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# The Effect of Measurement Time When Evaluating Static Muscle Endurance during Sustained Static Maximal Gripping

Shunsuke Yamaji[1], Shinichi Demura[2], Yoshinori Nagasawa[3], Masakatsu Nakada[4] and Tamotsu Kitabayashi[5]

*1) Fukui National College of Technology*
*2) Kanazawa University Faculty of Education*
*3) Akita Prefectural University*
*4) Kanazawa College of Art*
*5) Kanazawa University Graduate School of Natural Science and Technology*

**Abstract** The purpose of this study was to examine the useful measurement time when evaluating static muscle endurance by comparing various parameters during sustained static gripping for 1, 3 and 6 min. Fifteen males (mean ± SD age 20.8 ± 1.3 yr, height 172.9 ± 4.6 cm, body mass 67.7 ± 5.7 kg) and fifteen females [mean ± SD age 20.2 ± 0.9 yr, height 158.5 ± 3.2 cm, body mass 55.9 ± 4.6 kg] volunteered to participate in this study. The subjects performed the sustained static maximal grip test with a sagittal and horizontal arm position for 1, 3 and 6 min on different days. Eleven force-time parameters were selected to evaluate static muscle endurance. The trial-to-trial reliability of each measurement time of sustained static maximal gripping was very high ($r_{xy}$ = 0.887–0.981 (1 min), 0.912–0.993 (3 min), 0.901–0.965 (6 min)). The errors of exertion values between trials were very small (below 10%). A significant correlation was found in the following parameters: the final strength and the exponential function between 1 min and 3 min, all parameters except for the time required to reach 80% of maximal grip, the regression coefficient at post-inflection between 3 min and 6 min, and the decreasing rate between all measurement times (1 min, 3 min, and 6 min). Significant differences between the measurement times were found in all parameters except for the time to 60, 70, and 80 % force decreases, and the regression coefficient of pre-inflection. There was a tendency that the longer the measurement time, the larger the decreasing force. It is suggested that for the 6 min measurement, the subjects unconsciously restrained the maximal gripping force, influenced by a psychological factor as the pain became greater. The 1 min measurement may evaluate only the remarkable decreasing phase of the decreasing force, and not evaluate the phase of an almost steady state. *J Physiol Anthropol 21 (3): 151–158, 2002* http://www.jstage.jst.go.jp/en/

**Keywords:** force-time curve, muscle endurance, inflection point

## Introduction

In general, muscle endurance has been evaluated from sustaining times or achievement times during sustained force exertion. It is defined as the ability to maintain a force exertion at a certain intensity. Representative evaluation methods such as sit-ups, push-ups or pull-ups, using one's body as a load, have major issues involving physique and technical factors in measurements during sustained force exertion, and it is difficult to measure a person with low physical fitness, such as the elderly. On the other hand, laboratory tests have used a relative load based on an individual's maximal strength with specific body segments, and the technical factors (e.g. grip, elbow flexion, and plantar flexor) are not much of an issue. Most of these methods record time series of digital data during sustained force exertion (Caldwell et al., 1963; Huczel and Clarke, 1992; Kagaya et al., 1989; 1994; Walamies and Turjanmaa, 1993; Yamaji et al., 2000). Previous studies proposed various parameters to evaluate muscle endurance from various viewpoints, such as the time to decrease the force to a certain level (% MVC), the rate of force decrease, and the average integrated area during sustained force exertion. The contribution of physiological factors (e.g. muscle oxygenation, recruitment of muscle fibre, excitation-contraction coupling, energy supply to muscle) involve sustained maximal static force exertion changes over time (Hermansen et al., 1967; Humphreys and Lind, 1963; Kagaya, 1994; Nielson and Ingvar, 1967). Therefore, an evaluation or interpretation of muscle endurance in an analysis of the force-time curve will be different depending on the evaluated phase (Saito and Kagaya, 1999). It is important that the evaluation parameters selected for muscle endurance consider the contribution of physiological factors. However, measurement conditions, such as intensity levels and measurement times, have not yet been generally standardized.

We used a hand grip test that was highly safe with simple measurements, and proposed effective evaluation parameters for muscle endurance by analyzing the decreasing curve of sustained static hand grip (SSHG) (Yamaji, et al., 2000). We also proposed an inflection point that divides the force-time curve into two phases, namely a rapid decrease (a pre-inflection phase) and an almost steady state (a post-inflection phase). It was suggested that the pre- and post- phases of the inflection point represent not only the change of the decreasing speed force, but are also dependent on respectively different physiological factors, such as muscle fibre recruitment or muscle oxygenation kinetics. Furthermore, we suggested that most parameters could be evaluated almost equally for 6 min instead of 12 min. However, whether the endurance test can be evaluated by shorter measurement times needs to be examined, because 6 min as an evaluation time imposes high pain to subjects and is inferior for practical use. Walamies and Tujanmaa (1993) used 1 min as the measurement time because the decrease in motivation caused by the long measurement time would affect the force exertion value. With a long measurement time there is the possibility of a subject unconsciously skimping the force exertion through psychological factors to the pain in a test. The purpose of this study was to examine effective measurement times to evaluate muscle endurance in a comparison of various parameters during measurement times of 1, 3, and 6 min.

## Methods

*Subjects*

Subjects were 15 healthy males [mean ± SD age 20.8 ± 1.3 yr, height 172.9 ± 4.6 cm, body mass 67.7 ± 5.7 kg] and 15 females [mean ± SD age 20.2 ± 0.9 yr, height 158.5 ± 3.2 cm, body mass 55.9 ± 4.6 kg] with no upper extremity impairments. Their physical characteristics approximated the standard values for Japanese individuals within that age range (Lab Physical Edu in Tokyo Met Univ ed., 1989). 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-290, Sakai, Japan). Each signal during sustained static grip exertion was sampled at 20 Hz by an analog-to-digital interface, and then relayed to a personal computer. To increase the motivation of the subjects during sustained static grip exertion, the recorded digital data was immediately displayed on a screen as a force-time curve to give feedback.

*Experimental procedure*

The dominant hand of each subject was judged using Oldfield's Handedness Inventory (Oldfield, 1971). All subjects performed the handgrip test with the dominant hand, and grip width was individually adjusted. Handgrip measurements were performed with subjects seated in an adjustable ergometric chair. The arm, supported by an armrest, was in a sagittal and horizontal position, the forearm being vertical with the hand in a semi-probe position. The subjects performed the maximal grip test twice before the sustained handgrip test, and the higher exertion value was used as the target value of the test. Before the test, subjects rehearsed sustained maximal handgrip exertion. They were instructed not to change the grip, and not to break into a posture during the handgrip measurement. Furthermore, the subjects were instructed to maintain maximal force for the measurement time (1, 3, and 6 min), during which the maximal value line was displayed on a screen for encouragement. No verbal encouragement was given during the test. Experimental design selected the cross over design, namely each subject performed all measurement conditions (1, 3, and 6 min) with an interval of about one or two days between the measurements. This was randomized in consideration of the effect of the measurement order.

To examine the reproducibility of a muscle exertion value for each measurement time, 5 of the 30 subjects performed the same test twice with an interval of about one or two days between trials.

*Force-time parameters*

Eleven force-time parameters proposed as effective parameters by Yamaji et al. (2000) were selected; time required to decrease from maximal grip strength to 60%, 70%, and 80% of maximal grip strength; average integrated area during grip exertion; average of strength for 1 sec before finishing (final strength); sum of the values to take the exertion value from maximal strength for the first 1 min (1 min decreasing force); the sum of the values to take the final strength from the exertion value every 30 sec (decreasing rate); maximal difference value of the linear line from maximal grip strength to final strength and the exertion value (maximal difference from

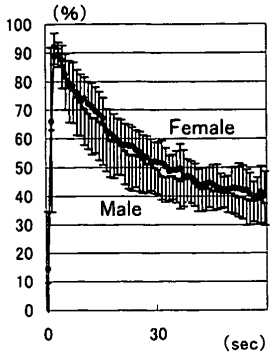


**Fig. 1-1** Average curves of the changes for grip force value during SSHG for 1 min.

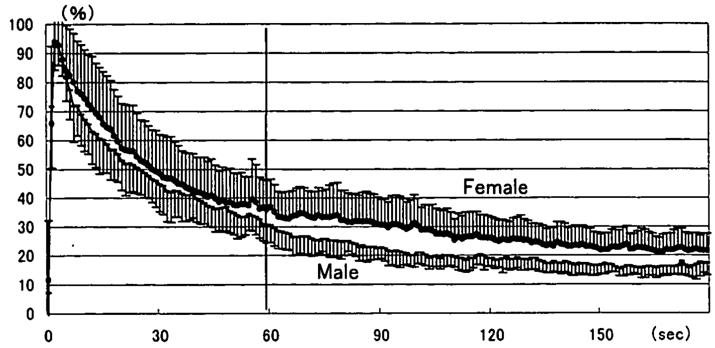


**Fig. 1-2** Average curves of the changes for grip force value during SSHG for 3 min. Vertical line in the figure indicates 1 min from the start of the test.

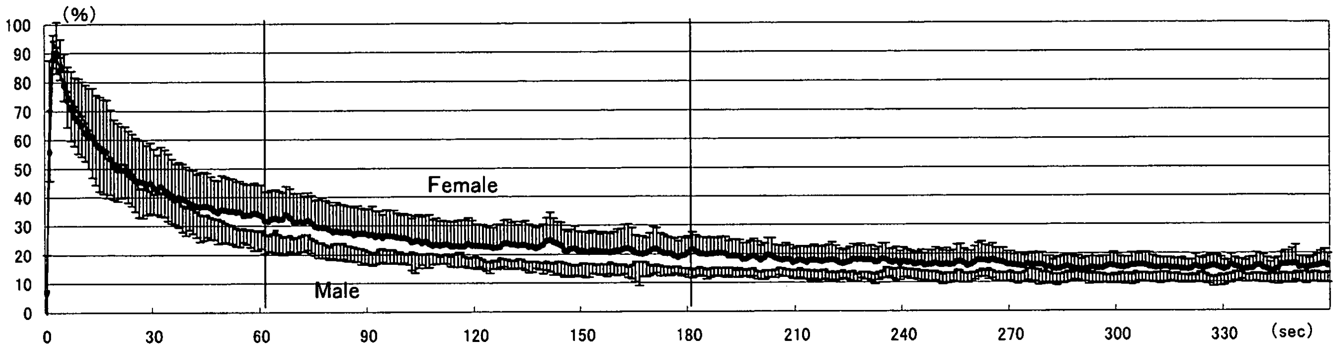


**Fig. 1-3** Average curves of the changes for grip force value during SSHG for 6 min. Vertical lines in the figure indicate 1 min and 3 min from the start of the test.

the linear line); time at an inflection point; and the regression coefficient at pre-inflection and at post-inflection; the rate of decrement constant (k) in the exponential function ($y=ae^{-kt} + b$).

The inflection point was the time at which the decreasing speed of force exertion remarkably changed (see Fig. 1-2 or 1-3). The decrease of the force exertion value in the pre-inflection phase was remarkable, while in the post-inflection phase it was almost at a steady state (Kagaya and Iwamura, 1989). To determine the inflection point (time) in this study, two regression lines were fitted by the method of least square on the force-time curve. These used the force-time data to divide into two sections, namely the first and latter half. The sections dividing force-time data sifted all sampling data, the regression line was calculated on all such occasions. The inflection point (time) was determined with the following conditions: 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 the highest.

*Data analysis*

Pearson's correlation coefficients were calculated to examine the relationships among the measurement times for each parameter and among all parameters for each measurement time. Repeated one way ANOVA was used to examine the differences between each parameter among the measurement times. Multiple comparison was done by Tukey's HSD method. The inter-trial reliability of force exertion value was evaluated by the cross correlation coefficient between two trial values. The intra-correlation coefficients (ICC) were calculated for the reliability of each parameter. The probability level of 0.05 was used as indicative of statistical significance.

## Result

There was a tendency for the exertion value after 1 min for females during SSHG to be approximately 5–10% higher than that for male (see Figs. 1-2, 1-3). This agrees with a previous report (Kagaya, 1994). On the other hand, Yamaji et al. (2000) reported that there was almost no gender difference in the decrement pattern, in which an exertion value during SSHG for 12 min remarkably decreased for the first 1 min, and then slowly decreased

**Table 1** Intra-class correlation (ICC) in examining the trial-to-trial reliability of each SSHG measurement time for 5 subjects

| | 1 min | | | | | 3 min | | | | | 6 min | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial 1 | | Trial 2 | | | Trial 1 | | Trial 2 | | | Trial 1 | | Trial 2 | | |
| Force-time parameters | mean | SD | mean | SD | ICC | mean | SD | mean | SD | ICC | mean | SD | mean | SD | ICC |
| Time to 80% (sec) | 6.7 | 5.1 | 7.9 | 5.1 | 0.353 | 4.5 | 2.6 | 9.7 | 7.0 | 0.458 | 3.9 | 0.5 | 6.3 | 3.2 | 0.079 |
| Time to 70% (sec) | 10.9 | 6.9 | 12.3 | 7.2 | 0.594 | 8.9 | 4.9 | 15.3 | 9.6 | 0.573 | 8.0 | 3.3 | 8.7 | 5.0 | 0.004 |
| Time to 60% (sec) | 17.7 | 8.2 | 18.6 | 9.0 | 0.513 | 14.2 | 7.1 | 21.2 | 11.4 | 0.721 | 15.2 | 6.0 | 14.9 | 9.0 | 0.379 |
| Average integrated area (% · sec$^{-1}$) | 51.8 | 8.3 | 53.6 | 6.7 | 0.045 | 30.4 | 3.0 | 32.2 | 4.3 | 0.949 | 25.4 | 3.5 | 27.8 | 4.8 | 0.758 |
| Final strength (%) | 35.4 | 7.8 | 38.5 | 5.5 | 0.179 | 19.8 | 6.0 | 23.7 | 10.8 | 0.968 | 15.3 | 3.1 | 17.2 | 5.4 | 0.059 |
| 1 min decreasing force (%) | 48.2 | 8.3 | 46.4 | 6.7 | 0.045 | 49.7 | 6.0 | 46.0 | 10.5 | 0.826 | 49.0 | 4.0 | 48.0 | 8.0 | 0.045 |
| Decreasing rate (%) | 53.6 | 11.7 | 51.2 | 9.2 | 0.920 | 72.6 | 9.8 | 74.1 | 8.5 | 0.958 | 78.2 | 3.2 | 76.0 | 5.6 | 0.610 |
| Maximal difference from the linear line | 21.4 | 9.0 | 24.1 | 8.0 | 0.421 | 45.2 | 5.7 | 47.7 | 5.6 | 0.951 | 53.6 | 5.9 | 51.5 | 5.6 | 0.355 |
| Regression coefficient at pre-inflection | −0.7 | 0.2 | −0.9 | 0.2 | 0.568 | −0.7 | 0.2 | −0.7 | 0.2 | 0.926 | −0.6 | 0.2 | −0.6 | 0.3 | 0.964 |
| Regression coefficient at post-inflection | 0.4 | 0.9 | 0.5 | 1.4 | 0.328 | −0.1 | 0.1 | 0.0 | 0.1 | 0.704 | 0.0 | 0.0 | 0.0 | 0.0 | 0.008 |
| Exponential function | 15.1 | 5.2 | 13.8 | 5.5 | 0.962 | 7.7 | 2.7 | 7.8 | 2.7 | 0.913 | 3.0 | 0.2 | 2.8 | 0.5 | 0.720 |
| Inflection time (sec) | 51.8 | 7.6 | 52.5 | 8.4 | 0.127 | 72.6 | 27.9 | 91.2 | 32.2 | 0.506 | 77.8 | 23.1 | 80.6 | 24.0 | 0.908 |
| Peak strength (MAX) | 45.2 | 10.2 | 45.6 | 12.4 | 0.935 | 48.9 | 10.4 | 44.1 | 8.7 | 0.977 | 37.4 | 7.6 | 39.4 | 11.2 | 0.653 |

Shadowed items indicate over 0.500 (P<0.05).

**Table 2** Difference in parameters (one-way ANOVA) and Pearson's correlation for each measurement time

| | 1 min | | 3 min | | 6 min | | Pearson's correlation | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Force-time parameters | Mean | SD | Mean | SD | Mean | SD | 1 min × 3 min | 1 min × 6 min | 3 min × 6 min | ANOVA F | post-hoc HSD |
| Time to 80% (sec) | 6.6 | 4.3 | 7.1 | 5.9 | 5.3 | 4.6 | 0.23 | 0.19 | 0.26 | 1.50 | |
| Time to 70% (sec) | 11.7 | 5.6 | 11.3 | 7.3 | 9.5 | 6.9 | 0.35 | 0.32 | 0.41 | 1.42 | |
| Time to 60% (sec) | 19.3 | 8.3 | 17.6 | 10.5 | 14.4 | 10.5 | 0.22 | 0.18 | 0.50 | 1.74 | |
| Average integrated area (% · sec$^{-1}$) | 54.0 | 6.3 | 32.5 | 7.0 | 22.6 | 5.4 | 0.18 | 0.08 | 0.49 | 10.51 * | 1>3>6 |
| Final strength (%) | 38.8 | 8.1 | 19.8 | 6.8 | 14.0 | 4.0 | 0.48 | 0.35 | 0.52 | 18.43 * | 1>3>6 |
| 1 min decreasing force (%) | 46.0 | 6.3 | 49.2 | 10.5 | 53.5 | 10.4 | 0.28 | 0.28 | 0.54 | 7.41 * | 1<3<6 |
| Decreasing rate (%) | 49.0 | 10.9 | 75.2 | 7.0 | 80.6 | 5.1 | 0.67 | 0.69 | 0.67 | 309.71 * | 1<3<6 |
| Maximal difference from the linear line | 25.2 | 5.9 | 45.8 | 6.9 | 58.6 | 8.1 | −0.03 | −0.05 | 0.51 | 159.31 * | 1<3<6 |
| Regression coefficient at pre-inflection | −0.80 | 0.27 | −0.85 | 0.30 | −0.75 | 0.33 | 0.13 | 0.00 | 0.66 | 1.54 | |
| Regression coefficient at post-inflection | 0.79 | 1.71 | −0.10 | 0.07 | −0.04 | 0.02 | 0.25 | −0.19 | 0.32 | 7.72 * | 1>3,6 |
| Exponential function | 12.78 | 4.79 | 6.84 | 1.99 | 3.02 | 0.84 | 0.41 | 0.20 | 0.62 | 96.64 * | 1>3>6 |
| Inflection time(sec) | 50.6 | 11.3 | 65.0 | 22.8 | 74.9 | 27.9 | 0.14 | 0.18 | 0.39 | 12.12 * | 1<3,6 |
| Peak strength (MAX) | 40.5 | 10.5 | 39.0 | 9.8 | 41.3 | 10.9 | 0.96 | 0.95 | 0.92 | 2.49 | |

*:P<0.05, HSD: Tukey's HSD, Shadowed items indicate significant correlations (p<0.05).

in both males and females. In this study as well, there was almost no remarkable difference in the decrement pattern during testing for 1, 3, and 6 min, therefore, genders were integrated for data analysis.

Table 1 shows the t-test, intra-class correlation (ICC) and cross correlation of two trials in examining the trial-to-trial reliability of each SSHG measurement time for 5 subjects. The reliability of each parameter for 3 min was the highest of all measurement times. The ICCs of all parameters except for the time required to decrease to 80% in 3 min were over 0.5. The cross correlation was very high for all measurement times ($r_{xy}$ = 0.887–0.981, 0.912–0.993, 0.901–0.965, respectively). No parameter showed a significant trial difference at any measurement time. The errors of exertion values between trials were very small (below 10%).

Figs. 1-1, 1-2, and 1-3 show the average curves of changes in grip force value during SSHG for each measurement time. The force exertion value decreased remarkably until about 30–60 s after the onset of grip exertion then decreased slowly and reached 20% of maximal grip at about 3 min, 15% at about 4 min, and an almost steady state at about 4–6 min.

Table 2 shows the difference in parameters (one-way ANOVA) and Pearson's correlation for each measurement time. The 1 min decreasing force evaluates the same phase in any measurement time, however there were significant differences among measurement times. With a longer measurement time, the decreasing force during 30–60 sec after the onset of grip exertion was larger, and the measurement for 6 min showed the largest decreasing force (Table 2, Fig. 2-1). Significant differences among measurement times were found in all parameters except the time required to decrease to 60, 70, and 80% of maximal grip, and the regression coefficient of pre-inflection. The tendency was that with a longer measurement time, the force decrease was larger. After 2 min from the start of the test, the difference of decreasing force between 3 min and 6 min was negligible (Fig. 2-2). In the relationship between each parameter and the measurement time, significant correlations between 3 min and 6 min were found in all parameters except the time required to decrease to 80% of maximal force and the regression coefficient of pre-inflection. The decreasing rate was significant for all measurement times. The final strength and the exponential function were significant between 1 min and 3 min.

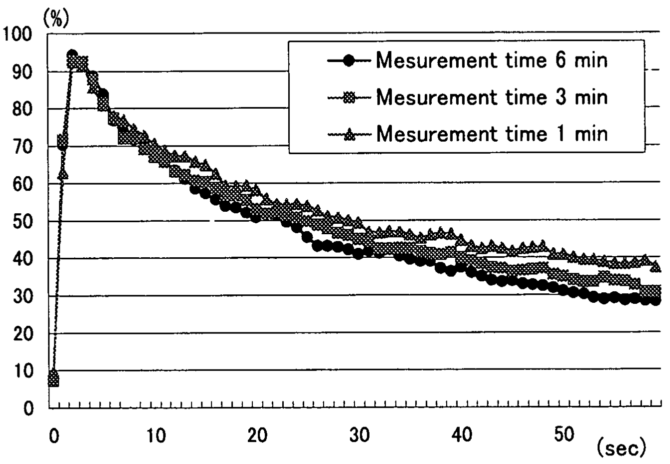


**Fig. 2-1** Average curves for 1 min of each measurement time (1 min, 3 min and 6 min).

Tables 3, 4, and 5 show the correlation coefficients for all parameters at each measurement time. Significant correlations were found among the parameters for the time required to decrease to 60, 70, and 80% of maximal grip, the average integrated area, the 1 min decreasing force, and the maximal difference from the linear line for all measurement times. Correlations significant at 3 min were significant at 1 min or 6 min, as well. On the other hand, correlations between the parameters significant at 1 min and 6 min were not significant at other measurement times. The inflection time at all measurement times significantly correlated to the regression coefficient at pre-inflection.

## Discussion

In this study, the reproducibility of the decreasing grip force values was judged as high at all measurement times, because of the high similarity.

The decreasing force value during maximal sustained static hand grip (SSHG) showed a similar decreasing tendency in males and females, which was the same result as Yamaji et al. (2000). The gripping force for all subjects remarkably decreased to 40% of maximal grip from the onset of SSHG to 30–60 sec, and then gradually decreased to 20% during 120–150 sec. The gripping force reached an almost steady state when it decreased to about 20% of maximal grip, and did not decrease below about 15% of maximal grip at any measurement time (1, 3, and 6 min). This result almost agrees with previous studies, which examined the tendency of decreasing grip force during SSHG (Bemben et al., 1996; Caffier et al., 1992; Clarke et al., 1992; Ishiguro and Kitamura, 1985; Yamaji et al., 2000), and it is considered that the steady state level (15–20% of maximal grip) was almost the same even if the SSHG test was measured over 6 min. It is considered that the gripping force value hardly decreases

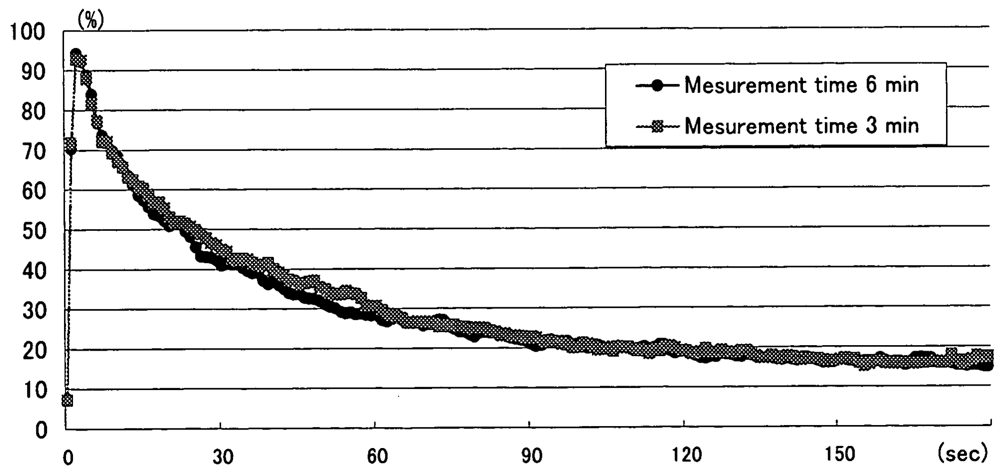


**Fig. 2-2** Average curves on measurement times of 3 and 6 min.

**Table 3** Correlation coefficients for all parameters at 1 min

1 min

| Force-time parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Time to 80% (sec) | | | | | | | | | | | | |
| 2. Time to 70% (sec) | 0.87 | | | | | | | | | | | |
| 3. Time to 60% (sec) | 0.62 | 0.77 | | | | | | | | | | |
| 4. Average integrated area (%·sec$^{-1}$) | 0.68 | 0.76 | 0.92 | | | | | | | | | |
| 5. Final strength (%) | 0.17 | 0.01 | 0.33 | 0.51 | | | | | | | | |
| 6. 1 min decreasing force (%) | -0.68 | -0.76 | -0.92 | -1.00 | -0.51 | | | | | | | |
| 7. Decreasing rate (%) | 0.36 | 0.45 | 0.10 | -0.04 | -0.74 | 0.04 | | | | | | |
| 8. Maximal difference from the linear line | -0.53 | -0.73 | -0.68 | -0.63 | 0.06 | 0.63 | -0.36 | | | | | |
| 9. Regression coefficient at pre-inflection | -0.16 | -0.17 | -0.44 | -0.27 | 0.02 | 0.27 | -0.07 | 0.18 | | | | |
| 10. Regression coefficient at post-inflection | -0.05 | -0.14 | -0.12 | -0.04 | 0.47 | 0.04 | -0.23 | 0.31 | 0.40 | | | |
| 11. Exponential function | 0.48 | 0.59 | 0.25 | 0.09 | -0.67 | -0.09 | 0.96 | -0.46 | -0.11 | -0.24 | | |
| 12. Inflection time(sec) | 0.16 | 0.16 | -0.11 | -0.07 | -0.15 | 0.07 | 0.40 | 0.08 | 0.58 | 0.34 | 0.41 | |
| 13. Peak strength (MAX) | 0.15 | 0.28 | 0.14 | 0.11 | -0.19 | -0.11 | 0.09 | -0.37 | -0.05 | -0.42 | 0.11 | -0.14 |

Shadowed items indicate significant correlations (P<0.05).

**Table 4** Correlation coefficients for all parameters at 3 min

3 min

| Force-time parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Time to 80% (sec) | | | | | | | | | | | | |
| 2. Time to 70% (sec) | 0.95 | | | | | | | | | | | |
| 3. Time to 60% (sec) | 0.86 | 0.94 | | | | | | | | | | |
| 4. Average integrated area (%·sec$^{-1}$) | 0.76 | 0.77 | 0.82 | | | | | | | | | |
| 5. Final strength (%) | 0.60 | 0.53 | 0.47 | 0.67 | | | | | | | | |
| 6. 1 min decreasing force (%) | -0.85 | -0.90 | -0.94 | -0.90 | -0.53 | | | | | | | |
| 7. Decreasing rate (%) | -0.05 | 0.02 | -0.01 | -0.33 | -0.64 | -0.01 | | | | | | |
| 8. Maximal difference from the linear line | -0.52 | -0.56 | -0.69 | -0.77 | -0.15 | 0.75 | 0.00 | | | | | |
| 9. Regression coefficient at pre-inflection | -0.17 | -0.04 | 0.06 | -0.10 | 0.11 | 0.04 | -0.26 | 0.15 | | | | |
| 10. Regression coefficient at post-inflection | -0.11 | -0.12 | -0.25 | -0.42 | 0.16 | 0.33 | -0.14 | 0.62 | 0.36 | | | |
| 11. Exponential function | 0.23 | 0.39 | 0.39 | 0.04 | -0.30 | -0.43 | 0.76 | -0.29 | 0.06 | -0.11 | | |
| 12. Inflection time (sec) | 0.35 | 0.43 | 0.43 | 0.18 | 0.30 | -0.36 | -0.04 | -0.06 | 0.69 | 0.53 | 0.33 | |
| 13. Peak strength (MAX) | -0.12 | -0.15 | -0.14 | -0.25 | -0.25 | 0.09 | 0.28 | 0.00 | 0.10 | 0.04 | 0.31 | 0.14 |

Shadowed items indicate significant correlations (P<0.05).

**Table 5** Correlation coefficients for all parameters at 6 min

6 min

| Force-time parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Time to 80% (sec) | | | | | | | | | | | | |
| 2. Time to 70% (sec) | 0.94 | | | | | | | | | | | |
| 3. Time to 60% (sec) | 0.92 | 0.97 | | | | | | | | | | |
| 4. Average integrated area (%·sec$^{-1}$) | 0.75 | 0.76 | 0.83 | | | | | | | | | |
| 5. Final strength (%) | 0.33 | 0.31 | 0.34 | 0.66 | | | | | | | | |
| 6. 1 min decreasing force (%) | -0.82 | -0.89 | -0.92 | -0.88 | -0.42 | | | | | | | |
| 7. Decreasing rate (%) | 0.16 | 0.22 | 0.17 | -0.25 | -0.75 | -0.11 | | | | | | |
| 8. Maximal difference from the linear line | -0.75 | -0.78 | -0.82 | -0.91 | -0.43 | 0.86 | 0.02 | | | | | |
| 9. Regression coefficient at pre-inflection | 0.00 | 0.14 | 0.23 | 0.41 | 0.28 | -0.37 | -0.20 | -0.40 | | | | |
| 10. Regression coefficient at post-inflection | -0.66 | -0.64 | -0.68 | -0.72 | -0.38 | 0.61 | 0.08 | 0.77 | -0.19 | | | |
| 11. Exponential function | 0.32 | 0.48 | 0.46 | 0.20 | -0.24 | -0.52 | 0.59 | -0.46 | 0.33 | -0.42 | | |
| 12. Inflection time (sec) | 0.20 | 0.39 | 0.45 | 0.55 | 0.32 | -0.61 | 0.00 | -0.57 | 0.82 | -0.32 | 0.58 | |
| 13. Peak strength (MAX) | -0.06 | -0.03 | -0.06 | -0.28 | -0.24 | 0.00 | 0.28 | 0.24 | -0.03 | 0.26 | 0.24 | -0.03 |

Shadowed items indicate significant correlations (P<0.05).

from 3 min, because the value decreased only by about 5% of the maximal grip, namely about 1.5–2.5 kg. It is inferred that the gripping force during the SSHG for 3 min almost reached a steady state. Furthermore, the relationship of all the parameters between 3 min and 6 min, except for the time required to decrease to 80% of maximal grip and the regression coefficient of pre-inflection, was fair. Therefore, the 3 min measurement can sufficiently estimate the decreasing tendency of grip force after 3 min.

The 1 min decreasing force differed among the measurements times. The 6 min measurement time was the largest, 10% lower than the maximal grip of the other measurement times. For this reason, it is inferred that the subjects unconsciously restrained maximal gripping because the measurement time was too long. The remarkable decreasing force in the initial phase possibly involves psychological factors. Therefore, it is necessary before the test to instruct the subjects to always keep a maximal grip if muscle endurance is to be evaluated from the parameters estimating this phase. On the other hand, the decline of the grip force values during the initial 120–180 sec at measurement times of 3 min and 6 min were very similar. This means that the properties of decreasing grip force can be evaluated almost equally at a measurement time of 3 min instead of 6 min. The gradual decreasing force at the nearly steady state will not be generally affected by the subject's psychological factor.

It is considered that gripping force by SSHG involves a larger measurement error due to force exertion over time than appears in the maximal strength test or muscle power test, and is affected by the subject's psychological factor of suffering a pain for the test (Bowei and Cumming, 1971; Nagasawa et al., 2000). Therefore, the reliability of the gripping force value during SSHG is considered to be lower than that of the static strength test or the muscle power test. In previous studies, there has been little examination of the reliability of gripping force during SSHG. The reliability of all evaluation parameters for SSHG, except the time required to decrease to 80% of maximal grip, was fair at the 3 min measurement time. On the other hand, at 1 min and 6 min, the reliability of the following parameters was low: the time required to decrease, 1 min decreasing force, maximal difference from the linear line, final strength, and the regression coefficients during the post-inflection phase. At 6 min, there is the possibility of unconsciously restraining maximal gripping during SSHG because of higher pain than at other measurement times. For 1 min, it may be considered that the trial-to-trial error is large because the measurement time is too short. Although the following parameters are considered to agree theoretically even at different measurement times, their degree of agreement was not very high; the time required to decrease, 1 min decreasing force, the regression coefficients during the pre-inflection phase and the inflection time. The relationships of the parameters between 1 min and 6 min were low except for the decreasing rate. It is inferred that the phase evaluated by these parameters differs for each measurement time. The inflection time and the regression coefficients during both phases were influenced by the length of the post-inflection phase, because of a property of the calculation method for inflection time, namely dividing the decreasing force into the pre- and post- phases, and deciding from the determination coefficients of both regression equations. Therefore, the inflection time tended to increase with a longer measurement time. A significant difference among the measurement times was found for all parameters, except for the time required to reach 60, 70, and 80% of maximal grip, and the regression coefficient at the pre-inflection phase, because they evaluate a different phase according to the measurement time. However, it is considered that at 3 min these parameters can evaluate the property of the decreasing phase for 6 min, because there were significantly fair correlations between 3 min and 6 min.

The decreasing force for each individual showed two decreasing phases, namely a remarkable decrease of force and an almost steady state, as seen in Figs. 1-2 and 1-3. However, most subjects only showed a remarkable decrease of force at a 1 min measurement time, as seen in Fig. 1-1. The statistical calculation method of the inflection point, proposed by Yamaji et al. (2000), can be used if the decreasing force does not show two decreasing phases. To compare the decreasing force-time curve in Fig. 1-3, the decreasing force during a 1 min measurement time showed only a remarkable decreasing phase of gripping force, and it is judged that the inflection time at 1 min cannot evaluate the inflection point from a remarkable decrease of force exertion to an almost steady state. Royce (1958) compared force-time curves during SSHG with and without occlusion of arterial blood flow, reporting that the decrease in the grip force was greater at 60% of maximal grip strength with occlusion. This suggests that the decreasing force-time curve for a maximal contraction depends on blood flow or muscle oxygen kinetics at the phase below 60% of maximal strength rather than during the initial phase. Yamaji et al. (2000) suggested that both phases, which show a remarkable decrease of force exertion and an almost steady state, depend on respectively different physiological factors. Therefore, it is considered that muscle endurance should be evaluated from both phases. It is suggested that a 1-min measurement time is not enough as a muscle endurance test, because the inflection point of the decreasing grip force cannot divide the force-time curve into the above-stated phases during 1-min of measurement time.

From the relationship among the parameters at each measurement time, it is considered that the time required to decrease to 60, 70, and 80% of maximal grip, the average integrated area, the 1 min decreasing force, and the maximal difference from the linear line may evaluate the same decreasing phase during SSHG at each measurement time (see Tables 3, 4, 5). It was suggested that these parameters might combined into fewer parameters.

A fair relationship among the parameters at 3 min was also found at 1 min and 6 min. On the other hand, there was a different tendency for the relationship among the parameters at 1 min and 6 min. It was considered that the measurement time of 3 min showed the properties of both the 1 min and 6 min measurement times, however, the 1 min and 6 min showed independent properties.

In summary, this study aimed to establish a test for muscle endurance using hand gripping, and to examine the measurement times, which is the most important factor in evaluating muscle endurance. It is suggested that at 6 min, the subjects unconsciously restrained maximal gripping because of the influence of psychological factors such as the pain associated with force exertion became greater. It is considered that at 1 min, the decreasing force showed only a remarkable decreasing phase, and cannot evaluate the phase of an almost steady state, which depends on different physiological factors.

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Correspondence to: Shunsuke Yamaji, Fukui National College of Technology, Geshi, Sabae, Fukui 916-8507, Japan
e-mail: yamaji@fukui-nct.ac.jp