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Comparison of Force Exertion Characteristics of Sustained Hand Grip and Toe Grip

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Abstract This study aimed to examine the differences in decreasing force during maximal sustained hand grip and toe grip exertions values. Fourteen males aged 18 to 22 years old performed hand and toe grip exertions for 6min. The sustained times of forces 40, 60, 70, and 80% of maximal strength (max), strength values at 90sec and 3min, and final strength value (% of max) were selected as evaluation parameters. The forces (% max) during both sustained grip exertions markedly decreased until about 60sec from their exertion onset, after which they slowly decreased, then decreased very little at 4-6min. Toe grip exertion values were significantly larger than hand grip exertion values until after 60sec from exertion onset (about 15% ～ 20% vs about 30% ～ 35%). Correlations among sustained time parameters (60%～80% max) were significant (r =0.657～0.960). The strength at 3 min in toe grip exertion significantly correlated to final strength, sustained time of forces 40% of max, and strength at 90sec. In summary, the forces during sustained hand grip and toe grip exertions show a similar decreasing tendency, but the latter's exertion values maintain a higher level than the former's after a marked decrease. The strength value at 3min for toe grip exertion may be useful as muscle endurance parameter.

Keywords: *hand, toe, grip, strength, muscle endurance*

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1. Introduction

Movements using sustained hand grip are used frequently in daily life, i.e. holding onto an object or hanging onto a strap in a subway. Because a decrease in muscle endurance of the upper limbs interferes with daily life activities, adequate evaluation is necessary. Studies have been conducted evaluating muscle endurance based on the force decreasing phase of sustained grip exertion [1,2] and regarding the effects of different elbow positions on grip strength and grip endurance [3]. However, endurance of maximum toe grip has not been well studied.

Walking is the most basic activity in daily life. A decrease of muscle strength related to toe and proximal ankle joins is considered to largely affect the independent life of the elderly. In addition, a standing posture and walking have generally been continuously performed for a certain period, and strengths related to the above-stated joints are sustainably developed. It was reported that toe plantar flexion strength decreases with age [4]. Scott et al. [5] reported that the elderly have a slower walking speed and shorter step length as compared with young adults. Hence, evaluating adequately muscle endurance in addition to maximum strength of the toe is considered to be important.

The following aspects of sustained static maximal hand grip have been studied: the relationship of decreasing force and muscle oxygenation kinetics [6], the effect of measurement time on static muscle endurance [1], and the relationships among parameters of static muscle endurance [7]. In addition, Nakada and Demura [8] examined the change of exertion force during sustained toe grip exertion for 3 min. For an activity requiring the upper limbs, the dominant hand of the upper limb is usually used. But common movements, such as walking and running, require both lower limbs generally used simultaneously and continuously. Therefore, endurance characteristics of muscle groups related to gripping force may differ between the hands and toes. However, this difference has not been well studied.

According to Yamaji et al. [1], after sustained static hand gripping for 3 min, grip strength decreased until the final grip strength was about 20% of maximal grip strength. However, Nakada and Demura [8] reported that final strength after sustained toe gripping for 3 min was 39% of maximal toe grip strength. These reports indicate that the tendencies of grip force to decrease during maximal sustained hand and toe grip exertions are different. This study aimed to examine characteristics of grip force decreases during maximal sustained hand and toe grip exertions, and the relationships between muscle endurance parameters in both exertions.

2. Methods

2.1. Subjects

Fourteen males aged 18-22 years old were selected as subjects (height 170.7±5.0cm, weight 65.0±6.6kg). Thirteen of them belonged to athletic clubs. Informed consent was obtained after detailed explanation regarding experimental purpose and protocol.

2.2. Materials

Hand grip strength was measured using a handgrip sensor (EG-210, Sakai Medical. Co., Ltd., Tokyo, Japan), an indicator (EG-220, Sakai Medical. Co., Ltd., Tokyo, Japan), and the related software (EG-290, Sakai Medical. Co., Ltd., Tokyo, Japan). Exerted grip values were recorded at 20 Hz. Toe grip strength was measured using a toe finger dynamometer (T.K.K.3361, Takei Scientific Instruments Co., Ltd., Niigata, Japan). Exerted grip values were recorded at a 20 Hz sampling rate by an analog-to-digital interface (Power Lab/16sp, ADInstruments).

2.3. Experimental Procedure

2.3.1. Measurement Hand and Foot

Each subjects' dominant hand was determined as the hand mainly used in 4 activities (hammer, cutter knife, writing and throwing) based on Demura et al.'s report [9]. Among 14 subjects, 12 were judged to be right-handed. The dominant hand of all subjects was used for measuring hand grip. Each subjects' dominant leg was determined as the leg mainly used in 4 activities (hopping on one foot, stepping up on a chair, kicking a ball and stamping on an object) based on Demura et al.'s report [10]. Among 14 subjects, 13 were judged to be right-footed. The dominant foot was used to measure toe grip.

2.3.2. Measurement of Hand Grip Exertion Values

Maximal hand grip strength was measured while the subject was in a seated posture on a chair, before sustained hand grip exertion was measured. Subjects performed two maximal grip trials while keeping the arm supported by an armrest and the trunk at 90 degrees. The larger value was used as a representative value. For the sustained hand grip exertion measurement, subjects were instructed to exert maximal grip strength as fast as possible after a whistle signal, and to continue maximal exertion for 6 min in the same seated posture as above. To confirm reproducibility, all subjects performed the same test again on a different day.

2.3.3. Measurement of Toe Grip Exertion Values

Maximal toe grip strength was measured while the subject was in a seated posture on a chair with the knee joint angled at 90 degrees, before sustained toe grip exertion was measured. Subjects performed two maximal toe grip trials, and the larger value was used as a representative value. In the sustained toe grip exertion measurement, subjects were instructed to exert maximal toe grip as fast as possible after a whistle signal, and to continue maximal exertion for 6 min in the same seated posture as above. To examine reproducibility, all subjects performed the same test again on a different day. Of the 14 subjects, seven were measured in the order of the two hand grip exertion tests followed by the two toe grip exertion tests. The remaining seven were measured in reverse order.

2.4. Parameters

Parameters on sustained hand and toe grip exertions were selected by referencing previous studies [1,6]. The sustained times of 40, 60, 70, and 80% forces of maximal strength (max) were selected as the sustained time parameters. Grip strength at 90 sec, 3 min, and final strength (average at 1 sec before finishing) during the sustained grip test were selected as strength parameters. These strength parameters were expressed with percentage of maximal strength (% max).

2.5. Data Analysis

The cross-correlation coefficients were calculated to examine the reproducibility of the force during sustained hand and toe grip exertions. Changes of the forces (% max) in each elapsed time were examined by two-way repeated measure ANOVA (grip exertion style and elapsed time). Significant interaction or main effect was found, and multiple comparison was performed with Bonferroni post-test. The quadratic regression was calculated to examine changes of force values in each elapsed time. Pearson's correlation coefficient was calculated to examine the relationships among parameters in both grip exertions.

3. Results

Figure 1 shows the cross-correlation coefficients and the changes of force values during two maximal sustained hand grip and toe grip exertions. Both forces (% max) markedly decreased until about 60 sec after the onset of their grip exertions (hand grip: about 30% max, toe grip: about 45 % max), and then decreased more slowly. However, the force values decreased very little during the 4-6 min period (hand grip: about 25% max, toe grip: about 30% max). The cross-correlation coefficient was 0.995 (lag=0) in hand grip and 0.982 (lag=0) in toe grip. Hence, the reproducibility of each grip exertion was judged to be very high. The first trial data was used for the further analysis.

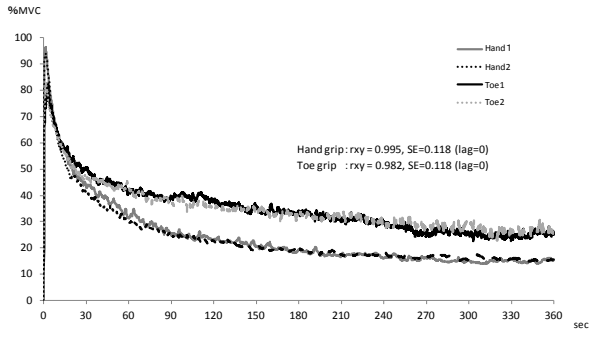
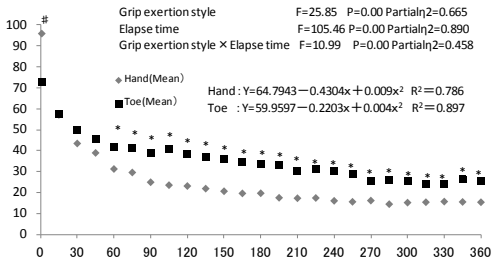


Figure 1. Cross-correlation coefficients and the changes of force values during two maximal sustained hand grip and toe grip exertions

Figure 2 shows the changes of the force values (% max) every 15sec (starting value at 1sec) in two maximal sustained hand and toe grip exertions, and the results of two-way repeated measure ANOVA (grip exertion style and elapsed time). A significant interaction was found. Results of multiple comparison showed that the forces

were higher in the hand grip exertion than in the toe grip exertion at 1sec after the exertion onset, but higher in the latter exertion values from 60sec onward. In addition, results of multiple comparisons among mean force values at each elapsed time showed that no significant differences were found from 210sec in the hand grip exertion and from 240sec in the toe grip exertion. A significant quadratic regression between each elapsed time and the corresponding force was found, and the determination coefficient was about 79% in the hand grip exertion and about 90% in the toe grip exertion.

Table 1 shows the correlation coefficients among parameters of sustained hand and toe grip exertions. Correlations between each time parameter (40% ~ 80% max) were significant in the hand grip exertion. Their correlations in toe grip exertion were significant, but not between the 40% max sustained time and 70% max sustained time. In both grip exertions, there was no significant correlation between max strength and each parameter. In addition, no significant correlation between final strength and each sustained time parameter was found. In both grip exertions, no significant correlation between strength at 90 sec and final strength was found. However, significant correlation between strength at 3 min and final strength was found.



Note) *：p<0.05（Toe＞Hand）、＃：p<0.05（Hand＞Toe）

Figure 2. Changes of the force values (% max) in two maximal sustained hand grip and toe grip exertions, and the result of two-way repeated measure ANOVA (grip exertion style and elapsed time)

Table 1. Correlation coefficients between parameters of sustained hand and toe grip exertions

			Mean	SD	1	2	3	4	5	6	7
Hand grip	1. Maximal strength	kg	46.4	5.7							
	2. 80% max sustained time	sec	5.2	3.8	0.156						
	3. 70% max sustained time	sec	9.2	6.7	0.139	0.896*					
	4. 60% max sustained time	sec	12.6	8.0	0.165	0.861*	0.960*				
	5. 40% max sustained time	sec	35.9	20.3	0.022	0.614*	0.764*	0.842*			
	6. Strength at 90 sec	%	24.9	7.1	-0.310	0.075	0.279	0.315	0.656*		
	7. Strength at 3 min	%	19.7	7.3	-0.181	-0.104	0.016	0.246	0.513	0.425	
	8. Final strength	%	15.3	5.1	-0.359	0.370	-0.336	-0.129	0.101	0.087	0.815*
Toe grip	1. Maximal strength	kg	15.6	2.5							
	2. 80% max sustained time	sec	2.2	2.0	-0.220						
	3. 70% max sustained time	sec	5.1	3.7	-0.008	0.769 *					
	4. 60% max sustained time	sec	11.5	11.2	-0.108	0.657 *	0.801*				
	5. 40% max sustained time	sec	58.3	57.9	-0.291	0.616 *	0.423	0.545 *			
	6. Strength at 90 sec	%	39.1	10.8	-0.254	0.372	0.290	0.411	0.827*		
	7. Strength at 3 min	%	33.8	11.1	-0.379	0.401	0.307*	0.368	0.561*	0.786*	
	8. Final strength	%	25.6	10.9	-0.382	-0.107	-0.129	-0.047	0.043	0.488	0.645*

Note)*: p<0.05

4. Discussion

The cross-correlation coefficients of two trials in each grip exertion were 0.995 in hand grip and 0.982 in toe grip. Nakada et al. [11] reported that the cross-correlation of grip force between trials on maximal repeated rhythmic grip exertion for 6 min was very high (r_{xy}=0.994). It is inferred that the reproducibility of the forces during both grip force exertions is very high.

Yamaji et al. [1] reported that the force exertion during sustained static maximal gripping decreased remarkably until about 30-60 sec after the onset of grip exertion, then decreased slowly, reaching 20% of maximal grip at about 3 min, 15% at about 4 min, and an almost steady state at 4-6 min. The decreasing force during the hand grip exertion in this study is similar to the results reported by Yamaji et al. [1]. In addition, Nakada and Demura [8] reported that the force during sustained toe grip exertion decreased markedly until about 30 sec after the start of exertion, then slowly decreased and reached about 40% of maximal toe grip strength at 3 min. The strength at 3 min in the present toe grip exertion was about 34% of max and was a little low as compared to the result of Nakada and Demura [8]. However, the decreasing tendency of forces was similar to that in the previous study [8].

The force was only higher in the hand grip exertion than in the toe grip exertion at 1 sec after beginning of the grip exertions. Time to max was 1.18±0.66 (Mean±SD) sec in the hand grip exertion and 2.02±1.00（Mean±SD）sec in the toe grip exertion. In short, it is considered to be affected by the latter slowness. Miyata et al. [12] reported that the higher % FT fibers are, the faster its conduction velocity, and that the conduction velocity depends on the recruitment style of muscle fibers. It is inferred that muscle fiber composition related to hand and toe grip exertions as well as a difference in the recruitment style of muscle fibers affected the present results.

From 60 sec after the beginning of sustained grip exertions, the forces were higher in the toe grip exertion than in the hand grip exertion. Yamaji et al. [7] reported that, since oxygen saturation maintains low values by obstruction of the blood flow from the beginning of sustained static maximal hand gripping to 40-60 sec, the oxygenation supply of this time period will be decreased. In addition, Yamaji et al. [6] reported that from examination of muscle oxygenation kinetics during sustained static gripping, the regression coefficient in the Deoxy-Hb decreasing phase correlated significantly with decreasing force at 1-2 min. This parameter can evaluate the phase when resumption of the blood flow begins. However, this process of obstruction and resumption of blood flow may differ between the hand grip and the toe grip exertions. Ordway et al. [13] reported that the elbow flexors initially fatigued more rapidly, but reached a plateau at a relatively higher strength level than the knee extensors when comparing both via transformed scores to the same base. In addition, in the case of different muscle groups, fatigue tends to occur with a different rate even if comparing relative strengths [13]. It is now theorized that although the present results differed from those in previous studies, this depends on different characteristics of muscle groups in the upper and lower limbs. A difference of muscle group fibers recruited in each movement may affect strength levels at muscle fatigue.

There were no significant relationships between maximal strength and each sustained time parameter in both exertions. Each time parameter is thought to evaluate different abilities from max in both exertions. Yamaji et al. [1] reported that significant correlations (r=0.92-0.97) were found between parameters regarding time to 60, 70, and 80% of maximal grip during sustained static maximal gripping. In addition, Yamaji et al. [7] reported that persisting times of 80%, 70%, and 60% of max and the decrement size of exertion values for the first 1 min during sustained static maximal hand gripping for 12 min can evaluate a remarkable phase of strength decrease. On the other hand, Nakada and Demura [8] reported that significant correlations (r=0.786-0.958) were found between parameters at the sustained times of 60, 70, 80% forces of maximal toe grip strength during sustained toe grip exertion for 3 min. In the present results, significant correlations (r=0.614-0.960) were found between the times of 40-80% forces of maximal hand grip strength during sustained hand grip exertion. In addition, significant correlations (r=0.657-0.801) were found between the times of 60-80% max forces of maximal toe grip strength during sustained toe grip exertion. Strength at 3 min showed a significant correlation with final strength in both exertions (0.815 and 0.645), but significant correlation was only found between 40% max sustained time (0.561) and strength at 90 sec (0.786) in toe grip exertion. The force at 90 sec after start of exertion corresponds to the 20% max in hand grip exertion and the 40% max in toe grip exertion. From these results, the strength value at 3 min in toe grip exertion may be a useful parameter of toe grip endurance. On the other hand, it was reported that hand grip strength had significant correlation with isometric knee extensor strength [14]. However, a significant correlation between hand grip and toe grip strength was not found. In addition, no significant correlations among the same sustained time parameters in both exertions were found. The two grip exertions, even in the same limbs, are considered to evaluate different abilities.

5. Conclusions

This study examined characteristics of decreases in force exertion during maximal sustained hand and toe grip exertions, and the relationships between muscle endurance parameters in both exertions. The reproducibility of each grip exertion is high. Forces (% max) during both exertions markedly decreased until about 60 sec after the onset of their grip exertion (hand grip: about 30% max, toe grip: about 45% max.) The latter exertion values maintain a higher exertion level than the former after a marked decrease. Relationships between sustained time parameters (60-80% max) are high. Strength at 3min showed a relationship with final strength, 40% max sustained time, and strength at 90 sec in toe grip exertion. This parameter may be a useful parameter of toe grip endurance.

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