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TEST-RETEST INTRA-RATER RELIABILITY OF GRIP FORCE IN PATIENTS WITH STROKE

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Objective: **Coefficients of repeatability and reproducibility can be guides in differentiating between real changes and measurement error. The aim was to evaluate test-retest intra-rater reliability of a clinical procedure measuring grip force with Grippit® in stroke patients, to assess relationship between grip force of the hands and between sustained and peak grip force.**

Patients and methods: **Eighteen patients were tested using the Grippit® at two occasions one hour apart. Each occasion comprised three consecutive trials per hand.**

Results: **The paretic hand needs to score a 50 N change within and between occasions to exceed the measurement error in 95% of the observations, irrespective of calculation method. Expressed by CV_{within} the measurement error was 10%. There was no learning or fatigue effect during measuring. There was a wide variation between subjects but the mean ratio between sides was 0.66. The mean ratio between sustained and peak grip force was 0.80–0.84.**

Conclusion: **The measurement errors were acceptable and the instrument can be recommended for the use in stroke patients at a department of rehabilitation medicine.**

Key words: grip force, measurement, physiotherapy, reliability, stroke.

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INTRODUCTION

Stroke is the most frequent cause to disability in Sweden (1). The frequency of arm paresis in stroke victims and the recovery of lost arm function were investigated by Parker et al. (2). They reported that 80% of 3-month-survivors had more or less impaired arm function. They also found that severe initial paresis is an important prognostic factor; few patients with an initially severe paresis regained good recovery.

Grip strength is one of many important factors of function and ability in the hand. Weakness or the inability to recruit motor neurons is a major constraint affecting all aspects of upper extremity function including the ability to transport, grasp and release objects (3). Heller et al. (4) found grip strength to be a sensitive measure after stroke.

Strength (often a concentric contraction) is either assessed with some grading system or with special measuring instruments (3). Different kinds of dynamometers can be used to quantify strength more objectively (3). When grip strength is measured by dynamometers it is the force generated directly by the muscles that is measured (5).

One method of measuring grip strength is with the Grippit® instrument (6) (AB Detektor, Göteborg, Sweden) that is an electronic device easily administered clinically. Grippit® has been found to be reliable (6, 7) through test-retest procedures. Nordenskiöld & Grimby (6) found the measurement error (CV_{within}) with Grippit® to be approximately 5% in healthy individuals but up to 27% in patients with rheumatoid arthritis (RA) and 23% in patients with fibromyalgia. Grippit® could be suitable for stroke patients since the test position is fixed.

According to Lagerström's & Nordgren's study (8) a standardised procedure with a fixed test position is more reliable than for example an optional position. This is also one conclusion in a review of one hundred and thirty-one articles by Innes (9). There is some discussion about the number of successive trials to reach a reliable measure of maximal voluntary contraction (MVC) (7). One trial is probably not enough. It seems like the mean of three successive trials or the highest value is most reliable (7). Hamilton et al. (10) determined test-retest reliability and found no significant difference in reliability between four methods to determine grip strength score. The methods used were the score of one trial, the mean score of two trials, the mean score of three trials and the highest score of three trials.

The difference between grip force in both hands is reported to be up to 10% (6, 7, 9) in healthy people. In one study of stroke patients the grip strength of the affected hand was in average 18% of the unaffected (11). This would certainly vary according to what sample of stroke patients is included in the investigation.

In physiotherapy and rehabilitation in general it is often important to be able to evaluate processes over time with measurements that are reliable and valid (12). Spontaneous recovery and treatment effects are often followed. It is important to investigate if a variation from one time to another is a substantial change and not just due to variation in measurements. It is necessary to know if the outcome results exceed the measurement error. Variation between different occasions should be due to actual improvement/decrement and not to

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random error. Nevertheless there exists a random error because of natural variability in the subject, some variation in the measurement procedure or other factors (13, 14). The measurement error needs to be identified.

For a group of individuals the within-subject standard deviation (S_w) can be calculated with the ANOVA (analysis of variance) procedure (12, 14). This within-subject standard deviation (S_w) is one way to express the measurement error and 95% of the measurements could be expected to be within 1.96 S_w of the true value (14–16). Other ways of expressing the measurement error are by calculating the coefficient of repeatability (C_R), referring to the short-term, time-dependent within-session variations (14–16) and the coefficient of reproducibility (C_R), referring to long-term, between occasion variations (7). C_R has the same unit as the measurement. These coefficients express that the difference between the measurements for the same subject is expected to be less than $2.77 \times S_w$ for 95% of the observations. This method is valid if the SD does not depend on the size of the measurement (14, 16). If the standard deviation is proportional to the mean the CV_{within} (= within subject coefficient of variation (%)) should be used which is S_w/mean $\times$ 100 (16).

Nordenskiöld & Grimby (6) stress that reliability studies using disabled subjects are necessary. To our knowledge there are few such investigations of grip force in stroke patients and it seemed interesting and relevant to try the clinical usage of Grippit®.

The first aim of this study was to evaluate the test-retest reliability of a clinical procedure measuring grip force with Grippit® in stroke patients, (using within-subject variation, repeatability and reproducibility). The second aim was to assess the relationship between the grip force of the paretic and the non-paretic hand and finally, to assess the relationship between sustained grip force and peak grip force of the hands.

The definitions used by Nordenskiöld & Grimby (6) are used in this study (Table I).

METHODS

Design

A test-retest design (12) was used where the patients were tested at two occasions on the same day approximately one hour apart (mean 53 min, SD ± 14) between 9 am and 3 pm. This was chosen to avoid change or improvement from one day to another and to be able to study the variation just caused by two repeated occasions. Each occasion comprised three consecutive trials per hand (called one session) starting with the non-paretic hand. The rest intervals between each trial were ≥30 seconds (7).

Subjects

The study comprised 18 patients who had sustained a stroke 2–25 weeks ago (median 9.5). The patients were in- or outpatients at the department of Rehabilitation Medicine at a hospital. They formed a small but suitable sample of recent stroke patients who would probably be measured by this instrument at a department of Rehabilitation Medicine. The diagnosis was verified through medical records. They were included if the stroke had given some extent of hemiparesis and if they could perform a Grippit testing exceeding zero. Patients observed to accomplish a volitional finger flexion were asked to participate in the study. The sample represented a variation both in severity of the stroke and stage of recovery. The mean age was 54.9 years (SD ± 5.7 range 38–63). There were fourteen men (mean age 55.5 SD ± 3.8 years, range 51–63) and four women (mean age 53.0 SD ± 10.6 years, range 38–61). Thirteen patients had right-sided hemiparesis and five had left-sided. According to self-report all but three had a premorbid right hand dominance. Convenience sampling was used (12). All subjects had given informed consent and the Ethics Committee in Örebro approved the study as part of a larger investigation.

Instrument

Isometric grip strength was measured with the Grippit® instrument (6) (AB Detektor, Göteborg, Sweden) which is an electronic device used clinically that registers the grip force (N) generated by the muscles. Grippit® consists of an elliptical handle, 12.5 cm in circumference, an electronic unit and an adapter for connection to electricity. The grip handle and a forearm support are fixed on a wooden board, which enables the test position to be standardised (Fig. 1).

Procedure

The first author performed all measurements. The hour between the two occasions was not standardised concerning activities or rest but each patient followed his individual schedule according to his rehabilitation program.

The procedure was standardised concerning sitting positions, instructions and encouragement (9). The patients were seated in front of the instrument, upright in a chair of 0.44 m height with both feet level on the floor. The Grippit® wooden board was placed on the table right to the front. The height of the table was adjusted so the lowest rib levelled the edge of the table. The hand gripped the handle and the forearm was placed in the support. Hence, the shoulder is positioned in neutral rotation and in approximately 10° of flexion and abduction. The elbow joint is in approximately 90° of flexion. The other hand rested on the table.

The examiner first showed the grip procedure and the patient could try the position and a sub-maximal practise. When familiarised the verbal instruction was "I want you to hold the handle like this and squeeze as hard as you can for ten seconds". The patient got the command "Begin now" and the examiner pushed the start-button when the patient started to squeeze the handle.

No verbal or other encouragement was made during the 10 s trials (6).

Grip force (N) was registered for each trial automatically every half second during the 10 seconds. Peak value, mean value for the 10 s and

Table I. *Definitions of isometric grip force used in this study which are the displayed measurements in Grippit® according to Nordenskiöld & Grimby (6).*

Displayed grip force measurements in Grippit®	Corresponding force registrations automatically in Grippit®	Corresponding definitions	Gives information about
Peak value	Peak force of the 10 s contraction	Maximum momentary grip force	Maximal voluntary contraction (MVC)
Mean value	Average force of the 10 s contraction	Sustained grip force	Ability of the muscles to sustain their contraction in 10s
Last value	Final force of the 10 s contraction		Momentary grip force at the end of the 10 s contraction

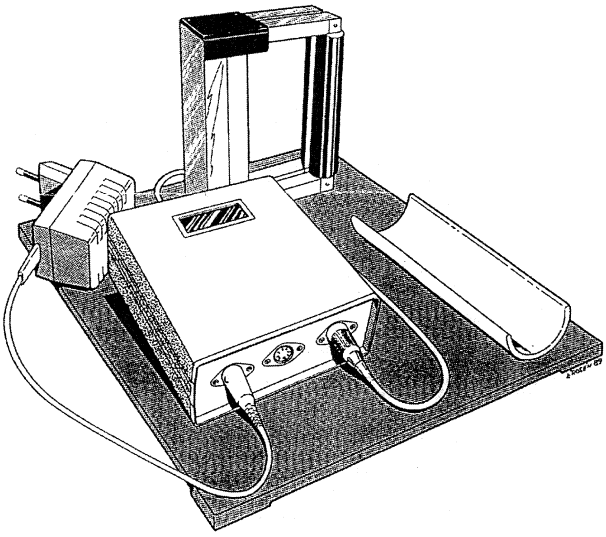

Fig. 1. The Grippit® instrument.

the last value over the 10 s were given in the display. These three values were manually entered in a protocol for all trials (totally 36 values per patient).

Analyses and statistics

As the values of grip force (peak values) in this study were fairly normally distributed (skewness ≤ 1.0), parametric statistics were used. Results were presented as one sample since data (peak values) of the men did not significantly differ from data of the women in the paretic side ($p > 0.05$, t-test independent groups and ANOVA repeated measures). Though, there was a significant difference between the results of men and women in the non-paretic side (t-test independent groups, $p \leq 0.01$) but not according to ANOVA repeated measures. Also, since the women were a small sample it was most appropriate to present all data together.

Descriptive statistics including mean and standard deviation was calculated (Statistica™ 5.0 StatSoft® 1995). The individual SD versus the means was inspected through graphs to check that the size of the SD was not proportional to the size of the mean (14, 16). This was estimated as acceptable. Analysis of variance (one factor ANOVA for repeated measures) was therefore used to determine S_w (the within-subject standard deviation) (12, 14–16). The coefficient of repeatability (C_R) referring to the short-term, time-dependent within-session variations was used (14–16). To assess the test-re-test reliability the coefficient of reproducibility between occasions (C_R) was calculated. This was calculated with two values: the highest value and the mean of all three values. Calculations for both these coefficients use the formula $C_R = \sqrt{2} \times 1.96 \times S_w = 2.77 \times S_w$ (14–16). They have the same unit of measure as the observed variable, newton (N). Since some positive skewness was present, the CV_{within} (= within subject coefficient of variation (%)) was also calculated for within-session variability and test-retest (16). The formula is S_w/mean $\times$ 100.

The ratios between the paretic and the non-paretic hand and between sustained grip force and peak grip force were calculated. Differences were considered significant if the p-value was <0.05.

RESULTS

The peak values were used to represent the MVC according to definition (6). The means per trial are presented in Table II. Differences were tested for systematic errors. MVC tended to be lower on the second occasion in both sides at all three trials but these differences were non-significant ($p > 0.05$). The difference between sides was approximately 100 N ($p \leq 0.001$). There were no significant differences between the means of the three trials ($p > 0.05$) though the means tended to decrease successively in the paretic hand.

In each session MVC was determined in two different ways: as the highest of the three peak values and as the mean of the three peak values (Table III). Differences were tested for systematic errors. The difference between occasion one and two was not significant with either of these two methods ($p > 0.05$). The mean of the three values was significantly lower than the highest value of the three values for both sides at both occasions ($p \leq 0.001$).

Since each patient performed one session (= three trials) with each hand at both occasions there was a total of 18 patients $\times$ 2 hands $\times$ 2 occasions = 72 sessions. To study the effect of multiple trials it was also noted in what trial the highest peak value occurred. The highest peak value occurred 33 times in the first trial, 18 times in the second trial and 21 times in the third trial of the 72 sessions.

Within-session reliability of MVC, repeatability

The within-subject standard deviation (S_w) was around 20 N in the paretic hand and 15 N in the non-paretic hand. C_R (the coefficient of repeatability) was around 55 N in the paretic hand and 43 N in the non-paretic hand. Corresponding values of CV_{within} (the within subject coefficient of variation) was 11% and 5%, respectively. S_w, C_R and CV_{within}, respectively, were similar for both occasions independent of the hand. This implies that for the paretic hand a difference in the same session needs to be more than 55 N to exceed the measurement error and to be called a true difference in 95% of the observations. Expressed by CV_{within} the measurement error was 11%.

Test-retest reliability, reproducibility

The coefficients of reproducibility between occasions (C_R) were lower when calculated with the mean of all three values. C_R for the paretic side was 48.2 N when calculated with the mean of the three values and 55.5 N when calculated with the highest value. C_R for the non-paretic side was 45.4 N and 48.5 N, respectively. The coefficients of variation (CV_{within}) were rather alike with either method: for the paretic side 9.8 and 10.4%, and for the non-paretic side 5.9 and 6.0%. This implies that for the paretic hand a change from one occasion to another needs to be more than 48 N to detect a genuine change in grip force in 95% of the observations. Expressed by CV_{within} the measurement error was 10%.

Ratio between the paretic and the non-paretic hand

The highest peak value was chosen to represent the patients' MVC in analyses concerning the ratio between the paretic and the non-paretic hand for occasion one and two. Minimum ratio was 0.07 and 0.09 and maximum ratio was 1.29 and 1.25. Five ratios exceeded 1.0 representing the paretic side being stronger than the non-paretic hand. Mean ratio for occasion one was 0.67 SD $\pm$ 0.37 and for occasion two was 0.66 SD $\pm$ 0.35. This

Table II. *Peak values (N = newton) of grip force at each of three trials recorded on two occasions with an interval of one hour (n = 18), mean, SD and range*
Occ = occasion; P = paretic side; NP = non paretic side

		Trial 1			Trial 2			Trial 3		
Occ	Hand	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
I	P	182.4	124.5	12–448	182.0	117.2	20–420	174.2	115.8	16–456
II	P	182.0	125.0	20–464	175.3	117.7	20–396	171.6	116.1	20–424
I	NP	288.0	131.6	104–576	282.4	123.7	104–544	282.9	119.9	120–572
II	NP	280.7	123.7	108–552	272.4	114.3	100–504	274.0	111.2	104–524

variation of ratios and values of grip force is illustrated in Fig. 2, which shows the highest peak values at occasion one for both the paretic and the non-paretic hand.

Ratio between sustained grip force and peak grip force

Ratios between the recorded mean value of the 10 s and the peak value of the 10 s were calculated. The highest values of the paretic and the non-paretic side were used at two occasions 1h apart. The ratios in the paretic side spanned from 0.66–0.90 (mean 0.80 SD $\pm$ 0.08) and in the non-paretic side from 0.59–0.93 (mean 0.82–0.84 SD $\pm$ 0.06–0.09).

DISCUSSION

Results showed that the paretic hand needs to score a 55 N change within session and 48 N between occasions to be called a difference in 95% of the observations. Expressed by CV_{within} the measurement error was 11% within session and 10% between occasions. Accordingly, a smaller difference/change is due to random error such as physiological fluctuations or some other variation. Mean ratio between the paretic and the non-paretic hand was 0.66–0.67 SD $\pm$ 0.35–0.37. There was a wide variation between subjects in the sample concerning this ratio and values of grip force. The mean ratio between sustained and peak grip force was 0.80–0.84 (SD $\pm$ 0.06–0.09).

The peak values (Tables II and III) for the non-paretic side were close to the values of the non-dominant hand in healthy persons (7) but SD and range showed greater variability in this stroke sample. There was altogether a wide variation between subjects in the present study. Compared to normative peak values (6) the stroke patients in the present study had lower values. In the paretic side slightly more than half of the values were within normal range for gender but all were below the normative average for gender. In the non-paretic side all but one person showed values within normal range for gender and values were below the normative average for gender for all but two persons (6). Though, the stroke sample was slightly older than the healthy sample (6). Boissy et al. (17) discusses this controversy of using the nonparetic limb as an index of normal function in stroke patients. They report on studies suggesting that ipsilateral extremities do not function at a normal level, but also one study showing no significant alteration of ipsilateral grip strength in stroke patients (17). The present study could not detect a certain disturbance of grip force in the non-paretic hand. The non-paretic side can probably be used as a reference for the paretic side after stroke in accordance with the discussion about patients after Colles' fracture (18).

Neither fatigue nor practice or learning effects seemed to effect our results, since the mean differences between the trials and between the occasions were non-significant. One could have expected recent stroke patients to be easily tired. The standardised manner with a non-tiring activity or rest before a test could have been suitable and might have reduced the variability. Hamilton et al. (10) showed a fatigue effect between trials in a study of healthy men and women but they had no rest interval between the trials. Another study of healthy subjects showed a significant drop in peak force between occasions four weeks apart and stated that variation although standardised procedures can be expected (19).

Lagerström & Nordgren reported that a multi-trial test is to prefer and that the last trial should not be the highest (7, 8). In this present study three trials were used since this is the clinical recommendation and less than a third of the sessions were highest in the last trial.

Table III. *MVC (maximal voluntary contraction) values (N = newton) determined by two different methods from the two occasions of measuring grip force with an interval of one hour (n = 18), mean, SD and range*
Occ = occasion; P = paretic side; NP = non paretic side

		Mean of three values			Highest value of three values		
Occ	Hand	Mean	SD	Range	Mean	SD	Range
I	P	179.6	118.1	16–439	194.2	124.4	20–456
II	P	176.3	118.6	21–405	192.2	127.4	24–464
I	NP	284.4	124.5	109–564	297.3	127.4	120–576
II	NP	275.7	115.9	104–527	288.7	118.7	108–552

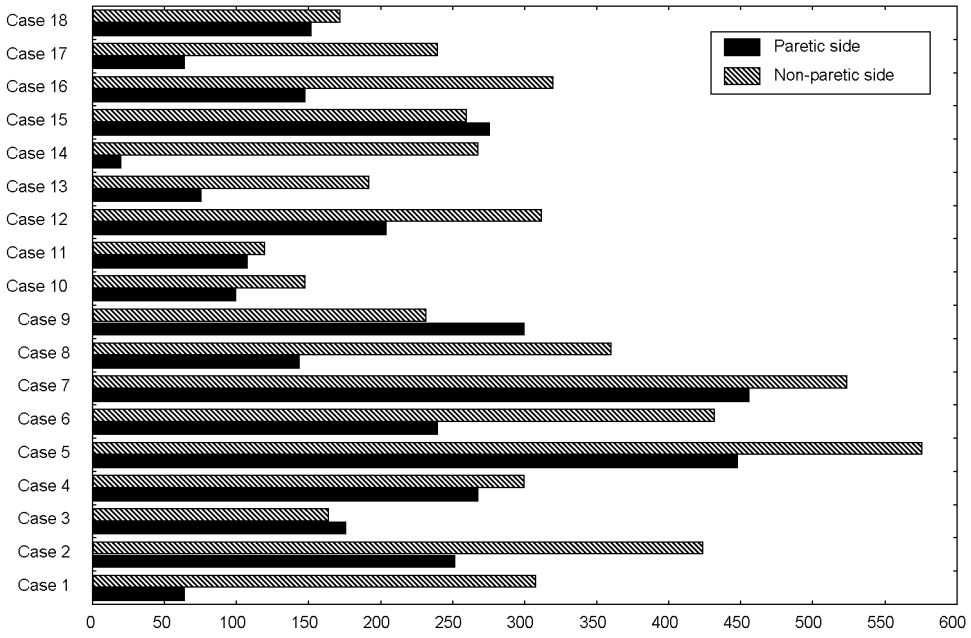

Fig. 2. The highest peak values at occasion one for the paretic and the non-paretic side, respectively ($n = 18$)

Within-session reliability of MVC

The coefficient of repeatability (C_R) and CV_{within} were higher in the paretic hand (around 55 N; 11%) than in the non-paretic hand (43 N; 5%). These coefficients were fairly alike the results in healthy persons (7) and in the uninjured side of patients after Colles' fracture (18). Another source says that grip force readings are reliable if they vary less than 20% (20). Accordingly, the within-subject variation in our stroke patients was not markedly different from healthy persons and the measurement error can be considered as acceptable.

Test-retest reliability

There is an on-going discussion of which method to use (7) for representing the maximum grip force clinically. Often the highest peak value is used clinically since this intuitively makes sense as a maximum for the patient and the clinician. Both the highest peak value (6, 17) and the mean of three trials (19) has been used in research. This study showed slightly lower coefficients of reproducibility between occasions (C_R) when calculated with the mean of all three values. This is not in agreement with Lagerström & Nordgren's results (7). Our results also showed that the mean of the three values was significantly lower than the highest value which Lagerström & Nordgren also report (7). CV_{within} was lower than for patients with RA and fibromylgia (6). Though, CV_{within} was higher in the paretic arm than in healthy persons (6, 7) but these studies used longer test-retest interval. Coefficients of reproducibility were similar to those in healthy persons (7). In a very recent study (17) fifteen chronic stroke patients were tested at three occasions and their strength deficit was represented by the ratio between hands. Their standard error of measurement in the paretic hand was 25 N compared to 20 N in the present study. A smaller error could be expected within session than between occasions (21) but our errors were similar. Nitschke et al. (21) published a recent study of the size of the measurement error for healthy women and women with non-specific regional pain with 4–7 days between test-retest. Their result was considered to have high test-retest reliability and the measurement error showed to be 6 kg (roughly 60 N) for both groups which was even more than in our study. The measurement error in the present study can be considered as acceptable.

Ratio between the paretic and the non-paretic hand

The mean ratio between sides was around 0.66 which is quite different from healthy persons who have a reported difference between grip force in both hands from 0–10% (6, 7, 9). Because of the diagnosis the result, however, was expected. However, a few patients in the stroke sample had less than 0–10% difference between sides suggesting that the paresis had recovered fairly well. The variation between subjects showed heterogeneity. In the above mentioned study of Boissy et al. (17) the mean ratio was $34\% \pm 20$ and ranged from 11–82% which indicate that their sample was more paretic and more homogenous. In the study by Sunderland et al. (11) this ratio was $18\% \pm 27$ on average 11 days after stroke.

Ratio between sustained grip force and peak grip force

The mean ratios between sustained grip force and peak grip force were 0.80 (paretic side) and 0.82–0.84 (non-paretic side) and are close to healthy peoples' ratio which is 83% in women and 85% in men (6). The variation between subjects in the stroke sample was rather small. This could be interpreted as that the weakness in the paretic side is effecting the sustained grip force as much as the maximum force, both measured in 10 s contraction. Compared to women with RA and fibromyalgia the

stroke sample had higher ratios (6), which might depend on that only three of the stroke patients had any pain or stiffness affecting the hand.

Hermsdorfer & Mai (22) reports that there are more aspects of grip force than just measuring the MVC. They demonstrate additional impairments of hand function, which varied within and between patients with brain lesions.

There are still other questions to be answered. The critical level of grip strength for using the hand in daily activities is not defined. It is reported in general terms that 4 kg of force is necessary for the grip in performance of 90% of ADL (20). The correlation between strength and the use of the arm and hand (23, 24) is unknown. Sensitivity to change over time of grip strength in stroke patients must be further surveyed. Sunderland et al. (11) found good sensitivity to change, detecting early recovery as well as later changes three to six months after stroke. They stated that increased grip strength was associated with improving function and not increasing spasticity. To generalise the results of this present study to a greater population of stroke patients, the sample needs to be increased in size and include more women and other ages.

Coefficients of repeatability and reproducibility calculated in this study can be guides in differentiating between real changes and measurement error of grip force in stroke patients. This study showed that the paretic hand needs to score a 10% or 50 N change within and between occasions to exceed the measurement error, irrespective of calculation method when using Grippit® as measurement method. These are acceptable measurement errors and the instrument can be recommended for stroke patients at a department of Rehabilitation Medicine. This information is important when the improvement of hand function is followed during a rehabilitation period. The ratio between hands was varying between subjects but this measure could be one useful way of clinically describing the deficit of force.

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