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ON THE RELIABILITY AND USEFULNESS OF METHODS FOR GRIP STRENGTH MEASUREMENT

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ABSTRACT. The purposes of this investigation were to assess the accuracy of a grip strength measuring instrument, the Grippit®, to modify previously developed methods for measuring maximal isometric grip strength (12) and to evaluate the reliability of these methods, with the use of the Grippit®. Grip strength during short (maximal voluntary isometric strength, MVC) and sustained (SMVC) contractions was measured. The modifications concerned the definitions of MVC and SMVC, the measuring position, the intervals between trials and sessions, and the recording procedure. The intra-observer reliability study comprised 29 healthy subjects, and the inter-observer study 10 other healthy subjects. The Grippit® had very high precision. The intra-observer reliabilities of MVC and SMVC measurements were improved compared to those with the previous methods (12). The inter-observer reliability was very high.

Key words: isometric grip strength, measurement method, reliability.

INTRODUCTION

Grip strength measurement is an important component in the clinical evaluation of the hand. The most commonly reported measure is the maximal voluntary isometric strength (maximal voluntary contraction, MVC) at a certain, often not defined, moment during a short contraction. The ability of the grip muscles to maintain their contraction is presumably more important in performing activities of daily living. Objective measurements of sustained MVC of the grip (SMVC) might add useful information about hand function (12, 15, 17, 20). We have previously used standardized methods for measuring MVC and SMVC of the knee muscles (18, 19, 23) when developing methods for measuring isometric strength of the grip muscles in a laboratory setting (12). We found that three trials in a session could be insufficient to obtain a true measure of MVC. The within-session and test-retest reliability of the multitrial procedure which we developed was satisfactory. In agreement with Mathiowetz (13), Trossman et al. (22) and Hamilton et al. (9), the mean value of three trials tended to show higher intra-observer reliability and a lower degree of short-term and long-term variability than the first value, the highest value or the mean of the two highest values. We found (12) that MVC measurements performed in the standardized measurement position recommended by the American Society of Hand Therapists (ASHT) (8) seemed more consistently to yield higher test–retest reliability and lower variability over time, compared with those in an optional position. Our method for measuring SMVC, expressed as area and as the highest value (peak value) obtained during a sustained contraction of 60 s, showed high test–retest reliability and an acceptable degree of short-term and long-term variability. The time taken to reach the peak value was found not to be a reliable measure (12).

The standard Jamar® dynamometer (J. A. Preston Corporation, Jackson, MI, USA) has been recommended as an accurate instrument for measuring MVC in clinical practice and in research (8, 10). However, this instrument makes considerable demands upon the wrist and elbow muscles when testing is performed in the standardized position recommended by the ASHT (8). This may limit the possibility of performing reliable measurements in patients with disorders affecting the capacity for maintaining the wrist and elbow joints in a stable position. The standard Jamar® dynamometer registers the maximal momentary strength, but provides no grip versus time curves of MVC or SMVC. The

Grippit® (AB Detector, Göteborg, Sweden), an instrument for measuring grip strength described by Nordenskiöld (16), and Nordenskiöld & Grimby (17), can minimize these disadvantages.

The methods which we developed previously (12) were used in a longitudinal study on functional results after Colles' fracture (11) for assessment of isometric grip strength during short and sustained contractions one and a half years after the fracture.

The purposes of the present investigation were (i) to assess the accuracy of the Grippit® instrument, (ii) to modify previously developed methods for measuring maximal isometric grip strength during short (MVC) and sustained contractions (SMVC) and (iii) to evaluate the intra-observer and inter-observer reliability of these modified methods, all with the use of the Grippit®.

MATERIALS AND METHODS

Instrument

The Grippit® (16, 17) is a portable instrument designed for measuring maximal isometric grip strength. In brief, it consists of an elliptical handle with electronic force transducers based on strain gauges, and a base on which an arm guide is mounted. The strength is automatically recorded every half-second. The grip handle used in this investigation measured 125 mm in circumference. The range of measurement was 0 to 510 Newton (N), with a resolution of 2 N. The electronic unit was interfaced with a personal computer (model LCD 286). A computer program which recorded numerically and graphically the strength exerted for set periods of time was constructed. Thus, grip versus time curves could be visualized. Examples of print-outs are shown in Fig. 1.

The instrument was calibrated mechanically through the measuring range in 50- to 100-N increments before and after the testing period. The force transducers of the Grippit® and a calibrated force transducer were squeezed together between the jaws of a mechanical vice. The squeezing forces were varied and the real and the displayed force values registered.

Designs and subjects

To evaluate intra- and inter-observer reliabilities two different designs were applied. The *intra-observer* study had a test–retest design and comprised 29 subjects (25 women and 4 men). The subjects performed grip strength tests twice, under the supervision of one of the authors (C.L.), with an interval of 4 weeks. The mean age (± standard deviation) was 49 ± 8.9 years, range 28–71. The women's height was 163.5 ± 5.1 cm and the men's 178.0 ± 6.6 cm; their weights were 61.5 ± 13.6 and 85.0 ± 9.1 kg, respectively. One woman and one man reported left-hand dominance.

The *inter-observer* study comprised 10 other subjects (9 women and 1 man). Two observers (one of whom was C.L.) supervised the measurements alternately, starting in randomized order, with an interval between observers of at least one and a half hours. The procedure was repeated one week later, the other observer now starting the measurements. Both observers were methodologically experienced physical therapists. The mean age of the subjects was 37 ± 11.4 years (range 21–51). The women's height was 167.9 ± 5.8 cm and the man's 176.0 cm, and their weights were 60.6 ± 6.0 and 74.0 kg, respectively. One woman reported left-hand dominance. The one male subject exceeded the upper limit of the measuring range in two sessions of MVC measurements. Because of headache, one woman did not complete the SMVC measurements.

All subjects included were volunteers with no signs of disease or injury. None of them reported heavy work loads or regular participation in heavy sports activities at a high level of performance. They were asked not to change their level of physical activity during the testing periods. The

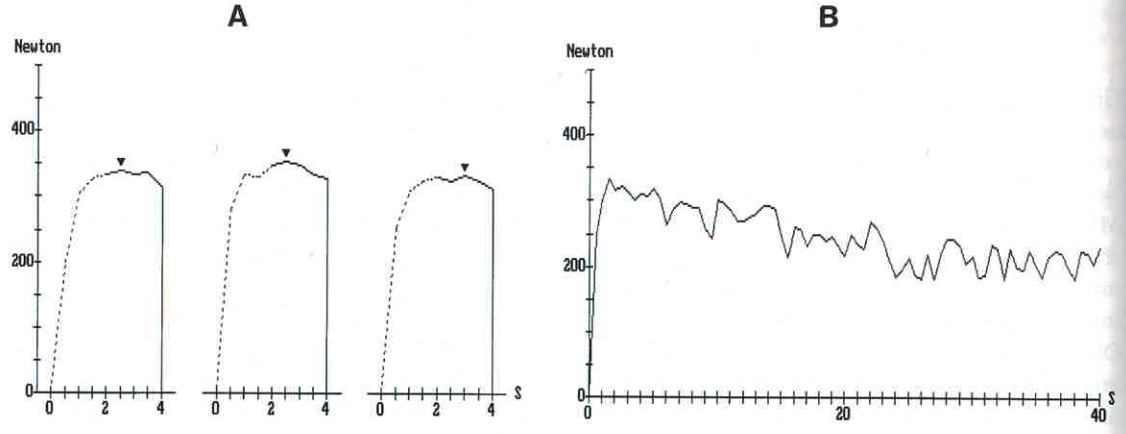

Fig. 1. Print-outs of typical grip versus time curves from a healthy subject, measured with the Grippit®. (A) Maximal isometric contraction, exerted for 4 s. (B) Maximal isometric contraction, sustained for 40 s.

Table I. *Intra-observer study. Within-session MVC values (N) recorded on two occasions with an interval of 4 weeks (n = 29)*

Occ, occasion; D, dominant; ND, non-dominant.

		Trial 1			Trial 2			Trial 3		
Occ	Hand	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
I	D	307.2	72.8	150–448	310.5	78.8	158–492	298.5	75.7	166–458
II	D	302.8	80.7	136–458	298.0	83.0	126–468	291.9	81.9	128–454
I	ND	277.7	61.2	178–412	285.7	59.4	180–418	265.5	56.6	178–394
II	ND	278.3	65.8	168–440	271.7	65.8	146–444	262.2	65.8	142–410

same instrument and the same measurement procedure were used in both the studies.

Measurement procedure

The Grippit® was placed on a table. The subjects were seated in front of the instrument, upright in an adjustable chair with their feet supported. They were close to the table, the lowest rib levelling with the edge of the table. The forearm was placed in the arm support. Hence the shoulder joint was positioned in 10–15° and the elbow joint in 75–85° of flexion (2). In all other respects, the positions of the joints of the upper and lower extremities and of the trunk were standardized as described in our earlier report (8, 12). The grip handle mounted on the fixed base and the use of the forearm guide ensured that the wrist and hand were placed in a position that was minimally affected by gravity. Instructions and verbal encouragements were standardized as described previously (12).

All measurements were performed bilaterally. On the first measuring occasion, a coin was tossed to decide which hand should be tested first. After instructions and a trial with submaximal effort, the multi-trial procedure of measuring MVC (12), continuously exerted for 4 s, was carried out. The last three trials were used for analysis of the MVC. Three trials for each hand comprised one session, making a total of two sessions of MVC measurements on each occasion. For SMVC, there was only one trial for each hand on each occasion. In our earlier study (12) some subjects complained of discomfort during the later phase of the SMVC measurement lasting 60 s. Evaluation of those grip versus time curves showed that most subjects had reached their peak value and a plateau of the subsequent decrease of strength within 30s. In this investigation, therefore, SMVC was measured as the maximal contraction continuously exerted for 40 s.

Trossman & Li (21) concluded that when testing MVC the same rest intervals between trials should be used on subsequent re-evaluations. The non-standardized, rather short rest periods between trials in the MVC measurements previously reported by us (12) may have influenced the reliability and variability. For this reason the minimum durations of all rest periods were standardized in the present investigation. The intervals between MVC trials were $\geq$30 s, and between tests of MVC and SMVC and between two SMVC sessions they were $\geq$2 min. After each session, the subjects were asked to report any pain or discomfort in connection with the measurement. In order to reduce errors due to fatigue or practice, the sequence of the measurements was identical in all sessions. All tests were performed at approximately the same time of the day on the different occasions in each subject.

Statistical analysis

Comparisons of mean differences, using paired *t*-tests, were made in order to disclose any systematic differences between occasions or observers. Analyses of variance (one factor ANOVA for repeated measures) were performed and intra-class correlation coefficients (ICC) were calculated to assess within-session reliability (3, 24). The intra-individual standard deviation(s) was calculated as: $s = \sqrt{(\Sigma d_i^{-2}/2)/n}$, where d is the difference between the compared measurements for each individual. From this, coefficients of repeatability, referring to the short-term time-dependent within-session variations, and of reproducibility, referring to the long-term variations between occasions or observers, were computed (C_R for both = $1.96 \times \sqrt{2} \times s$). These coefficients give the limit below which the absolute value of the difference between two test results is expected to lie with a 95% probability level. They have the same unit of measure as the observed variables. Coefficients of variation (C_V; %) were computed to express the variation between the values of two occasions or of two observers in relation to the magnitude of the observed values. The Pearson product-moment correlation coefficient (r) was used to determine whether the variation showed any tendency to change with the magnitude of the measurements (1, 4, 5). Differences were considered significant if the p value was <0.05.

RESULTS

Accuracy of the instrument

On calibration, the Grippit® showed fully acceptable deviation accuracy (range: −2 to +2 N) between pre- and post-measurement period calibration. The correlation coefficients between the applied standard forces and the measurement values indicated by the Grippit® were both $r = 0.9999$. The average amount of discrepancy was 1.5 N for the lower half of the measuring range before measurements, and 2 N for the upper half of the measuring range after measurements.

Table II. *Intra-observer study. Coefficients of repeatability (C_R) and of variation (C_V) of the within-session MVC values on two measurement occasions with an interval of 4 weeks (n = 29)*

Occ, occasions; D, dominant; ND, non-dominant.

	C_R (N)		C_V (%)	
Hand	1st occ	2nd occ	1st occ	2nd occ
D	45.9	48.4	5.4	7.9
ND	51.1	41.9	9.0	7.5

Table III. *Intra-observer study. MVC values (N), measured by the same observer on two occasions with an interval of 4 weeks, and calculated by three methods (n = 29)*

Occ, occasion; D, dominant; ND, non-dominant.

		Mean of three values		Mean of two highest values		Highest value	
Occ	Hand	Mean	SD	Mean	SD	Mean	SD
I	D	305.4	74.7	311.7	75.0	318.3	75.8
II	D	297.6	80.7	303.2	80.6	311.5	81.4
I	ND	276.3	57.7	283.8	59.0	290.0	60.3
II	ND	270.7	65.0	277.0	65.4	283.7	65.4

Table IV. *Intra-observer study. Coefficients of reproducibility (C_R; N) and of variation (C_V; %) from comparisons of MVC values on two occasions, 4 weeks apart (n = 29)*

D, dominant; ND, non-dominant.

	Mean of three values		Mean of two highest values		Highest value	
Hand	C_R	C_V	C_R	C_V	C_R	C_V
D	47.5	5.6	51.6	6.1	49.0	5.6
ND	52.4	6.9	53.2	6.8	52.5	6.6

Intra-observer study

Within-session reliability of MVC. The maximal value obtained between the second and fourth seconds of the grip versus time curve was used to represent MVC (Fig. 1A). The average within-session MVC (Table I) was usually lower on the second occasion. The highest MVC value occurred in the first trial in 43%, and in the second trial in 56% of the 116 sessions. There were no significant differences between the first and second trials, but there were significant differences between the first and third and between the second and third trials (ANOVA for repeated measures). Within-session ICCs ranged from 0.97 to 0.98. The correlation coefficients between trials were all significant ($r = 0.92–0.98$). The coefficients of repeatability (C_R) and of variation (C_V), presented in Table II, were low.

Intra-observer reliability of MVC. In each session MVC was determined in three different ways: (i) as the highest of the three values, (ii) as the mean of the two highest values, and (iii) as the mean of all three values (Table III). MVC determined as the mean of all three trial values was significantly lower than that determined as the highest value of three in all sessions. MVC decreased on the second occasion, but the differences were not significant, irrespective of the method used for determining MVC (paired *t*-test). The correlation coefficients between occasions were significant ($r = 0.91–0.96$). The coefficients of reproducibility and of variation (Table IV) were low. The mean of all three values and the highest value yielded lower coefficients than the mean of the two highest values. The differences were small. All coefficients for the dominant hand were lower than those for the non-dominant hand.

Table V. *Intra-observer study. Area below the grip versus time curve (Ns), peak value (N) and value at 40 s (N) on two occasions, 4 weeks apart (n = 29)*

Occ, occasion; D, dominant; ND, non-dominant.

		Area (Ns)		Peak value (N)		Value at 40 s (N)	
Occ	Hand	Mean	SD	Mean	SD	Mean	SD
I	D	8,357.4	2,624.7	301.2	78.6	185.0	59.0
II	D	8,366.6	2,683.6	294.3	81.6	180.3	58.7
I	ND	7,521.7	2,066.6	274.0	61.2	165.6	48.0
II	ND	7,511.0	2,152.1	269.2	63.9	165.7	51.1

Table VI. *Intra-observer study. Coefficients of reproducibility (C_R; Ns, N) and of variation (C_V; %) for comparisons of areas, peak values and values at 40 s on two occasions with an interval of 4 weeks (n = 29)*

D, dominant; ND, non-dominant.

	Area (Ns)		Peak value (N)		Value at 40 s (N)	
Hand	C_R	C_V	C_R	C_V	C_R	C_V
D	1,631.8	7.0	59.6	7.2	64.4	12.7
ND	1,353.4	6.5	48.8	6.5	53.8	11.7

Intra-observer reliability of SMVC. The area below the grip versus time curve, expressed in Newtonseconds (Ns), the highest value (peak value; N) obtained during the contraction, and the value at 40 s (N) were chosen to represent SMVC (Table V). The time taken to reach the peak value (s), calculated from the origo of the grip versus time curve, averaged between 2.9 and 3.1 s (range 1–6 s). There were no significant differences between occasions for either of the four variables (paired *t*-test). The correlation coefficients were significant between occasions for areas, peak values and values at 40 s ($r = 0.84$–0.95), but not significant for the time taken to reach the peak value. When the results of the two measurement occasions were compared, the coefficients of reproducibility and of variation were lowest for area and peak value (Table VI), and highest for the time taken to reach the peak value (C_R: 2.9–3.9 s; C_V: 36.7–47.2%). All coefficients were lower for the non-dominant than for the dominant hand.

Inter-observer study

Inter-observer reliability of MVC and SMVC. The average within-session MVC values, recorded by two observers on two occasions, ranged between 327.8 and 369.8 N for the dominant hand and between 276.0 and 318.4 N for the non-dominant hand. The values were higher than those for the subjects in the intra-observer study. The differences ranged from 3.8 to 18.7% (mean 12.9 ± 5.1%). The intra-observer reliability for each of the two observers was essentially the same as was found in the intra-observer study. There were no significant differences between the MVC values recorded by the two observers. The coefficients of reproducibility and of variation were low on both measurement occasions (Table VII).

The SMVC values were also higher, on average, than those in the intra-observer study. The area values ranged from 8,033.2 to 10,379.3 Ns, the peak value from 302.9 to 349.3 N and the values at 40 s from 165.2 to 214.0 N. The inter-observer coefficients of reproducibility and of variation are presented in Table VII. The C_Vs were lower for area and peak value than for the value at 40 s. The average time taken to reach the peak value was similar to that in the intra-observer study, but the standard deviations were higher (ranges 0.6–2.7 s, compared to 1.2–1.5 s). The reliability coefficients were very high ($C_R = 2.7$–5.0 s; $C_V = 34.8$–81.9%).

Table VII. *Inter-observer study. Coefficients of reproducibility (N, Ns, s) and of variation (%) for comparisons of MVC and SMVC, measured by two observers with an interval of ≥1.5 hours. Two measurement occasions with an interval of one week (n = 10)*

D, dominant hand; ND, non-dominant hand.

	First occasion				Second occasion			
	D		ND		D		ND	
MVC (N)	C_R	C_V	C_R	C_V	C_R	C_V	C_R	C_V
Mean of three values	41.7	4.2	50.1*	6.2*	39.5*	4.2*	46.6	5.4
Mean of two highest values	39.4	3.9	50.0*	6.1*	45.5*	4.7*	49.4	5.6
Highest value	49.1	4.8	57.5*	6.9*	49.6*	5.0*	53.2	5.9
SMVC*								
Area (Ns)	1,246.4	4.4	1,339.6	5.4	1,017.3	3.8	1,316.1	5.8
Peak value (N)	29.7	3.1	39.6	4.6	49.9	5.2	48.4	5.8
Value at 40 s (N)	57.0	9.8	53.5	11.4	57.8	9.9	43.7	9.3

General

None of the subjects experienced pain or discomfort in connection with the measurements of MVC or SMVC. In all sessions of the two studies, the dominant hand was significantly stronger than the non-dominant. The differences ranged between 8 and 17%. There was no significant difference between hands regarding the time taken to reach the peak value (paired *t*-test: $p = 0.52$ and 0.77).

DISCUSSION

The accuracy of the instrument

The Grippit® had very high precision. Compared with the results reported by Härkönen et al. (10), the average deviations from linearity and the amount of discrepancy of the Grippit® were much lower than those of a new Jamar® dynamometer. Fess (7) reported calibration coefficients of 0.9994 as the minimum level of tolerance for re-calibration and re-adjustment of Jamar® dynamometers. The Grippit® showed calibration coefficients above that level both before and after the measurements. The error of the Grippit® (0.4%) was slightly higher than the reproducibility error of the Pressductor® (0.1% of the full scale of deflection (6)) which we used in the earlier study mentioned above (12).

Within-session reliability of MVC

In agreement with our earlier study (12), the multi-trial procedure showed high within-session reliability. The repeatability and short-term variability were acceptable. The variability was very similar to that reported by Trossman et al. (22). The fact that there were no significant differences between the values from the first and second trials indicated that there were no clear-cut signs of effects of learning, practising or motivational factors on the reliability. The standardization and the increase in the length of the inter-trial rest periods did not seem to improve the within-session reliability. Possibly the rest periods were still too short (21).

Intra-observer reliability of MVC and SMVC

The test–retest reliability of the MVC values was high. Over the same length of time, the reproducibility was much higher and the variability much lower than those in our previous study (12). Despite a much longer test–retest interval the variability (C_V, Table IV) was rather similar to those found by Nordenskiöld & Grimby. They found methodological errors between 4.4 and 6.6% for peak values in healthy women (17). Furthermore, the variability was in close agreement with that reported by Trossman et al. (22), despite the fact that in their study the within-session intervals were longer and the between-occasions interval much shorter.

Several authors have claimed that the mean of three values in a session tends to show higher reliability than other ways of determining MVC (9, 12, 14, 22). In the present investigation, the highest value and the mean of three values showed equally high reproducibility (Table IV). Furthermore, the highest value was significantly higher than the mean of three values. These findings actualize the discussion about which value in a multi-trial session of MVC measurements should be chosen to represent the maximal grip strength of a patient in clinical care. Since there is no consensus on this matter, the method of calculation of MVC should always be stated and this same measure should be used on re-evaluations.

In the present study, the intra-observer reproducibility of the SMVC, expressed as area and as peak value, was more than twice as high as that with our previously presented method (12). The long-term variability was $\geq$4.5% lower. The standardized length of the rest periods before and between sessions of SMVC measurements ($\geq$2 min) may have influenced these results. Furthermore, the reduction of the sustained contraction by 20 s may have resulted in improved reliability for area, since in our present investigation no subject reported any pain or discomfort in connection with SMVC measurements. In agreement with our earlier results (12), the time taken to reach the peak value was not a reliable measure. The values at 40 s showed satisfactory reproducibility and variability. The reliability of this parameter has not previously been studied.

Inter-observer reliability of MVC and SMVC

The MVC and SMVC values in the inter-observer study were higher than in the intra-observer study, possibly because the subjects were younger, thinner and taller. The reproducibility of MVC and of SMVC was mostly higher and the variability mostly lower in the inter-observer than in the intra-observer study.

The shorter interval between the measurements made by the two observers (about one and a half hours compared to 4 weeks) is one plausible explanation for these findings.

Conclusions

In healthy subjects our modified methods for measuring MVC and SMVC, applied with the Grippit®, had a higher intra-observer reliability than our original methods with the Pressductor® (12), and could be applicable for the assessment of isometric grip strength in research and in clinical work. Coefficients of repeatability and of reproducibility, as calculated in this investigation, might be helpful tools in differentiating between changes in strength due to treatment and changes due to measurement error.

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