during intense intermittent isometric exercise. The blood flow increase with the force decrease in the latter phase may also be related to the central command decrease. In any case, it is inferred that the former phase and the latter phase during the 6 min in the SIG and RRG with a 2 s interval are related to different physiological factors. The SIG and RRG with a 2 s interval have an inflection point, and may be able to evaluate different muscle endurances from that in RRGs with over 3 s intervals. In addition, there were high interrelationships ($r=0.866$–0.941) among force-time parameters (time to 80% MVC, average integrated area, and final force values) in the RRGs with over a 3 s interval. In short, the above parameters are judged to measure almost the same phase. Therefore, the SIG and RRG with a 2 s interval may be useful as a muscle endurance test. The RRG with a 2 s interval may be able to evaluate similar muscle endurance to the SIG without much pain. Meanwhile, the present study assumes that the force exertion time and muscle activity time are the same. The validity of the above -stated assumption should be examined in the future by using EMG.

In summary, the decrease properties of the RRG with a 2 s interval are similar to those in the SIG, but differ fairly from those of the RRGs with over a 3 s interval. The former grip forces see a curvilinear decrease in the initial phase, but the latter grip forces decrease gradually. The RRGs with over 4 s intervals are not useful as a muscle endurance test, because grip force decreases little at 3 min later with around 70% MVC. The relationships between the time at the lowest Oxy-Hb/Mb and the time at the highest Deoxy-Hb/Mb are high in the SIG and RRG with a 2 s interval, but low in the RRGs with over 3 s intervals. These may be influenced by the time difference of the increase and decrease in intra-muscular pressure by muscular contraction and relaxation.

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Correspondence to: Masakatsu Nakada, National Defense Academy, 1–10–20 Hashirimizu, Yokosuka, Kanagawa 239–8686, Japan
Phone: +81–46–841–3810 (ext.3199)
Fax: +81–46–844–5908
e-mail: nakada@nda.ac.jp