Force-time parameters during explosive isometric grip correlate with muscle power

【Original Article】

Force-time Parameters During Explosive Isometric Grip Correlate with Muscle Power

Running Title: Relationships between force-time parameters and muscle power

Yukio Ikemoto

Yonago National College of Technology

Shinichi Demura

Kanazawa University, Faculty of Education

Shunsuke Yamaji

University of Fukui, Faculty of Medical Science

Masaki Minami

Yonago National College of Technology

Masakatsu Nakada

National Defense Academy

Masanobu Uchiyama

Kanazawa University, Graduate School, Natural Science & Technology

Corresponding Author

Shunsuke Yamaji

University of Fukui, Faculty of Medical Science

23-3, Shimoaizuki, Matsuoka, Yoshida, Fukui, 910-1193, JAPAN

Phone: (+81) 7766-1-3111, Fax: (+81) 7766-1-8141

e-mail: yamaji@fmsrsa.fukui-med.ac.jp

Abstract

Although explosive isometric contraction provides little work toward the outside, force-time parameters of the rising phase of the force-time curve may be able to predict muscle power. The purpose of this study was to examine the relationship between muscle power with work (power grip) and force-time parameters during the rising phase in explosive isometric grip. Fifteen healthy young adult males participated in this study. Power grip was measured using loads of 20-50% MVC (peak isometric force). Subjects pulled explosively on a grip bar held with the second digital joints without the thumb. Peak power was calculated from peak velocity and load. Explosive isometric grip was measured using a hand dynamometer. Time-series data of both tests were sampled by an analog-to-digital interface. Both tests were performed with the subjects seated with a sagittal and horizontal position of the arm supported by an armrest. Peak power in the power grip test tended to be larger with an increase of the load, but there was no significant difference between 40% and 50% MVC. Only the peak power in 50% MVC significantly correlated with peak grip force ($r = 0.52$, $p < 0.05$). The force-time parameters related to the peak rate of the rising force phase in explosive isometric grip significantly correlated with the peak powers (30-50% MVC) ($r = |0.58\text{-}0.78|$). Peak rate of the rising force phase in explosive isometric grip may be useful for predicting muscle power with loads between 30-50% MVC.

Key words: Power grip, Peak power, Force-time curve

Introduction

Muscle power has been defined as an ability to produce a short burst of force output, and, generally, has been evaluated from mechanical power (W) calculated by work (J)/time(s). The amount of force and velocity achieved to the outside during isotonic or isokinetic muscle contraction has been measured [1-3]. Therefore, isometric contraction, where the work is zero, has been excluded from the general concept of muscle power [2, 4]. Muscle power should focus attention on the amount of force output in a short time, and should not be evaluated only the existence of work. Although the work in isometric muscle contraction is zero, the amount of force output in a short time can be measured from time series data (force-time curve). Force-time data of the rising phase in explosive isometric contraction may predict muscle function corresponding to muscle power in a dynamic situation [5].

Analysis of the rising force phase (the initial phase until reaching the peak force) in force-time curves during explosive isometric contraction has revealed the existence of individual differences and gender differences [6-14]. Walamies and Turjanmaa evaluated the integrated area until the peak strength (impulse) during explosive isometric grip as a ‘power factor’ with a similar concept to muscle power [14]. Moreover, Demura et al. reported that the relationship between maximal isometric strength and peak increase in force during the rising force phase was low ($r = 0.100$-0.273) [15]. Demura et al.’s report suggested the possibility that the individual difference during the rising phase in explosive isometric contraction reflects a different muscle function from maximal strength. From this background, we developed a machine that measures velocity during explosive dynamic gripping with different fixed submaximal external loads, which allows calculation of power [16].

The purpose of this study was to examine the relationships between muscle power with work in explosive dynamic gripping and force-time parameters during the rising force phase in explosive isometric grip.

Methods

Subjects

The subjects were 15 young males (mean age 22.2 ± 2.4 yr, mean height 172.2 ± 4.9 cm, mean weight 66.5 ± 9.8 kg). All subjects were healthy with no upper extremity impairments. Their physical characteristics were considered to approximate the standard values for Japanese males of the same age range [17]. Informed consent was obtained from all subjects after a full explanation of the experimental purpose and protocol.

Experimental device

Power grip was measured using a new dynamic grip measurement machine with various loads (20-50% of MVC) attached to the end of a wire (Yagami, Japan) (Figure 1) [16]. A rotary encoder was attached at the pulley, and the rotational angle was measured in a rate per unit of time of the fixed pulley rated with the wire. The rotational angles were sampled with the recording device at 100 Hz by an analog-to-digital interface, and converted to the distance the load moved . The velocities were calculated with respect to each sampling frequency (distance moved/0.01s). The data was relayed to a personal computer. Therefore, the peak power was calculated from the peak velocity and the load. Subjects pulled explosively on a grip bar held between the second digital joints without the thumb. Although the distance moved differed somewhat by the size of the individual fingers or palm length, the load was jerked only the distance of the finger flexion (5-7 cm).

*************** Figure 1 insert near here *********************

Explosive isometric grip was measured using a digital hand dynamometer with a load cell sensor (EG-290, Sakai, Japan) [15] (Figure 1). This measures isometric grip exertion (peak grip strength) without the external work. Each signal from the hand dynamometer was sampled at 100 Hz by an analog-to-digital interface, and then relayed to a personal computer. The digital data was immediately displayed as a force-time curve on the screen.

Both grip tests were performed with the subjects seated in an adjustable chair. The grip width could be adjusted individually by a dial to achieve a 90 degree angle with the proximal-middle phalanges. The arm was supported by an armrest and was extended with the forearm in a sagittal and horizontal position and the hand in a semi-pronated position (Figure 1). The wrist was attached to a bowling glove (Strong Arm Plus Wrist Support; Storm, West Brigham) to fix the wrist during grip exertion, and was fixed in a wrist extension position (0 degree). Considering the systematic error, the rotary encoder and load cell were calibrated before each measurement for both measurement machines.

Experimental procedure

To determine the submaximal load for the power grip test, the subjects performed the maximal voluntary grip contraction (MVC) test twice in advance, and the higher value was determined as the MVC. The MVC test was carried out by maximal isometric contraction in both conditions using each machine with the same finger angle. The correlation coefficients of MVC in both machines were very good ($r=0.923$, $p<0.05$). In the case of the power grip machine, the MVC was measured by a grip dynamometer with a spring scale attached to the end of the wire. All subjects performed the power grip test and explosive isometric grip test with the dominant hand based on Oldfield's handedness inventory [18]. The load of the power test was selected as 20, 30, 40 and 50% of MVC [19]. The trial order in the power test was randomized to consider the effect of trial order.

The experimental design was within the subject design. In both tests, subjects were instructed to exert maximal force as fast and forcefully as possible immediately after hearing a beeping sound from the recording device. In the explosive isometric grip test, subjects were instructed to hold the contraction for 5 sec. Both grip test orders considered the effect of trial order. The interval between both grip tests was set for at least 5 min in consideration of the influence of muscle fatigue. The subjects carried out one practice trial to accustom them to the grip device and explosive gripping. Both grip tests were performed on the same day.

Evaluation parameters

Muscle power evaluation parameters in the power grip test were peak power and time to peak velocity (s) (Figure 2). Figure 2 shows the average curves of power in the power grip test, and the highest value in the curve was defined as peak power. Peak power (W) was calculated from the following equation.

$$\text{Peak power(W)} = \text{load (kg)} \times \text{gravitational acceleration} (9.80665\ m/s^2) \times \text{peak velocity (m/s)}$$

Eight evaluation parameters in the explosive isometric grip test were calculated from the force-time curve for each measurement [5, 7, 15]. They were selected from factors such as time-course of force, average force, integrated area, and peak rate of the rising force (Figure 3). Peak force was determined as the highest value on the force-time curve. Both times to 90% and 100% of peak force were measured as the time-course of force. The average forces to 90% and 100% of peak force were calculated by dividing the integrated area by time. The integrated area was calculated by integrating the force value on the force-time curve. The integrated areas from exertion onset to 1 and 2 sec were also calculated. The peak rate of the rising force (PRRF) was measured every 0.1 sec, and the force (just FPR) at the end of the time interval (0.1 sec) of the peak rate of force was determined. Parameters have been examined with respect to trial-to-trail reliability [5, 15], the inter-relationship of parameters [5, 20], and the individual differences [4, 9].

Data analysis

The average curves for power grip and explosive isometric grip were calculated from time-series data for each subject. The data for further analysis used the highest peak value (power grip: peak power, explosive isometric grip: MVC) in the duplicate trials. Pearson's correlation coefficients were calculated to examine relationships between parameters (above 0.9: very high, 0.7-0.9: high, 0.4-0.7: moderate, below 0.4: low). ANOVA was used to reveal the mean differences for power parameters in each relative load. The probability level was set at 0.05 to determine statistically significant differences.

Results

Figure 2 shows the average curves of power in the power grip test. The cross correlation coefficients of average curves between duplicate trials were above 0.95. As the load increased, the distance moved by gripping was shorter (20% MVC; 6.5 ± 0.2 cm, 30% MVC; 5.7 ± 0.3 cm, 40% MVC; 5.3 ± 0.3 cm, 50% MVC; 5.1 ± 0.4 cm) and time to finish grip was longer (Figure 2).

****************** Figure 2 insert near here *********************

Table 1 shows the correlations between MVC, and peak power in the power grip test, force-time parameters in the explosive isometric grip test and test results of ANOVA between the power parameters at each load. Peak power tended to be larger with an increase of load, and the time to peak velocity tended to be longer. The peak powers at 50%, 40%, and 30% MVC were significantly larger than that at 20% MVC, and at 50% MVC was significantly larger than that at 30% MVC. Only the peak power at 50% significantly correlated with MVC ($r = 0.52$, $p < 0.05$). The time to peak velocity increased significantly with increased load.

Force-time parameters except for the time to peak and 90% of peak force and the average force until 90% of peak force correlated moderately or highly with MVC ($r = 0.60-0.89$, $p < 0.05$). In particular, the average force until peak force and the integrated area until 2 sec correlated highly with MVC ($r=0.78$, 0.89, $p<0.05$, respectively).

****************** Table 1 insert near here **********************

Table 2 shows the correlation coefficients between the power and force-time parameters in both grip tests. Peak power at 30%-50% MVC and time to peak velocity at 40% and 50% MVC significantly correlated with the force-time parameters regarding the peak rate of the rising force (PRRF and just FPR) ($r = |0.58-0.78|$). Peak power at 50% MVC correlated moderately with the average force and the integrated area until 2 sec ($r = 0.54 - 0.66$, $p < 0.05$).

****************** Table 2 insert near here **********************

Discussion

Until now, many researchers [5, 7, 14, 15, 20] have suggested that the rising force phase of the force-time curve in explosive isometric contraction can evaluate different muscle functions from maximal strength, explosive strength (power) or muscle contraction speed.

Baker et al. reported that the relationships between vertical jump and isometric leg strength were very poor ($r = 0.098-0.127$), and suggested that muscle power is different from muscle strength [21]. In this study, power parameters also correlated poorly with the MVC ($r = |0.003-0.41|$) except for peak power at 50% MVC. Because the former is determined by the product of force and velocity, it is obvious that either factor relates closely with muscle power. In other words, the power parameters were influenced by the contribution of both factors. For example, peak power at 50% MVC, which correlated significantly with MVC in this study, may mainly depend on the force factor. Ikemoto et al.

[16] considered that muscle power at 20% and 50% MVC depends on respective different factors because their relationship was poor.

On the other hand, force-time parameters except for the time to reach and average force until 90% of peak force in explosive isometric grip showed fair or good correlations with MVC ($r = |0.60-0.89|$). Especially, the average force until peak force and integrated area until 2 sec related very closely with MVC and agreed with Demura's report [5]. Ikemoto et al. suggested that the phases before and after a change point (inflection point) of the rising force speed in explosive isometric grip evaluate different muscle functions, and reported that the parameters evaluating the phase after the inflection point relate closely to MVC [16]. Force-time parameters such as integrated area or average force around a peak force are considered to largely reflect MVC. On the contrary, they suggested that force-time parameters evaluated before the inflection point such as the PRRF or just FPR reflect muscle contraction speed. In fact, power parameters at 30%-50% MVC significantly correlated with these parameters in this study. The peak power above 30% MVC related highly with the peak rate of rising force (PRRF) in explosive isometric grip, in particular, the peak force when the peak rate of force appeared (just FPR) ($r = 0.74-0.78$, $p < 0.05$). Ikemoto et al. reported that an inflection point of increasing force speed in isometric contraction appears at 0.3 sec after the grip onset, corresponding to 80% of peak grip force, and their reliabilities were good [16]. Moreover, they proposed that the inflection point is a useful parameter to distinguish strength and contraction speed, because it related closely to force-time parameters evaluating the rising force phase until this point in spite of a poor relationship with the peak value. The PRRF and just FPR did not relate as high to maximal strength ($r = 0.60$, 0.61, $p < 0.05$). These may be useful parameters when evaluating muscle power in the explosive isometric grip, reflecting a different ability (muscle contraction speed) from maximal strength.

Hakkinen et al. reported that there is a proportional relationship between changes of force-time parameters in explosive muscle strength exertion and the integrated EMG and the FT/ST fiber ratio after explosive muscle resistance training for 8 weeks, and that the former parameters regarding the rising force rate may be able to evaluate explosive strength (muscle power) [12]. The peak rate of rising force parameters (PRRF and just FPR) is considered to reflect the individual difference of muscle power rather than the other force-time parameters evaluating the phase near peak force. The relationship between the peak power at each load and the peak rate of rising force parameters (PRRF and just FPR) shows a tendency for the peak rate of rising force in explosive isometric grip to become larger in proportion to peak power in power grips at 30%-50% MVC. It is possible that PRRF and just FPR in explosive isometric contraction relate closely to the peak power of muscle contraction over 30% MVC, and are useful parameters that reflect individual differences in muscle power calculated by force and contraction velocity.

Only peak power at 50% MVC showed a high relationship with parameters on the average force around MVC and integrated area until 2 sec, in addition to MVC. The above force parameters may evaluate muscle power (50% MVC) relating strongly to maximal strength. In power grip, time to peak velocity was longer with an increase of load (20%-50% MVC) and peak power was larger, but the latter did not show a significant difference between 40% and 50% MVC. Muscle contraction speed does not become slow in proportion to an increase of the load, but may change markedly beyond a critical load. In this study, because a marked decrease of muscle contraction speed at 50% MVC closely affects peak power determined by force and velocity, a significant difference might not be found between their peak powers.

Power parameters (peak power and time to peak velocity) at 20% MVC did not show significant correlations with any force-time parameter in explosive isometric grip. The relationships between power parameters at 20% MVC and those at the other loads (30%-50% MVC) were poor. The former is considered to depend strongly on contraction speed because of a very light weight. Therefore, force-time parameters that did not correlate with power exerted at 20% MVC, may be unable to evaluate muscle power reflected by a strong muscle contraction speed.

Power parameters at all loads related little with the time to reach the explosive isometric grip. The time to reach was assumed to reflect muscle contraction speed reaching a fixed force level [3, 16]. However, the time to reach in this study became markedly long at over 90% of peak force, and the individual difference tended to increase. Therefore, it may reflect the phase of peak force. The time of reaching peak force may not be a useful parameter when evaluating muscle power.

Gravel et al. measured isometric strength at several sarcomere lengths, and reported that muscle tension differs corresponding to the overlapping degree of actin and myosin filaments [22]. We assumed that explosive isometric grip and power grip use force exertion in the same region, and examined the relationships between parameters in both grip tests. However, because finger joint angles during power gripping change, both may not be completely the same. In other words, because the finger joint angles at the time point when peak power in power grip appears are somewhat different from those in explosive isometric grip (90 degree angle with the proximal-middle phalanges), power parameters might not show as high a relationship with force-time parameters. In further study, it may be necessary to accurately measure the joint angles when peak power appears and examine the relationship between peak power and the force-time parameters during explosive isometric adjusted joint angles.

In conclusion, power parameters at 20% MVC do not relate to force-time parameters. Parameters (PRRF and just FPR) on the peak rate of rising force in explosive isometric grip relate highly to peak powers at 30-50% MVC, and they may be useful parameters when evaluating muscle power in the explosive isometric grip.

References

1. Davies CT, Sandstrom ER. (1989) Maximal mechanical power output and capacity of cyclists and young adults. Eur J Appl Physiol Occup Physiol. 58: 838-844.
2. Thompson CJ, Bemben MG. (1999) Reliability and comparability of the accelerometer as a measure of muscular power. Med Sci Sports Exerc. 31: 897-902.
3. Yoshimura Y, Demura S, Yamaji S, Nagasawa Y, Minami M, Matsuzawa J. (2001) Examining force-exertion patterns based on force-time relationships in the development phase during static explosive grip. Japanese Society of Education and Health Science. 47: 194-201.
4. Demura S, Yamaji S, Minami M, Nagasawa Y, Kita I, Matsuzawa J. (1999) Examining reproducibility of force-exertion pattern and reliability of force-time parameters in the development phase during static explosive grip exertion. Japanese Society of Physical Fitness and Sports Medicine. 48: 493-500.
5. Demura S, Yamaji S, Nagasawa Y, Sato S, Minami M, Yoshimura Y. (2003) Reliability and gender differences of static explosive grip parameters based on force-time curves. J Sports Med Phys Fitness. 43: 28-35.
6. Bemben MG, Clasey JL, Massey BH. (1990) The effect of the rate of muscle contraction on the force-time curve parameters of male and female subjects. Res Q Exerc Sport. 61: 96-99.
7. Bemben MG, Massey BH, Bemben DA, Misner JE, Boileau RA. (1991) Isometric muscle force production as a function of age in healthy 20- to 74-yr-old men. Med Sci Sports Exerc. 23:1302-1310.
8. Chengalur SN, Smith GA, Nelson RC, Sadoff AM. (1990) Assessing sincerity of effort in maximal grip strength tests. Am J Phys Med Rehabil. 69: 148-153.
9. Demura S., Yamaji S., Nagasawa Y., Masaki M. (2000) Examination of force-production

properties during static explosive grip based on force-time curve parameters Percept Mot Skills. 91: 1209-1220

10. Gilbert JC, Knowlton RG. (1983) Simple method to determine sincerity of effort during a maximal isometric test of grip strength. Am J Phys Med. 62: 135-144.

11. Hakkinen K, Komi PV, Alen M. (1985) Effect of explosive type strength training on isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. Acta Physiol Scand. 125: 587-600.

12. Hakkinen K, Alen M, Komi PV. (1985) Changes in isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. Acta Physiol Scand. 125: 573-585.

13. Smith GA, Nelson RC, Sadoff SJ, Sadoff AM. (1989) Assessing sincerity of effort in maximal grip strength tests. Am J Phys Med Rehabil. 68: 73-80.

14. Walamies M, Turjanmaa V. (1993) Assessment of the reproducibility of strength and endurance handgrip parameters using a digital analyser. Eur J Appl Physiol Occup Physiol. 67: 83-86.

15. Demura S, Yamaji S, Nagasawa Y, Ikemoto Y, Shimada S. (2001) Force developmental phase and reliability in explosive and voluntary grip exertions. Percept Mot Skills. 92: 1009-1021.

16. Ikemoto Y, Demura S, Yamaji S, Nakada M, Kitabayashi T, Nagasawa Y. (2006) The characteristics of simple muscle power by gripping: gender differences and reliability of parameters using various loads. J Sports Med Phys Fitness. 46: 62-70.

17. Laboratory of Physical Education, Tokyo Metropolitan University (2000). New Physical fitness standards of Japanese people, 5th edition (pp. 98-101). Tokyo: Fumaido.

18. Oldfield RC. (1971) The assessment and analysis of handedness: the Edinburgh

inventory. Neuropsychologia. 9: 97-113.

19. Suzuki M, Yamazaki Y, Matsunami K. (1994) Relationship between force and electromyographic activity during rapid isometric contraction in power grip. Electroencephalogr Clin Neurophysiol. 93: 218-224.

20. Ikemoto Y, Demura S, Yamaji S. (2004) Relations between the inflection point on the force-time curve and force-time parameters during static explosive grip. Percept Mot Skills. 98: 507-518.

21. Baker D, Wilson G, Carlyon (1994) Generality versus specificity: a comparison of dynamic and isometric measurements of strength and speed-strength. Eur J Appl Physiol. 68: 350-355.

22. Gravel D, Richards C, Filion M. (1988) Influence of contractile tension development on dynamic strength measurements of the planter flexors in man. J Biomechnics. 21: 89-96.

Table and Figure captions

Table 1 One-way ANOVA between work load regarding power parameters and correlation coefficients with MVC

Note: *: $P<0.05$

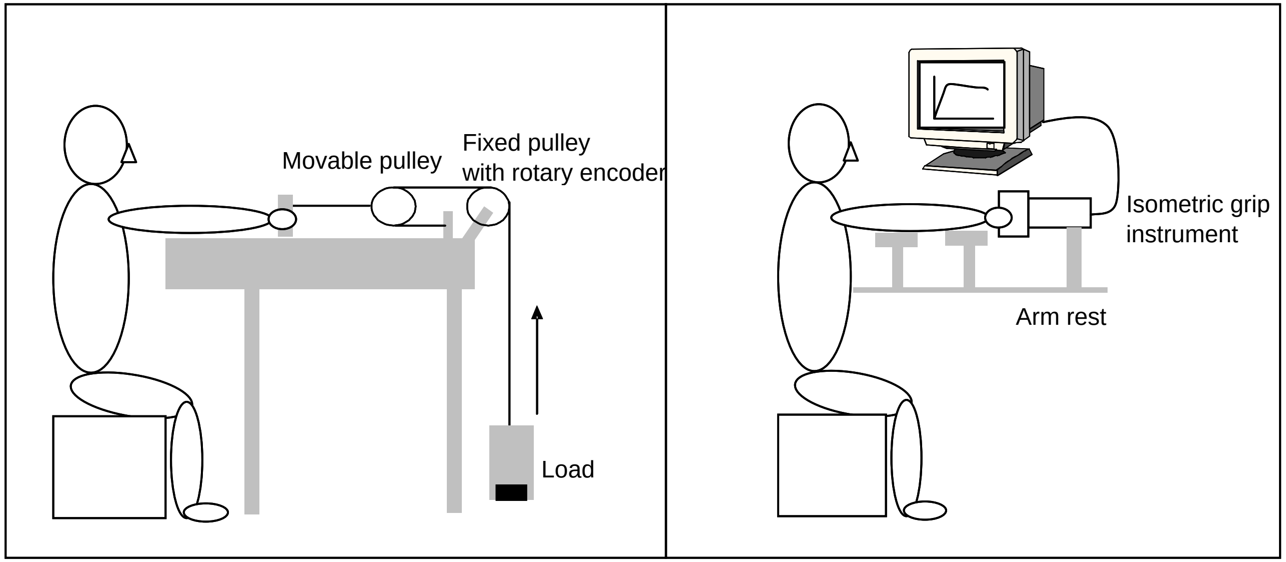
Table 2 Correlation coefficients between force-time and power parameters.

Note: Numbers 1-8 correspond to force-time parameters as follows: 1. Time to peak force, 2. Time to 90% of peak force, 3. Average force until peak force, 4. Average force until 90% of peak foce, 5. Integrated area until 1s, 6. Integrated area until 2s, 7. Peak rate of the rising force (PRRF), 8. Force when peak rate of force appeared (just FPR). *: $p < 0.05$

Figure 1 Overview of the two grip tests (left panel: power grip, right panel: explosive isometric grip).

Figure 2 Average curve of the power in the power grip test.

Power = load (kg) × gravitational acceleration (9.80665m/s2) × velocity in each sampling (m/s)



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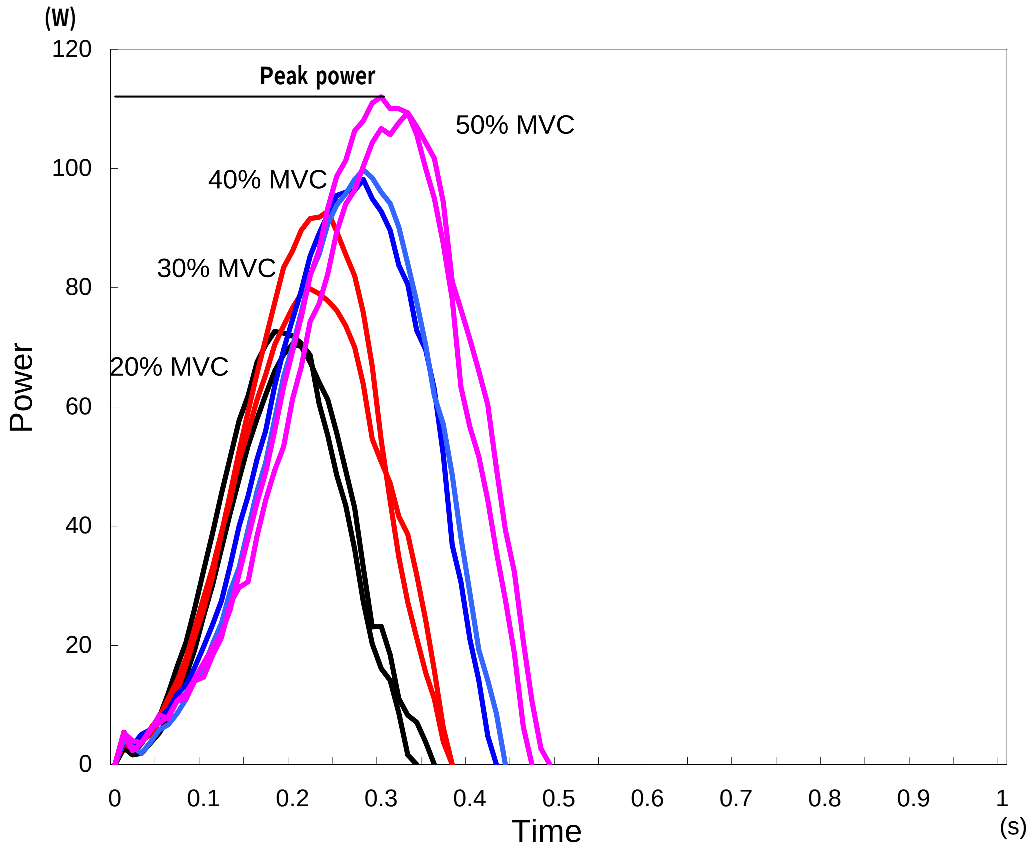

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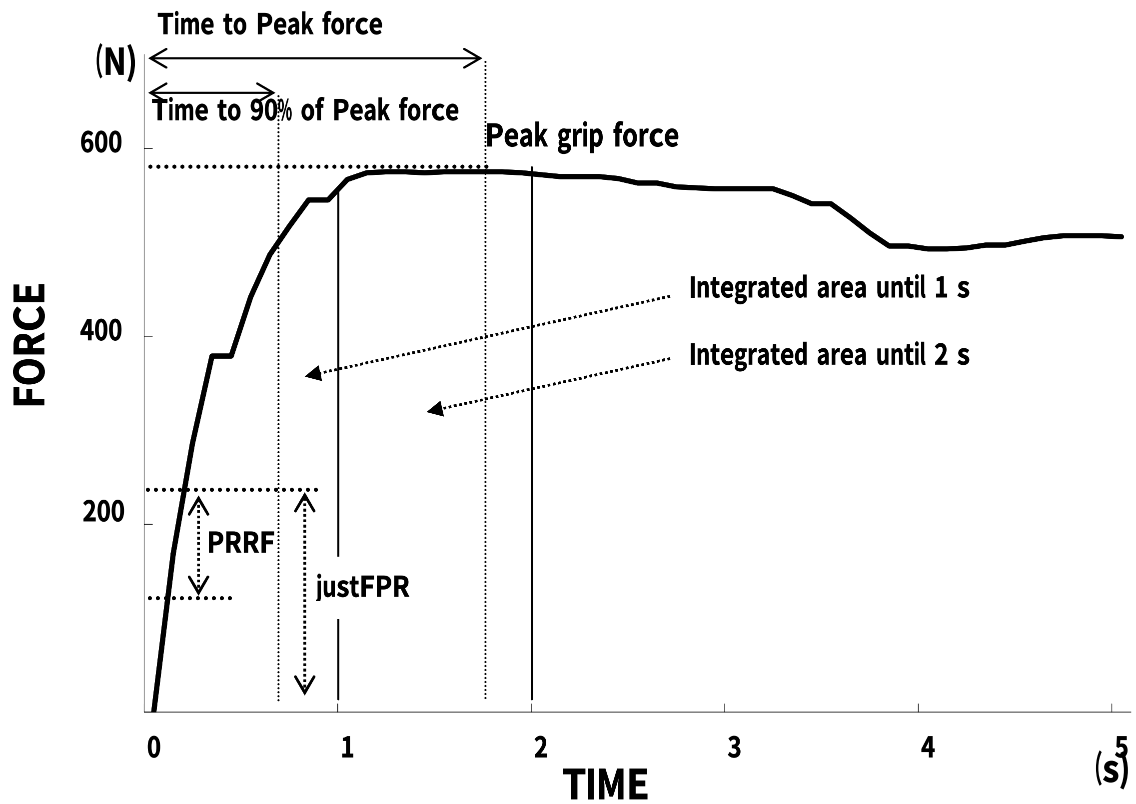

Fig. 3 Force-time parameters in the explosive isometric grip test. PRRF: peak rate of rising force, just FPR: force when peak rate of force appeared. The average forces to 90% and 100% of peak force were calculated by dividing the integrated area by time.

Table 1 One-way ANOVA between work load regarding power parameters and correlation coefficients with MVC

	Parameters	Unit		Mean	SD	Correlation with MVC		F-value	Post-hoc
Power test	Peak power	W	20%	81.20	9.69	0.21		25.98 *	50, 40, 30% > 20% 50% > 30%
		W	30%	97.90	13.01	0.41			
		W	40%	110.40	15.46	0.36			
		W	50%	120.83	30.98	0.52	*		
	Time to peak velocity (s)	sec	20%	0.20	0.04	-0.03		69.05 *	20% < 30% < 40% <50%
		sec	30%	0.25	0.04	-0.19			
		sec	40%	0.29	0.05	-0.39			
		sec	50%	0.32	0.05	-0.40			
Explosive isometric grip	Peak grip force	N		502.80	66.90				
	Time to Peak force	sec		1.08	0.20	-0.02			
	Time to 90% of Peak force	sec		0.50	0.16	-0.09			
	Average force until Peak force	N		7890.51	1315.41	0.78	*		
	Average force until 90% of Peak force	N		5574.55	1081.56	0.50			
	Integrated area until 1 s	N･sec		7689.80	1481.66	0.64	*		
	Integrated area until 2 s	N･sec		17682.20	2649.15	0.89	*		
	Peak rate of the rising force (PRRF)	N		134.73	42.52	0.61	*		
	Force when peak rate of force appeared (just FPR)	N		231.87	62.28	0.60	*		

Note: *: $p < 0.05$

Table 2 Correlation coefficients between force-time and power parameters.

		Force-time parameters during explosive isometric grip (Parameter number)							
		1	2	3	4	5	6	7	8
20%	Peak power	0.27	0.31	-0.02	-0.12	-0.12	0.05	0.19	0.39
	Time to peak velocity	-0.15	0.22	-0.20	-0.06	-0.14	-0.12	-0.29	-0.42
30%	Peak power	0.03	-0.24	0.46	0.48	0.44	0.46	0.58 *	0.74 *
	Time to peak velocity	-0.17	0.18	-0.28	-0.11	-0.20	-0.24	-0.35	-0.45
40%	Peak power	-0.03	-0.20	0.41	0.49	0.39	0.41	0.63 *	0.78 *
	Time to peak velocity	0.11	0.39	-0.47	-0.23	-0.46	-0.49	-0.49	-0.63 *
50%	Peak power	0.12	-0.09	0.55 *	0.66 *	0.47	0.54 *	0.61 *	0.76 *
	Time to peak velocity	0.04	0.20	-0.33	-0.06	-0.25	-0.37	-0.45	-0.71 *

Note: Numbers 1-8 correspond to force-time parameters as follows: 1. Time to peak force, 2. Time to 90% of peak force, 3. Average force until peak force, 4. Average force until 90% of peak foce, 5. Integrated area until 1s, 6. Integrated area until 2s 7. Peak rate of the rising force (PRRF), 8. Force when peak rate of force appeared (just FPR). *: $p < 0.05$