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# Methods for Measuring Maximal Isometric Grip Strength during Short and Sustained Contractions, Including Intra-rater Reliability

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## ABSTRACT

The purposes of this study were to develop methods for measuring maximal isometric grip strength during short and sustained contractions in a laboratory setting, and to evaluate the test-retest reliability of these methods in short- and long-term perspectives. Eleven healthy men and women were assessed on four occasions. Maximal voluntary isometric grip strength (MVC) was measured in standardized and optional positions, and sustained maximal isometric strength (SMVC) in the standardized position. The results indicated that three trials in a session might be insufficient to obtain a true measure of MVC. The within-session and test-retest reliability of the described multi-trial procedure was considered satisfactory. The mean score of the last three trials tended to show the highest short-term and long-term variability. There were no clear differences between scores obtained in standardized and optional positions. The standardized position seemed more consistently to yield higher test-retest reliability and lower variability over time. The described method for measuring SMVC, expressed as area and peak score, had high test-retest reliability and an acceptable degree of short-term and long-term variability. The time taken to reach the peak score was not a reliable measure.

## INTRODUCTION

In the care of patients with disorders of the hand, grip strength scores are often used as an outcome measure. A number of studies have been published concerning the reliability of methods for measuring grip strength. Based on these results, standardized measurement procedures and the use of instruments with high accuracy have been recommended (6, 10). On the other hand, Spijkerman et al (17) compared four measurement protocols with various degrees of standardization of the arm position. They found that the reliability of measurements made when the subject was free to assume a

comfortable arm position, with standardized positions of the trunk and lower extremities, did not differ from that under other, standardized, arm conditions. No comparisons of the reliability of grip strength measurements between standardized and optional trunk and arm positions, all other conditions being the same, have been reported.

The most commonly reported measure is maximal voluntary isometric grip strength (MVC) at a certain, often not defined, moment during a short contraction (12). Agreement has not yet been reached as to the number of successive trials needed to reach a reliable measure of MVC. In some studies it was found that among various methods of determining the MVC in a session, the most reliable one was the mean of three successive trials (7, 11, 19). The magnitude of these three values was not discussed. In order to obtain the truest possible value for MVC in one session, the last trial should probably not be the highest.

The ability of the grip muscles to maintain their contraction is presumably more important than the MVC in performing activities of daily living. Measurements of sustained MVC of the grip (SMVC) might add useful information about hand function (12, 15).

In a study on the functional outcome after Colles' fracture (8) grip strength measurements were performed 1 1/2 years after the injury (unpublished data). Procedures for measurements of MVC and SMVC of the knee muscles in a laboratory setting had previously been standardized and evaluated by Nordesjö and Nordgren (13), Nordesjö et al (14), and Wigren et al (20). With these methods as a basis, the present study was undertaken 1) to develop methods for measuring maximal isometric grip strength during short and sustained contractions, and 2) to evaluate the intra-rater reliability of these methods in short- and long-term perspectives.

## MATERIAL AND METHODS

**Material.** The study comprised 11 volunteers, six women and five men, with a mean age of 37 years (range 24 - 62). Their mean height was 176.0 ±9.1 cm, and weight 70.5 ±9.3 kg. According to self-reports, all but one woman and one man had right-hand dominance. All subjects were healthy without signs of disease or injury. They were asked not to change their level of physical activity during the testing period.

**Equipment.** Isometric grip strength was measured in a laboratory setting with pressure transducers (Pressductor ®, ASEA Inc., Sweden), previously described by Bäcklund and Nordgren (4). The grip handle had a circumference of 125 mm. The range of measurement was 0 to 300 kp

(1 kp = 9.81 N). The reproducibility error was less than 0.1% of the full scale deflection (4). The device was calibrated mechanically, with standard weights, before, during and after the testing period. Strength scores were registered by a recorder (Multicorder, type MC611, Watanabe Instruments Corp., Tokyo, Japan).

**Procedure.** A test-retest design was used. One of the authors (C.L.) performed all measurements. MVC was measured in both standardized and optional positions, and SMVC in a standardized position. For MVC, each subject underwent a minimum of 12 trials (right and left hand, standardized and optional positions; three trials for each). Each three trials comprised one session, making a total of four sessions on each occasion. SMVC was only measured once bilaterally, and for this measurement there were therefore only one trial per session. These 6 sessions were carried out on two consecutive days, and 1 and 4 weeks thereafter. Measurements were made between 9:00 AM and 4:30 PM. Grip versus time curves were recorded. MVC was defined as the maximal plateau values of the curves during 2 of the 5 seconds of contraction. SMVC was the maximal contraction, continuously exerted for 60 seconds. The subjects were seated upright in an adjustable chair with their feet supported. They were in front of the handle, which was movable horizontally and vertically. In the standardized position, the subjects leaned against the back of the chair. The positions of the trunk, the shoulder and the forearm joints were as recommended by the American Society of Hand Therapists (6). Self-selected wrist extension and ulnar deviation were permissible during a trial (16). The palm, the fingers, and the web of the thumb were completely clasped around the handle. In the optional position, the subjects were free to assume any trunk and arm position they wished. During all measurements, the hand not being measured rested on the subject's thigh. Instructions and verbal encouragement during the MVC trials were standardized in most respects as described by Mathiowetz et al (11). During the SMVC tests the subjects were told to squeeze the handle in the same way as before, but for a longer time, and to keep squeezing until told to stop. The encouragements, given throughout the trial, were standardized as for the MVC trials.

MVC was always measured first, starting in a standardized or an optional position in a random order. After a trial with submaximal effort, three successive trials were performed. The intervals between the trials were determined by the feeling of readiness of the subject for another maximal contraction. If the third trial showed the highest score, more trials were performed, until the latest score obtained was equal to (± 0.5 kp) or lower than one of the two preceding scores. The last three successive trials were

used to represent MVC. SMVC was tested next. There was an interval of at least 3 minutes between the two SMVC trials.

**Statistical analysis.** Paired, two-tailed t-tests were performed to disclose any systematic difference between sessions. Analysis of variance (One Factor ANOVA for repeated measures), and intra-class correlation coefficients (ICC) were used to assess the test-retest reliability of average ratings (2, 21). The intra-individual standard deviation (s) was calculated as: $s = \sqrt{(\sum d_i^2/2)/n}$, where d is the difference between the compared measurements for each individual. The coefficient of reproducibility ($C_R$=1.96 x $\sqrt{2}$ x s) was calculated to determine the limit below which the absolute value of the difference between two measurement occasions was expected to lie with a 95% probability. This coefficient has the same unit of measure as the observed variables. The coefficient of variation ($C_V$; %) was computed to express the variation between the scores of two occasions in relation to the size of the observations. The Pearson product-moment correlation coefficient (r) was used to evaluate relations between the magnitude of paired observations and the size of their difference (1, 3). Differences were considered significant if the p value was <0.05.

## RESULTS

**Within-session reliability of MVC.** The last three successive scores, of which the third one should not be the highest, were chosen for analyses of the reliability of the MVC measurements. In 20 measurement sessions out of 176 (11%) there were 4 or 5 trials, 15 with 4 trials and 5 with 5 trials. The maximal scores of the last three trials of these sessions were significantly higher than those calculated from the first three trials (p = 0.03). The average within-trial MVCs are shown in Table 1. The inter-trial rest periods were ≥8.8 s.

Table 1. Average within-session MVCs (kp), measured in standardized (std) and optional (opt) positions (Pos) on four occasions. Dominant (D) and non-dominant (ND) hands (Hd). n = 11.

| Hd | Pos | Trial 1 | | | Trial 2 | | | Trial 3 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Range | Mean | SD | Range | Mean | SD | Range |
| D | std | 39.6 | 14.8 | 17.5-74.0 | 38.5 | 13.8 | 16.5-65.0 | 36.5 | 13.5 | 18.0-64.0 |
| D | opt | 40.7 | 14.2 | 18.0-73.0 | 39.5 | 14.1 | 18.5-75.0 | 36.4 | 12.1 | 18.0-68.0 |
| ND | std | 39.6 | 14.2 | 17.5-67.5 | 38.1 | 13.3 | 16.5-62.0 | 36.3 | 13.0 | 16.0-63.5 |
| ND | opt | 38.7 | 12.9 | 18.5-65.0 | 38.1 | 12.4 | 16.5-67.0 | 35.0 | 10.9 | 16.0-55.0 |

The average within-session scores decreased successively. Analyses of variance showed significant differences between trials in both standardized

and optional positions, mostly for the non-dominant hand (p=0.03-0.0003). Post hoc analysis revealed that the differences between the first and second trials were significant for the dominant hand in the standardized position on the third occasion, and for the non-dominant hand in both positions on the second occasion. The mean differences lay between 5.7 and 8.4% (2.23-3.36 kp). ICCs ranged from 0.97 to 0.99 in the standardized position, and from 0.92 to 0.98 in the optional position. The within-session correlation coefficients were all significant (r=0.91-0.99, and 0.77-0.99 for the two positions, respectively; $p<0.01$). The magnitude of the three scores of each session are shown in Table 2.

Table 2. Comparison of the magnitude of the three scores of each session, given as absolute numbers, relative frequencies, and number of significant positive differences. n=176 sessions.

| Scores | Absolute numbers | Relative frequencies (%) | No. of significant positive differences between scores |
|---|---|---|---|
| 1st $\geq$ 2nd | 119 | 68 | 3 |
| 2nd $\geq$ 3rd | 147 | 84 | 5 |
| 1st $\geq$ 3rd | 147 | 84 | 12 |

The highest score occurred in the first trial in 57.4% of the sessions, and in the second trial in 28.4%. The third score was equal to or higher than the first or second score in 30% of the comparisons (ratio 53:176).

There were no significant differences between the scores of the three trials obtained in different positions on any occasion (paired t-test: $p\geq0.05$). There was one significant difference between hands regarding the first-trial scores in the optional position on the first measurement occasion (p=0.003).

**Intra-rater reliability of the MVC.** In each session MVC was determined as the score of the first trial, as the highest score of the three trials, and as the mean score of the first two, of the two highest, and of all three trials. The average results in standardized and optional positions on all four occasions are presented in Table 3. The average scores decreased from the second occasion onwards. The dominant hand was usually the strongest. The differences in MVC between hands ranged between 7.7 and 11.1%, and were not significant, except in the optional position on the first occasion (paired t-test: p=0.01-0.02). There were no significant differences in strength between the five methods of determining MVC on any occasion, either in the standardized or optional position.

To assess the most reliable method of determining MVC, the test-retest scores were analysed with respect to hand dominance and position. ANOVA

Table 3. Average scores (kp) for five methods of determining MVC, measured in the standardized (std) and optional (opt) positions (Pos) on four occasions (Occ). n = 11.

| | | | First score | | Highest score of three | | Mean of first and second scores | | Mean of two highest scores | | Mean of three scores | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Occ | Hand | Pos | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | D | std | 40.9 | 16.9 | 43.7 | 17.0 | 40.8 | 15.5 | 41.5 | 15.8 | 39.8 | 15.4 |
| 2 | D | std | 38.0 | 14.0 | 39.9 | 14.9 | 38.1 | 14.4 | 38.7 | 14.6 | 37.3 | 14.2 |
| 3 | D | std | 39.9 | 15.2 | 40.9 | 14.7 | 38.2 | 14.0 | 38.8 | 14.0 | 37.2 | 13.4 |
| 4 | D | std | 39.7 | 15.1 | 40.8 | 14.8 | 39.2 | 14.2 | 39.6 | 14.2 | 38.6 | 14.0 |
| 1 | D | opt | 41.9 | 16.6 | 43.9 | 17.3 | 42.0 | 16.7 | 42.5 | 17.2 | 40.5 | 16.2 |
| 2 | D | opt | 40.7 | 15.0 | 41.7 | 14.8 | 39.4 | 14.2 | 39.9 | 14.3 | 37.8 | 13.3 |
| 3 | D | opt | 40.5 | 12.3 | 42.3 | 13.6 | 39.3 | 11.4 | 39.6 | 11.3 | 38.0 | 10.6 |
| 4 | D | opt | 39.7 | 14.7 | 42.3 | 14.4 | 39.9 | 14.4 | 41.3 | 14.3 | 39.2 | 13.5 |
| 1 | ND | std | 40.9 | 16.1 | 42.1 | 16.3 | 40.5 | 15.4 | 40.8 | 15.7 | 39.6 | 15.3 |
| 2 | ND | std | 38.9 | 14.8 | 39.3 | 14.7 | 37.8 | 14.1 | 38.0 | 14.1 | 36.9 | 13.7 |
| 3 | ND | std | 38.7 | 13.0 | 39.9 | 12.9 | 37.8 | 12.1 | 38.3 | 11.9 | 36.9 | 11.7 |
| 4 | ND | std | 40.0 | 15.0 | 40.9 | 15.2 | 39.5 | 14.5 | 39.7 | 14.6 | 38.8 | 14.3 |
| 1 | ND | opt | 37.2 | 13.7 | 41.5 | 14.4 | 38.6 | 13.8 | 39.1 | 13.9 | 37.4 | 13.3 |
| 2 | ND | opt | 39.0 | 12.6 | 39.0 | 12.6 | 37.9 | 12.6 | 38.2 | 12.7 | 36.9 | 12.3 |
| 3 | ND | opt | 38.6 | 13.1 | 39.9 | 12.9 | 38.3 | 12.6 | 38.4 | 12.6 | 36.6 | 11.3 |
| 4 | ND | opt | 40.1 | 14.0 | 41.0 | 13.6 | 38.8 | 12.6 | 39.6 | 12.7 | 38.2 | 12.0 |

for repeated measures showed no significant differences in any respect (p=0.05-0.93). The differences between occasions ranged from 2.3 to 8.8 %. They were independent of the method used for determining MVC. The ICCs for the dominant or non-dominant hand, and standardized or optional position, were between 0.97 and 0.99, except for the dominant hand in an optional position, for which ICC was 0.95. The correlation coefficients (r) varied between 0.63 and 0.99, but were mostly $\geq$0.90 ($p<0.05$).

It is of interest to study the variability of MVC scores over various lengths of time. Table 4 presents $C_R$ and $C_V$ in standardized and optional positions, for a comparison of the scores from the first measurement occasion with those from the second and fourth occasions. The intervals were 24-28 hours and 4 weeks respectively.

Table 4. Coefficients of reproducibility ($C_R$; kp) and of variation ($C_V$; %) for comparisons of MVC scores on the first measurement occasion with those of the second and fourth occasions. Standardized and optional positions. n = 11.

| | | Occasion 1 - 2 (interval = 24-28 hours) | | | | Occasion 1 - 4 (interval = 4 weeks) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Standardized position | | Optional position | | Standardized position | | Optional position | |
| MVC | | D | ND | D | ND | D | ND | D | ND |
| 1st score | | | | | | | | | |
| | $C_R$ | 14.98 | 10.33 | 13.16 | 9.36 | 11.68 | 11.30 | 18.00 | 13.43 |
| | $C_V$ | 13.69 | 9.35 | 11.50 | 8.86 | 10.45 | 10.08 | 15.91 | 12.53 |
| Highest score | | | | | | | | | |
| | $C_R$ | 10.37 | 12.46 | 10.19 | 7.51 | 10.46 | 11.20 | 12.88 | 9.66 |
| | $C_V$ | 8.96 | 11.05 | 8.59 | 6.73 | 8.94 | 9.73 | 10.78 | 8.46 |
| Mean of 1st + 2nd scores | | | | | | | | | |
| | $C_R$ | 9.35 | 11.74 | 10.42 | 5.31 | 8.20 | 10.53 | 13.17 | 10.37 |
| | $C_V$ | 8.62 | 10.83 | 9.24 | 5.01 | 7.40 | 9.50 | 11.61 | 9.66 |
| Mean of 2 highest scores | | | | | | | | | |
| | $C_R$ | 7.72 | 11.76 | 10.77 | 5.31 | 8.15 | 10.23 | 13.29 | 9.53 |
| | $C_V$ | 6.95 | 10.78 | 9.44 | 4.96 | 7.25 | 9.51 | 11.44 | 8.73 |
| Mean of 3 scores | | | | | | | | | |
| | $C_R$ | 7.10 | 11.36 | 10.69 | 5.06 | 7.32 | 9.57 | 11.12 | 9.90 |
| | $C_V$ | 6.64 | 10.72 | 9.85 | 4.92 | 6.74 | 8.82 | 10.06 | 9.46 |

D Dominant hand
ND Non-dominant hand

$C_R$ and $C_V$ were similar for all methods of determining MVC, except for use of the score of the first trial, which mostly yielded the highest coefficients. The mean of three trials mostly yielded lower coefficients than all other ways of determining MVC. $C_R$ and $C_V$ for the dominant hand were often lower for measurements performed in the standardized position, especially when the scores obtained at a 4-week interval were compared. The coefficients for the dominant hand were often lower than those for the non-dominant hand in this position. In the optional position, all coefficients for the non-dominant hand were lower than those for the dominant hand.

**Intra-rater reliability of SMVC.** The area below the grip versus time curve, expressed in kilopondseconds (kps), the highest value (peak score) obtained during the contraction (kp), and the time taken to reach the peak score (s), calculated from the origo of the grip versus time curve, were chosen to represent SMVC (Table 5).

Table 5. Area below the grip versus time curve (kps), peak score (kp), and time taken to reach the peak score (s) on four occasions (Occ). n = 11.

| | Dominant hand | | | | | |
|---|---|---|---|---|---|---|
| | Area (kps) | | Peak score (kp) | | Time to peak score (s) | |
| Occ | Mean | SD | Mean | SD | Mean | SD |
| 1 | 1580.2 | 526.5 | 39.32 | 11.96 | 5.13 | 4.25 |
| 2 | 1663.2 | 598.0 | 37.14 | 12.80 | 7.00 | 6.81 |
| 3 | 1605.4 | 632.2 | 37.46 | 11.34 | 6.75 | 7.49 |
| 4 | 1743.4 | 578.0 | 39.96 | 13.02 | 6.35 | 7.28 |
| | Non-dominant hand | | | | | |
| Occ | Area (kps) | | Peak score (kp) | | Time to peak score (s) | |
| | Mean | SD | Mean | SD | Mean | SD |
| 1 | 1503.0 | 682.2 | 37.73 | 12.75 | 3.40 | 1.85 |
| 2 | 1454.6 | 578.0 | 36.96 | 11.97 | 3.73 | 2.06 |
| 3 | 1483.9 | 606.5 | 38.18 | 15.23 | 5.60 | 6.34 |
| 4 | 1671.0 [a] | 620.2 | 41.14 | 14.28 | 4.89 | 6.67 |

[a] n = 10. One subject did not complete the test.

When comparing the dominant and non-dominant hands regarding the three parameters in Table 5 (paired t-test), no significant differences were

found except for the areas on the second (p=0.002) and fourth measurement occasions (p=0.03). The differences were 12.5 and 9.9% respectively. The areas and peak scores correlated significantly between the dominant and the non-dominant hand (r= 0.84-0.97; p<0.001). The time taken to reach the peak score correlated significantly only on the third measurement occasion (r=0.97; p<0.001). On this occasion, one subject took an extremely long time to reach the peak scores bilaterally (28.4 and 23.8 s respectively). Some subjects complained of discomfort during the later phase of the SMVC measurement.

Concerning the test-retest reliability, analysis of variance for area, peak score, and time taken to reach the peak showed no overall significant differences between occasions (p=0.11-0.89). The ICCs for the area and peak score lay between 0.96 and 0.98, and for the time taken to reach the peaks they ranged from 0.50 to 0.53. The correlation coefficients were significant for areas and peak scores (r=0.83-0.99; p<0.001), and not significant for the time taken to reach the peak score (r= -0.35-0.46; p>0.05). In nine sessions, distributed among four subjects, the strength during the first 10 seconds of the contraction showed a steep slope, followed by a usually low (1-13 kps) and slow rise.

When the scores of the first measurement occasion were compared with those of the second and fourth occasions, $C_R$ and $C_V$ for area and peak score were found to be low both for the dominant and non-dominant hands (Table 6).

Table 6. Coefficients of reproducibility (kps, kp) and of variation (%) for comparisons of areas and peak scores on the first measurement occasion with those of the second and fourth occasions (Occ). n = 11.

| | Coefficients of reproducibility | | | | Coefficients of variation | | | |
|---|---|---|---|---|---|---|---|---|
| | Area (kps) | | Peak score (kp) | | Area (%) | | Peak score (%) | |
| Occ | D | ND | D | ND | D | ND | D | ND |
| 1-2 | 353.4 | 365.5 | 8.0 | 4.5 | 7.9 | 8.9 | 7.5 | 4.3 |
| 1-4 | 601.3 | 552.7 [a] | 13.9 | 12.0 | 13.1 | 12.3 | 12.6 | 11.0 |

a) n = 10; one subject did not complete the test.

The coefficients for the time taken to reach the peak score were high, and of varying magnitude ($C_R$: 3.9-15.9 s; $C_V$: 39.3-124.9%). All coefficients were lower for short-term than for long-term comparisons.

## DISCUSSION

**Within-session reliability.** The results show that most individuals reach their MVC in a session of three trials, but that some individuals need four or five. This knowledge is of critical importance to all health professionals assessing grip strength. The results are not in agreement with those of Crosby et al (5), who found that repeat testing was unnecessary, and possibly even confusing, since half of their subjects had lower maximum grip strength in the second trial, which was the last one. Contradicting the results of Hamilton et al (7), but in agreement with Mathiowetz (9), and Trossman et al (19), the studied multi-trial procedure showed high within-session reliability. The variation did not tend to change with the magnitude of the measurements. As a rule there were no significant differences between the scores of the first and second, or second and third scores, indicating that there were no learning, practising or motivational factors influencing the reliability. On the other hand, the finding that the average scores of the three trials decreased successively, and that there were several significant differences between the first and third scores, might indicate an effect of fatigue. The relatively short resting periods between trials might be a factor of importance (18). The within-session scores for the non-dominant hand were more inconsistent than those for the dominant hand, possibly due to a lack of practice in exerting MVC with the non-dominant hand in activities of daily life. The within-session reliability was somewhat higher in the standardized position than in the optional position.

**Intra-rater reliability.** There was no difference in strength between the hands, positions or occasions. Spijkerman et al (17) considered that subjects unconsciously tend to standardize their optional position, probably because a freely chosen position is a comfortable one. O´Driscoll et al (16) reported that in grip strength measurements the self-selected position of the wrist was consistent, highly reproducible, and optimal for grip strength. It was not influenced by a fatigue effect after testing in multiple other positions.

The test-retest reliability was dependent on the method of determining MVC. The ICCs were very high with all methods, and the mean of three trials had the highest reliability, which was in agreement with reports by Mathiowetz et al (11), Trossman et al (19), and Hamilton et al (7). The lowest ICCs were obtained with use of the first score of three, supporting the need for more than one trial in each measuring session. However, in agreement with Hamilton et al (7), the differences in reliability between the five scoring methods were small.

The test-retest reliability of measurements of area and peak scores was high (ICCs $\geq$0.96). The time taken to reach the peak score showed poor reliability (ICC $\leq$0.53). In some subjects a gently ascending slope in the beginning of the SMVC measurement resulted in high means and standard deviations, especially on the third and fourth occasions (Table 5). This probably contributed to the very low intra-rater reliability of these measurements.

According to Åstrand and Rodahl (23), the day-to-day variation in any test of muscular strength is usually in the order of some ±10%. In the present study, CVs $\leq$10% for MVC, and $\leq$15% for SMVC between occasions were considered acceptable. The long-term and short-term variability of the MVC, was found fairly satisfactory, with the exception of using the first trial. The variability showed a tendency to increase with increasing interval between occasions for the scores obtained in the optional position (Table 4). The over-all variability of MVC was higher than found by Trossman et al (19). The coefficients for area and peak scores were all satisfactory, and consistently showed higher variability with increasing interval between measurements (Table 6). A plausible explanation for this is that a longer interval between measurements leaves more opportunities for influences of confounding variables, e.g., biological and temporal factors.

Perceived discomfort during the later phase of the SMVC measurements may have influenced the results. The effect of the duration of the SMVC, as well as of longer and standardized rest periods between the trials in the MVC measurements, on reliability, needs further investigation.

In order to scrutinize this measurement method, subjects of varying age, muscle strength and physical activity were included in the study. Despite this, the grip strength measurements were fairly stable over time. As is feasible in clinical work, measurements were performed at times of the day convenient for all involved. According to Young et al (22) the time of measurement does not appear to affect grip strength.

**Conclusions.** This study showed that three trials in a session might be insufficient to obtain a measure of MVC. The within-session and test-retest reliability of the described multi-trial procedure were considered satisfactory. The mean score of the last three trials tended to show the lowest degree of short-term and long-term variability. Differences between scores obtained in standardized and optional positions were not clear-cut. A standardized position seemed more consistently to yield higher test-retest reliability, and lower variability over time. The described method for measuring SMVC, expressed as area and peak score, had a high test-retest

reliability, and an acceptable degree of short-term and long-term variability. The time taken to reach the peak was not a reliable measure.

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