EVALUATION OF GRIP STRENGTH WITH A SUSTAINED MAXIMAL ISOMETRIC CONTRACTION FOR 6 AND 10 SECONDS

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The grip strength in which subjects sustained a maximal isometric contraction for 6 seconds (the 6-second test) was compared with that for 10 seconds (the 10-second test) to clarify a reliable sustained grip strength test procedure. Fifty healthy students (22 ± 4 years, 25 men and 25 women) participated in this study. Strength was measured continuously by the Dexter® (Cedaron Medical Inc.). The maximal grip strength, the peak time, and the momentary strength every second during a trial were evaluated. For both tests, the reliable maximal strength and a typical strength-time curve consisting of an early peak time and a decrease in the strength after the peak gradually over time were obtained. In the 6-second test, the momentary strength after 5 seconds that was $82 \pm 10 \sim 87 \pm 7\%$ of the peak strength showed good reliability. This variable may be effective in assessing the ability to sustain maximal grip strength.

INTRODUCTION

The grip strength measurement is one of the most commonly used evaluations of hand function. Only maximal grip strength is usually measured with a traditional test. Recently a new test to measure continuous isometric grip strength, in which a subject keeps exhibiting maximal efforts during a fixed time, was developed (1–10). With this kind of test, previous researchers continuously recorded the strength data and visualized the strength versus time curves (strength–time curve) (see Fig. 1) to assess the ability to sustain strength.

Myers et al. (1), Amundsen (2), Niebuhr et al. (3), Cramer et al. (4), and Kamimura et al. (5) examined the sustained maximal isometric grip strength for either 4, 5 or 6 seconds and showed that a healthy subject seems to have a typical strength–time curve (see Fig. 1), which consists of an initial rapid rise of force, an early peak height, a relatively smooth peak curve, and a subsequent decrease in height gradually over time. The analysis of the strength–time curve may have an advantage in evaluating

a hand disturbance. Helliwell et al. (6) examined the sustained maximal grip strength for 4 seconds and identified that the grip strength of patients with rheumatoid arthritis tended to decrease more rapidly after the peak strength than that of outpatients without any hand dysfunction.

Assuming that the sustained grip strength test is effective in detecting a hand disturbance, we should determine a standard procedure. The various duration times of 4, 5, 6, 10 or 40 seconds were used as the time for sustaining maximal grip strength (sustained-time) in previous studies (1–10). There are, however, few comparative studies focused on the influence of different sustained-times on the results. At first, 6 seconds and 10 seconds were used in a comparison of the measurement of sustained-time; we then investigated the reliability of the strength data and the characteristics of the strength–time curve of healthy subjects. These conditions were selected, because previous research did not show the above-mentioned typical strength–time curve for sustained-times above 6 seconds.

In this study we tried to determine how long subjects had to sustain a maximal isometric grip strength to elicit reliable strength data.

METHODS

Subjects

Twenty-five men (mean age 23 ± 4.5 years) and 25 women (mean age 20 ± 3.9 years) participated in this study. All of them had no signs of disease or injury. One man and three women reported left-hand dominance.

Procedures

To measure the grip strength, the Dexter® (Cedaron Medical Inc., USA) was used, which is a computer system that includes a Jamar dynamometer, a force transducer and an analog-to-digital converter. The Jamar dynamometer was set at the second handle position from the inside. With this system, the grip strength data were continuously recorded throughout the trials. During a trial, the strength data were taken 100 times per second. The time when the instrument detected a force above 0.8 lbs (0.38 kg) after the examiner gave the signal to start was expressed as "0 second". Each trial result was represented by a strength-time curve (Fig. 1). The vertical axis shows grip strength (kg), and the horizontal axis shows time (seconds). The Jamar dynamometer was calibrated at 70 and 50 lbs (33.6 and 24.0 kg) before and after the experiment. It was accurate to less than $\pm 2\%$ at 70 lbs, and accurate to less than $\pm 3\%$ at 50 lbs.

Positioning for the measurement standardized by the American Society of Hand Therapists (11) and Mathiowetz (12) was adopted. The subject sat on a chair with the shoulder adducted, the elbow flexed to 90°, the forearm neutralized, and the wrist between 0° and 30° extension. The dynamometer was fixed on a stable pole with clamps after each subject was placed in the proper position.

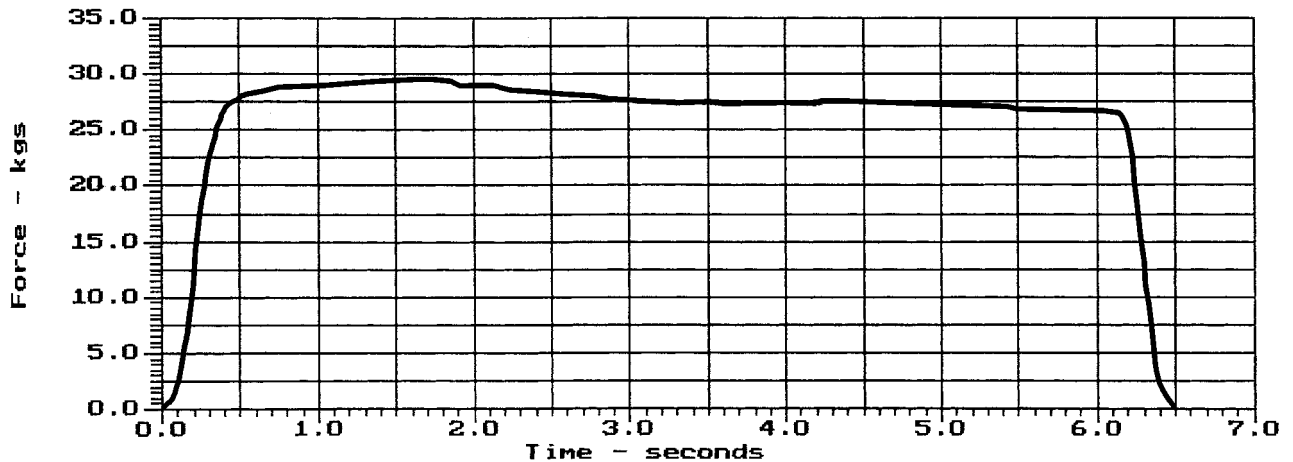There were two tasks in this study: (1) to maintain grip strength with a

Fig. 1. The strength−time curve for the 6-second test.

maximal effort isometric contraction for 6 seconds (6-second test), and (2) to maintain grip strength with a maximal effort isometric contraction for 10 seconds (10-second test). After an explanation of the tasks, the examiner told each subject, "Squeeze the dynamometer for 6 (or 10) seconds as hard as you can", and "Go". Six (or 10) seconds later, the examiner said, "Stop". No feedback regarding the performance was given during the measurement. Grip strength was measured once for each task, bilaterally, the non-dominant side first. The 10-second test followed the 6-second test. A 1-minute rest was allowed between trials, which is grounded on the recommendation of Trossman & Li (13). They pointed out that it seems prudent to allow at least a 1-minute rest between trials on an isometric grip strength test. Using each strength-time curve, we analyzed the maximal strength, the peak time (the time required to reach maximal strength), and the momentary strength every second during a trial, except the last second (after 1 second, after 2 seconds, …, and after 9 seconds).

To clarify the reliability of the strength data, we investigated the test-retest reliability of the maximal strength and the momentary strength every second during a trial, except the last second. To evaluate the strength changes during a trial, the peak time and the momentary grip strength ratio were examined. The momentary strength ratio was calculated by taking the ratio of the momentary strength to the maximal strength in the same trial.

The examination of the second session was conducted 2–7 (5 ± 1.6) days later in the same manner as in the first session. All the measurements were performed at approximately the same time of the day for each subject. It was not until all the examinations were finished that a subject knew the results.

Data analysis

The collected data for each test were divided into four groups, "dominant hand vs non-dominant hand" and "male vs female", to be analyzed. The test-retest reliability of both the maximal strength and the momentary strength was determined by calculating the interclass correlation coefficients (ICCs) and their associated 95% confidence intervals (95% CIs). The sum of the squares needed for the calculation of the ICC was obtained by using a one-way ANOVA. The observed ICCs were assessed by Meyers's (14) criteria: 0.80–0.89 as good reliability and 0.90–0.99 as high reliability.

In our data analysis, several tests were used to assess the significant differences of the measured values. For two independent samples, the Student *t*-test was used for variables with equal variance, and the Welch *t*-test was used for variables with non-equal variance. For paired samples, the paired Student *t*-test was used. *P* values of 0.05 or less were considered as statistically significant.

RESULTS

The maximal grip strength

The averages and the standard deviations of the maximal strength for the 6-second test and the 10-second test are shown in Table I. The mean maximal strength for males was greater than for females (Welch *t*-test, $p < 0.05$). The individual subject's maximal strength for the dominant hand was greater than that for the non-dominant hand in all the tests.

Table I. *The maximal grip strength (kg) for the 6-second test and the 10-second test*

	6-second test		10-second test	
	Session 1	Session 2	Session 1	Session 2
Dominant hand				
Male	50 ± 10.1	50 ± 10.4	49 ± 9.7	49 ± 9.8
Female	34 ± 4.9	34 ± 4.8	34 ± 4.7	34 ± 5.2
Non-dominant hand				
Male	46 ± 9.8	47 ± 9.7	46 ± 10.4	45 ± 8.4
Female	32 ± 5.8	33 ± 4.9	32 ± 5.4	32 ± 5.1

Table II. *The interclass correlation coefficients and their associated 95% confidence intervals of the maximal grip strength*

	6-second test		10-second test	
	ICC[a]	95% CI[b]	ICC[a]	95% CI[b]
Dominant hand				
Male	0.94**	0.89−0.97	0.93**	0.87−0.96
Female	0.83*	0.69−0.91	0.87*	0.76−0.93
Non-dominant hand				
Male	0.96**	0.93−0.98	0.90**	0.81−0.95
Female	0.87*	0.77−0.93	0.92**	0.85−0.96

[a] ICC: interclass correlation coefficient.
[b] 95% CI: the associated 95% confidence interval.
** ICC $\geqq$ 0.9;   *0.8 $\leqq$ ICC <0.9.

The ICCs and 95% CIs of the maximal strength for both the tests are shown in Table II. In the 6-second test, high reliability was found in the maximal strength of both hands for males. Good reliability was obtained in both hands for females. In the 10-second test, high reliability was found in both hands for males and in the non-dominant hand for females, and good reliability was obtained in the dominant hand for females.

The momentary grip strength

The averages and the standard deviations of the momentary strength of the 6-second test and the 10-second test in the first session are shown in Tables III and IV. In a comparison of each group, there was no significant difference between the mean momentary strength every second of the first and second sessions (paired Student *t*-test, $p < 0.05$). The mean momentary strength for the males each second was larger than that for the females (Welch *t*-test, Student *t*-test, $p < 0.05$). The mean momentary strength every second for all subjects and hands decreased gradually.

The ICCs of the momentary strength during both tests are shown in Tables V and VI. In the 6-second test, regardless of sex or hand side, high or good reliability was found for the momentary strength after 1 second, after 4 seconds and after 5 seconds. By contrast, in the 10-second test, regardless of sex or hand side, we could not find high or good reliability for the measured momentary grip strength.

The strength–time curve

In a comparison of the mean peak time between each group in each test, there was no significant difference found between sessions (paired Student *t*-test, $p < 0.05$). In the 6-second test, the mean peak time ranged from 1.1 ± 0.5 seconds (female's non-dominant hand in the first session) to 1.7 ± 1.0 seconds (male's dominant hand in the first session). The mean peak time in the 10-second test was similar to that of the 6-second test.

In both the 6-second test and the 10-second test, the mean momentary strength ratios of all the hands every second decreased gradually. In a comparison of each group, there was no significant difference between the mean momentary strength ratios for every second of the first and second sessions (paired Student *t*-test, $p < 0.05$). In the 6-second test, the mean momentary strength ratios after 5 seconds were $82 \pm 10\%$ (female's non-dominant hand in the first session) $\sim 87 \pm 7\%$ (male's dominant hand in the first session). In the 10-second test, the mean momentary strength ratios after 9 seconds were $71 \pm 12\%$ (female's dominant hand in the first session) $\sim 77 \pm 10\%$ (male's dominant hand in the first session).

DISCUSSION

Reliability of grip strength

We examined 50 healthy young people's sustained maximal isometric grip strength for 6 and 10 seconds. Their maximal grip strength demonstrated high or good reliability, whether the

Table III. *The momentary grip strength (kg) during the 6-second test of the first session*

	After 1 second	After 2 seconds	After 3 seconds	After 4 sseconds	After 5 seconds
Dominant hand					
Male	48 ± 10.6	48 ± 10.7	47 ± 9.8	44 ± 9.1	44 ± 8.7
Female	33 ± 5.2	32 ± 4.9	30 ± 5.1	29 ± 5.3	28 ± 5.0
Non-dominant hand					
Male	44 ± 10.6	44 ± 9.4	42 ± 9.2	40 ± 8.8	39 ± 8.8
Female	32 ± 6.2	31 ± 5.6	29 ± 4.9	27 ± 4.5	26 ± 4.7

Table IV. *The momentary grip strength (kg) during the 10-second test of the first session*

	After 1 second	After 2 seconds	After 3 seconds	After 4 seconds	After 5 seconds	After 6 seconds	After 7 seconds	After 8 seconds	After 9 seconds
Dominant hand									
Male	46 ± 10.0	46 ± 10.3	44 ± 8.6	43 ± 8.4	42 ± 7.1	40 ± 7.8	39 ± 7.2	39 ± 6.4	38 ± 7.3
Female	33 ± 5.0	32 ± 5.0	30 ± 5.6	29 ± 5.3	28 ± 6.1	27 ± 6.6	26 ± 6.0	25 ± 6.3	24 ± 6.1
Non-dominant hand									
Male	44 ± 11.0	42 ± 10.0	41 ± 9.1	39 ± 9.2	38 ± 9.0	37 ± 9.3	36 ± 8.0	35 ± 7.2	34 ± 7.5
Female	31 ± 6.2	30 ± 5.0	29 ± 5.1	27 ± 5.0	26 ± 4.1	25 ± 4.5	24 ± 4.5	23 ± 5.2	23 ± 5.1

sustained-time was 6 seconds or 10 seconds. And our results showed that the maximal grip strength in the dominant hand for males demonstrated a higher reliability (ICC = 0.94 and 0.93, in the 6-second test and the 10-second test, respectively) than for females (ICC = 0.83 and 0.87, respectively). There are few previous studies about the gender difference in the reliability of the maximal grip strength, even in the traditional measurement with unpredetermined sustained-time. Fairfax et al. (15) showed that healthy females had significantly greater variability of maximal grip strength among repeated trials than did healthy males. Our findings were consistent with Fairfax's (15) hypothesis. On the ground of only our findings, the effect of gender on the reliability of the grip strength should be interpreted with caution. We should, however, evaluate the test reliability separately in different populations. Considering that it has been reported in many studies that healthy males have significantly stronger grip strength than healthy females, we should show the reliability of the grip strength for both healthy males and healthy females separately.

We found good reliability for even the female's maximal grip strength at one measurement of the sustained maximal grip strength. Mathiowetz et al. (16) measured the maximal grip strength of 25 females (mean age 25 years) 3 times each occasion to determine the test-retest reliability. According to their results, the highest maximal grip strength of three trials and the mean of three trials were more reliable than that of one trial. Thus, the question is still whether two or three trials in the sustained grip strength test are needed to elicit a higher reliability.

For females, we found a higher reliability for the maximal grip strength in the former measurement side (the non-dominant hand) than that in the latter measurement side (the dominant hand) in the 6-second test and the 10-second test. By contrast, for males, a higher reliability was found for the maximal grip strength in the latter measurement side (the dominant hand) than that in the former one (the non-dominant hand) in the 10-second test. For a patient with hand weakness it may be better to measure the maximal grip strength of the affected side first to maintain a high reliability during testing.

We also evaluated the reliability of the momentary grip strength every second during a trial. In the 10-second test, regardless of sex or hand side, we could not find a high or good reliability for the measured momentary grip strength. By contrast, in the 6-second test, regardless of sex or hand side, high or good reliability was found for the momentary strength after 1 second, after 4 seconds and after 5 seconds. We may be

Table V. *The interclass correlation coefficients and their associated 95% confidence intervals of the momentary grip strength during the 6-second test*

	After 1 second	After 2 seconds	After 3 seconds	After 4 seconds	After 5 seconds
Dominant hand					
Male					
ICC[a]	0.89*	0.88*	0.87*	0.85*	0.89*
95%CI[b]	0.79–0.94	0.78–0.94	0.76–0.93	0.73–0.92	0.80–0.94
Female					
ICC[a]	0.80*	0.64	0.73	0.80*	0.83*
95%CI[b]	0.64–0.89	0.40–0.80	0.53–0.85	0.64–0.89	0.70–0.91
Non-dominant hand					
Male					
ICC[a]	0.92**	0.93**	0.82*	0.90**	0.81*
95%CI[b]	0.85–0.96	0.86–0.96	0.67–0.90	0.82–0.95	0.65–0.90
Female					
ICC[a]	0.88*	0.87*	0.87*	0.86*	0.86*
95%CI[b]	0.78–0.94	0.76–0.93	0.76–0.93	0.73–0.92	0.74–0.93

[a] ICC: interclass correlation coefficient.
[b] 95% CI: the associated 95% confidence interval.
** ICC $\geqq$ 0.9;   *0.8 $\leqq$ ICC <0.9.

Table VI. *The interclass correlation coefficients of the momentary grip strength during 10-second test*

	After 1 second	After 2 seconds	After 3 seconds	After 4 seconds	After 5 seconds	After 6 seconds	After 7 seconds	After 8 seconds	After 9 seconds
Dominant hand									
Male									
ICC[a]	0.79	0.80*	0.84*	0.87*	0.81*	0.80*	0.70	0.61	0.76
Female									
ICC[a]	0.79	0.79	0.79	0.75	0.70	0.63	0.67	0.70	0.67
Non-dominant hand									
Male									
ICC[a]	0.54	0.86*	0.79	0.73	0.72	0.75	0.67	0.67	0.75
Female									
ICC[a]	0.82*	0.88*	0.79	0.74	0.70	0.78	0.68	0.50	0.54

[a] ICC: interclass correlation coefficient.
** ICC $\geqq$ 0.9; *0.8 $\leqq$ ICC <0.9.

able to use these variables for the assessment of the sustained maximal isometric grip strength.

The characteristics of the strength–time curve

To describe the characteristics of the form of the strength–time curve, we examined the peak time and the momentary strength ratio. The mean peak times were 1.1 ± 0.5 seconds (female's non-dominant hand in the first session) $\sim 1.7 \pm 1.0$ seconds (male's dominant hand in the first session), when a subject sustained the maximal grip strength for 6 seconds. The mean peak time for the sustained-time with 10 seconds was similar. Additionally, the mean momentary strength ratios every second decreased gradually in both tests. Overall, we found that healthy subjects usually show a typical strength–time curve, consisting of an early peak and a subsequent decrease gradually over time, not only in the 6-second test, but also in the 10-second test.

When healthy young people sustained the maximal isometric grip strength for 6 seconds, high or good reliability was found in the momentary strength after 5 seconds. And, after 5 seconds, he/she could keep $82 \pm 10\%$ (female's non-dominant hand in the first session) $\sim 87 \pm 7\%$ (males' dominant hand in the first session) of the peak strength in the same trial. If the strength–time curve of a patient with a hand disturbance is as reliable as was found in this study, the momentary grip strength after 5 seconds in the 6-second test may be an effective variable in evaluating the tendency to be unable to sustain his/her maximal isometric grip strength.

REFERENCES

1. Myers DB, Grennan DM, Palmer DG. Hand grip function in patients with rheumatoid arthritis. Arch Phys Med Rehabil 1980; 61: 369–373.
2. Amundsen LR. Isometric muscle strength testing with fixed-load cells. In: Amundsen LR, ed. Muscle strength testing: instrumented and non-instrumented systems. New York: Churchill Livingstone; 1990. p. 89–121.
3. Niebuhr BR, Marion R, Fike ML. Reliability of grip strength assessment with the computerized Jamar dynamometer. Occup Ther J Res 1994; 14: 3–18.
4. Cramer SC, Nelles G, Schaechter JD, Kaplan JD, Finklestein SP. Computerized measurement of motor performance after stroke. Stroke 1997; 28: 2162–2168.
5. Kamimura T, Koyama C, Miyaguchi H, Yamashita Y. The reliability of the sustained grip strength test in stroke patients. The 2nd Asia-Pacific Occupational Therapy Congress, 1999. p. 73.
6. Helliwell P, Howe A, Wright V. Functional assessment of the hand: reproducibility, acceptability, and utility of a new system for measuring strength. Ann Rheum Dis 1987; 46: 203–208.
7. Nordenskiöld UM, Grimby G. Grip force in patients with rheumatoid arthritis and fibromyalgia and in healthy subjects: a study with the Grippit instrument. Scand J Rheumatol 1993; 22: 14–19.
8. Dellhag B, Burckhardt CS. Predictors of hand function in patients with rheumatoid arthritis. Arthritis Care Res 1995; 8: 16–20.
9. Lagerström C, Nordgren B. On the reliability and usefulness of methods for grip strength measurement. Scand J Rehab Med 1998; 30: 113–119.
10. Lagerström C, Nordgren B, Olerud C. Evaluation of the grip strength measurements after Colles' fracture: a methodological study. Scand J Rehab Med 1999; 31: 49–54.
11. Fess EE. Grip strength. In: American Society of Hand Therapists, ed. Clinical assessment recommendations. 2nd ed. Garner, NC: American Society of Hand Therapists; 1992. p. 41–45.
12. Mathiowetz V. Grip and pinch strength measurements. In: Amundsen LR, ed. Muscle strength testing: instrumented and non-instrumented systems. New York: Churchill Livingstone; 1990. p.163–177.
13. Trossman PB, Li P-W. The effect of the duration of intertrial rest periods on isometric grip strength performance in young adults. Occup Ther J Res 1989; 9: 362–378.
14. Meyers CR. Selecting tests. In: Measurement in physical education. 2nd ed. New York: Ronald Press Company; 1974. p. 82–108.
15. Fairfax AH, Balnave R, Adams RD. Variability of grip strength during isometric contraction. Ergonomics 1995; 38: 1819–1830.
16. Mathiowetz V, Weber K, Volland G, Kashman N. Reliability and validity of grip and pinch strength evaluations. J Hand Surg 1984; 9A: 222–226.