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ORIGINAL REPORT

EVIDENCE OF A LOGARITHMIC RELATIONSHIP BETWEEN MOTOR CAPACITY AND ACTUAL PERFORMANCE IN DAILY LIFE OF THE PARETIC ARM FOLLOWING STROKE

Marian E. Michielsen, MSc[1], Mark de Niet, MSc[1], Gerard M. Ribbers, MD, PhD[1,2], Henk J. Stam, MD, PhD[1] and Johannes B. Bussmann, PhD[1]

From the [1]Department of Rehabilitation Medicine, Erasmus University Medical Center and [2]Rijndam Rehabilitation Center, Rotterdam, The Netherlands

Objective: **To examine the associations between actual performance in daily life and function, capacity and self-perceived performance of the paretic upper limb following stroke.**
Population: **Seventeen individuals with stroke.**
Outcome measures: **Correlation coefficients between actual performance (measured with the Stroke-Upper Limb Activity Monitor), function (Fugl-Meyer Assessment), capacity (Action Research Arm test) and self-perceived performance (ABILHAND questionnaire).**
Results: **High correlations were found between actual performance and function ($r=0.75$; 95% confidence interval (CI): 0.42–0.90), and capacity (r=3270.71; 95% CI: 0.35–0.89), whereas a moderate correlation was found between actual performance and self-perceived performance ($r=0.64$; 95% CI: 0.21–0.86). For the relationship between actual performance and both function and capacity, logarithmic regression explained more variance than did linear regression.**
Conclusion: **The present study provides first evidence of the existence of a non-linear relationship between actual performance, function and capacity of the paretic upper limb following stroke. The results indicate that function and capacity need to reach a certain threshold-level before actual performance also starts to increase. Because of the small sample size of the present study caution is needed when generalizing these results.**

Key words: stroke, upper extremity, rehabilitation, monitoring, ambulatory.

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Correspondence address: Marian E. Michielsen, Department of Rehabilitation Medicine, Erasmus University Medical Center, PO Box 2040, NL-3000 CA Rotterdam, The Netherlands. E-mail: m.michielsen@erasmusmc.nl

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INTRODUCTION

Stroke is the major cause of long-term neurological disability in adults in Western society (1). In the acute stage of stroke approximately half of all stroke survivors are left with severe loss of function in the hemiparetic upper limb (2). Rehabilitation of the upper limb can be focused on different aspects of human functioning. The International Classification of Functioning, Disability and Health (ICF) described by the World Health Organization, distinguishes the following 3 levels: body function and structures, activity, and participation (3). For the activity level, 2 different qualifiers are provided: *capacity* and *performance*. Activity capacity describes what someone can do, indicating a person's highest probable level of functioning. It refers to a "standardized" environment to neutralize the varying impact of different environments on the ability of the individual and to allow for international comparisons for all persons in all countries. Activity performance on the other hand, describes what a person actually does in his or her home environment, expressing the individual's involvement in a life situation. In general, rehabilitation interventions for the upper limbs after stroke are focused on improvements in the levels of body function and activity capacity, whereas the ultimate aim is to improve activity performance (4).

Many evaluation tools are used to evaluate the efficacy of rehabilitation interventions, wherein different tools have been developed to measure at the different levels of functioning (5, 6). Whereas the levels of body function and activity capacity can be validly assessed in a laboratory setting, measurement of activity performance should be performed in a ecologically valid setting (e.g. the home setting) in order for environmental factors to be taken into account (7). When assessing activity performance, a distinction has to be made between self-perceived activity performance and actual activity performance. Self-perceived activity performance provides information about the manner in which someone experiences the difficulties caused by his disability (8), whereas actual activity performance provides objective information about the manner in which a disability affects one's functioning in daily life. Self-perceived activity performance can be regarded as a subjective construct, justifying a subjective (self-reports, questionnaires) assessment. Actual activity performance, on the other hand, is an objective construct and should be assessed accordingly. However, difficulties in objective assessment have so far had the result that actual activity performance is usually also assessed in a subjective manner (9).

In 2000, Uswatte et al. (10) were the first to present an objective measurement tool for upper limb usage. With the placement of accelerometers on both arms, their activity-

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monitoring device was able to register upper limb usage in a home setting. Vega-Gonzales and Granat (11) developed another objective measurement tool, using pressure techniques. Recently, De Niet et al. (4) presented the Stroke Upper-Limb Activity Monitor (Stroke-ULAM) to objectively measure upper limb usage. The Stroke-ULAM is based on both accelerometry and electro-goniometry. In comparison with earlier devices, the Stroke-ULAM has the added capability to detect body postures and motions. This is an important feature, as it creates the opportunity to discriminate between independent upper limb movements and upper limb movements caused by whole body movements (e.g. during walking).

The relationship between actual activity performance (from now on referred to as "actual performance") of the paretic upper limb and impairments at the levels of body function (from now on referred to as "function") and activity capacity (from now on referred to as "capacity") has so far received limited attention in scientific literature (12). It is, however, an important issue, as it can provide insight into whether and how rehabilitation interventions aimed at function or capacity will also lead to improvements in actual performance. The concept of learned non-use provides a good illustration that the former is not always the case, showing that patients often do not use their affected arm to its full ability (13, 14). Additionally, being able to objectively measure actual performance renders the opportunity to assess to what degree self-perceived activity performance (from now on referred to as "self-perceived performance") is related to actual performance, an issue that has also not yet received much attention.

The aim of the present study was to increase understanding of the relationship between actual performance and function, capacity, and self-perceived performance of the paretic upper limb following stroke. In order to realize this, outcomes on the Stroke-ULAM were compared with outcomes on regularly used measurement tools for function, capacity and self-perceived performance (15–17).

METHODS

Subjects

Patients in the chronic phase after stroke (minimum one year post-onset) were recruited through Rijndam Rehabilitation Center. Eighty-eight patients were contacted, of whom 12 agreed to participate. In addition, 5 sub-acute stroke patients (between 1 and 3 months post-onset) were randomly selected from patients who were hospitalized in the rehabilitation centre during the measurement period. Inclusion criteria were: knowledge of the Dutch language and the ability to walk indoors. Patients were excluded when they had co-morbidities that influenced upper limb usage. All participants gave written informed consent before participating in the study. The study was approved by the medical ethics committee of the Erasmus MC Rotterdam.

Procedure

The protocol contained both standardized measurements in a laboratory setting and prolonged ambulatory monitoring of upper limb activity using the Stroke-ULAM in the home environment (chronic patients) or in the rehabilitation centre (sub-acute patients). The laboratory measurements were done prior to the home measurements and consisted of 2 tests: the Fugl-Meyer Assessment (FMA) and the Action Research Arm Test (ARAT). During the home measurements, each patient wore the Stroke-ULAM for at least a 12-h period. To prevent fatigue in the patients, the laboratory measurements were executed a day in advance. After the ambulatory monitoring, the ABILHAND questionnaire was used to index self-perceived activity performance.

Instruments: Actual performance

Stroke-ULAM. The Stroke-ULAM measures wrist movement using accelerometers and goniometers. With accelerometers placed on the thigh and the sternum, the Stroke-ULAM also distinguishes body postures and motions from each other (e.g. periods of sitting, standing and walking are detected). As such, independent upper limb movements can be discerned from upper limb movement caused by whole body movement. The Stroke-ULAM has 2 main outcome measures: (*i*) an absolute measure for each upper limb (level of usage); and (*ii*) a relative measure indicating the level of usage of the affected upper limb compared with the unaffected upper limb (proportion). These outcome measures can be derived from both electrogoniometric and accelerometric data. The electrogoniometry level of usage (for both affected and unaffected upper limb) is the elbow joint movement of the upper limb per minute (in degrees per minute), whereas the proportion is the level of usage of the affected upper limb divided by the level of usage of the unaffected upper limb. The level of usage for accelerometry is expressed as the intensity per minute (in *g*/min). The intensity depends on the variability of the raw acceleration signal around the mean value, that is, the higher the variability, the higher the intensity. The accelerometric proportion is calculated in the same way as the electrogoniometric proportion. Previous research already showed that: (*i*) outcomes derived from goniometers and accelerometers did not differ much; and (*ii*) defined proportion of the level of usage as the most appropriate outcome measure of upper limb usage in daily living conditions (4, 10). Therefore, in the remaining part of this paper only the proportion derived from accelerometry will be used as outcome measure for actual performance.

Instruments: Function

Fugl Meyer Assessment. The upper extremity part of the FMA examines the voluntary movement and the ability to execute upper limb movements outside of synergies. It consists of 9 components: reflexes, flexor synergy, extensor synergy, movement combining synergies, movement out of synergy, normal reflex activity, wrist, hand, and co-ordination speed. The FMA assessment scores range from 0 to 66, with higher scores indicating better motor recovery (15).

Instruments: Capacity

Action Research Arm Test. The ARAT evaluates 4 types of movement: grasping, gripping, pinching and gross movement. The test contains 19 items arranged in hierarchical order starting with the most difficult item in each subgroup followed by the easiest item. The score on each item is based on both the completeness of the movement and the duration of the movement. For each item, a time limit has been determined and exceeding the time limit results in a point reduction of the item score. The maximal score for the ARAT is 57 (16).

Instruments: Self-perceived performance

ABILHAND. The ABILHAND is a questionnaire that measures the patient's perceived difficulty in performing activities of daily life that require the use of the upper limbs. Participants are asked to estimate their difficulty in performing each activity when done without help, irrespective of the limb(s) used and whatever the strategies used to do the activity. The manual ability is rated on a 3-level response scale. The score, given in logit, is the conversion of the ordinal score into a linear measure of ability located on a unidimensional scale (17).

Statistics

The Mann-Whitney Wilcoxon rank test was used to compare test scores between patients in the sub-acute phase and those in the chronic phase. Subsequently, a correlation analysis was performed to determine the strength of the relationships between Stroke-ULAM and FMA, ARAT

Table I. *Patient characteristics and mean test scores on the Fugl Meyer Assessment (FMA), Action Research Arm test (ARAT), ABILHAND questionnaire and Stroke Upper-Limb Activity Monitor (Stroke-ULAM)*

	Sub-acute, $n=5$	Chronic, $n=12$
Age, years, mean (SD)	58.6 (16.1)	50.8 (11.7)
Women, *n*	0	7
Time post-onset, months, mean (SD)	2 (0.91)	46.18 (4.65)
Haemorrhagic stroke, *n*	2	5
Paresis of right side, *n*	5	9
Paresis of dominant UL, *n*	2	5
FMA score, median (IQR)*	55 (12, 58) **2–63**	49 (31.25, 55.5) **5–58**
ARAT score, median (IQR)*	28 (0, 45) **0–55**	38 (19.75, 47) **0–56**
ABILHAND score, logits, mean (SD)*	1 (2.19) **–2.43–2.60**	1 (2.11) **–1.96–5.98**
Stroke-ULAM Proportion, mean (SD)*	36.94 (24.83) **13.07–68.85**	40.20 (20.89) **12.48–89.63**

*The range of the test-scores is shown in bold.
SD: standard deviation; IQR: interquartile range; UL: upper limb.

and ABILHAND. The strength of the respective relationships was described using Spearman's correlation coefficient (*r*) and was based on Munro's correlation descriptors (18) (very low = 0.15–0.24, low = 0.25–0.49, moderate = 0.50–0.69, high = 0.70–0.89, and very high = 0.90–1.00). Scatter-plots of the relationships between the measurement tools were visually inspected to determine linearity. Based on this, Stroke-ULAM values were log transformed, and for the relationships between Stroke-ULAM and FMA, ARAT and ABILHAND a logarithmic regression model ($y = a\ \ln(x) + b$) was compared with a linear regression model ($y = ax + b$). The difference between goodness-of-fit in the models was assessed by applying the Wilcoxon rank test on the individual square of the residuals of both models.

RESULTS

Table I shows patients characteristics and mean scores on all evaluation tools. No differences were found between test results of patients in the sub-acute phase and those in the chronic phase on any of the evaluation tools (all $p > 0.001$). Therefore, the 2 groups were collapsed for the remaining part of the analysis. In Table II, correlation coefficients between the scores on Stroke-ULAM, FMA, ARAT and ABILHAND are presented. Correlation coefficients between Stroke-ULAM and both FMA ($r = 0.75$) and ARAT ($r = 0.71$) are high, whereas the correlation coefficient between Stroke-ULAM and ABILHAND is moderate ($r = 0.64$). Fig. 1 shows scatter plots of the relationships between respectively Stroke-ULAM and FMA, Stroke-ULAM and ARAT and Stroke-ULAM and ABILHAND.

Table II also shows the results of both the logarithmic and the linear regression analysis between Stroke-ULAM and FMA, ARAT and ABILHAND, as well as a comparison between goodness-of-fit of both methods. As can be deduced from Fig. 1 and Table II, logarithmic regression explains more variance compared with linear regression for both the relationship between Stroke-ULAM and FMA ($p < 0.05$) and the relationship between Stroke-ULAM and ARAT ($p < 0.1$).

DISCUSSION

The aim of the present study was to examine the manner in which actual performance is related to function, capacity and self-perceived performance of the paretic upper limb following stroke. The results showed high correlations between actual performance and function and capacity, and a moderate correlation between actual performance and self-perceived performance. It is important to note that these strong correlations might be partly caused by the large data range in the present study, which typically enlarges the correlation coefficient. Furthermore, the small sample size of the present study and the resultant large confidence intervals make it necessary to be cautious when interpreting the values of these correlation coefficients. Still, our findings seem to contradict previous publications, which generally showed considerable differences between what a patient can do with his or her paretic arm and how much he or she actually uses it (19, 20). This discrepancy might be due to the fact that these previous studies all addressed performance subjectively, whereas the present study was the first to assess performance in an objective manner.

However, the most important finding from the present study comes from its explorations regarding the nature of the rela-

Table II. *Associations between actual performance and function, capacity and self-perceived performance*

	Spearman's correlation		Linear regression			Logarithmic regression			Linear vs logarithmic	
	R (95% CI)	p	R^2 (95% CI)	R_{ss}	p	R^2 (95% CI)	R_{ss}	p	Z score	p
Stroke ULAM										
FMA	0.75 (0.42–0.90)	<0.001	0.58 (0.31–0.85)	3102	<0.001	0.72 (0.52–0.92)	2078	<0.001	–2.49	<0.05
ARAT	0.71 (0.35–0.89)	<0.001	0.57 (0.30–0.84)	3120	<0.001	0.66 (0.43–0.89)	2494	<0.001	–1.73	<0.1
ABILHAND	0.64 (0.21–0.86)	<0.01	0.30 (–0.02–0.62)	44.73	<0.01	0.33 (0.01–0.65)	42.69	<0.01	–0.05	0.96

R: Spearman's correlation coefficient; CI: confidence interval; R^2: R squared; R_{ss}: Residual Sum of Squares; Stroke ULAM: stroke upper-limb activity monitor; FMA: Fugl-Meyer Assessment; ARAT: Action Research Arm Test.

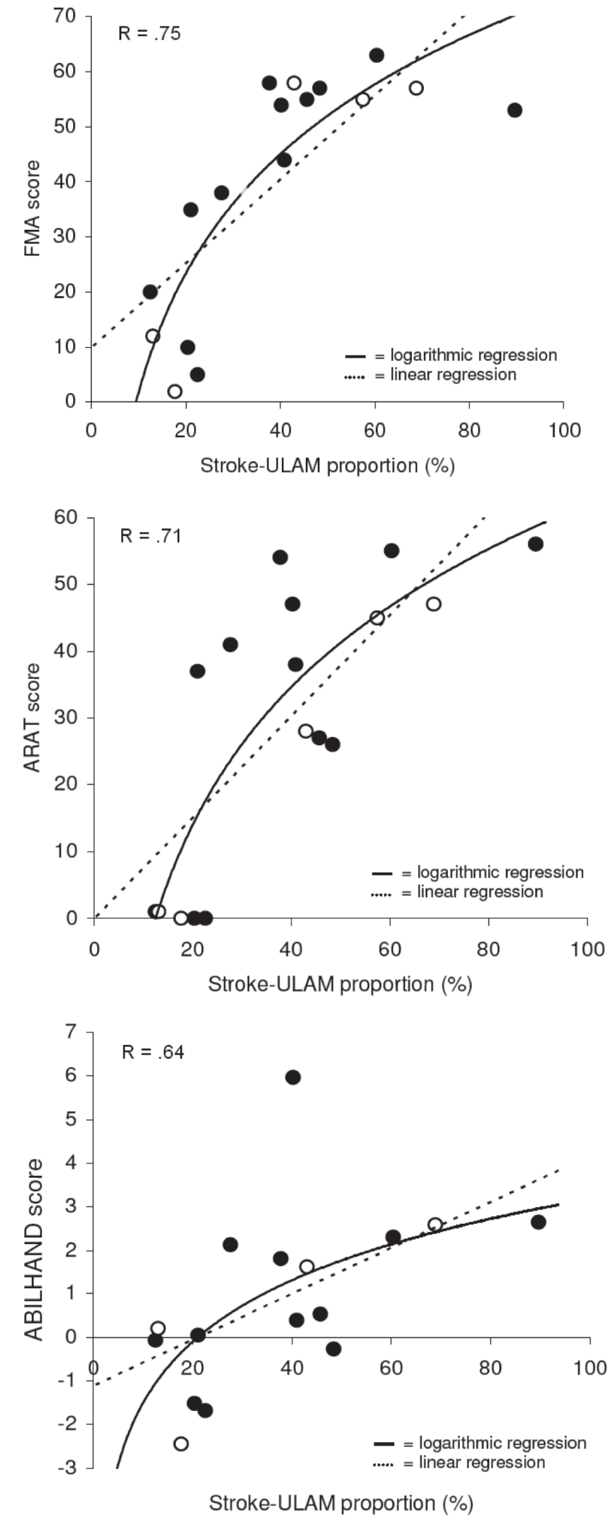

Fig. 1. Scatter-plots of the relationships between the Stroke Upper-Limb Activity Monitor (ULAM) and the Fugl Meyer Assessment (FMA) (top), the Action Research Arm Test (ARAT) (middle) and the ABILHAND questionnaire (bottom). Open dots represent values for sub-acute patients, whereas closed dots represent values for chronic patients.

tionships between actual performance, function and capacity. The results concerning this issue indicate that function and capacity need to reach a certain threshold level before actual performance starts to increase (Fig. 1). Beyond that level function and capacity only increase moderately in respect to actual performance, which itself starts to increase more rapidly. This idea is supported by the fact that the logarithmic regression model explained more variance compared with the linear regression model, indicating a non-linear relationship between actual performance and function and capacity (Table II). This is most notably so for the relationship between actual performance and function (72% variance explained with the logarithmic model vs 58% with the linear model), and to a lesser extent for the relationship between actual performance and capacity (66% variance explained vs 57%).

It must be remembered that the data in this study is cross-sectional. It thus only provides information about different subjects at a given time-point, whereas no conclusions can be drawn from it regarding the course of rehabilitation. However, the observed effect does imply that improvements in function and capacity will not automatically result in an improved actual performance, at least not until they exceed a certain threshold.

Concerning the associations between actual performance and self-perceived performance, the current study revealed a relationship of moderate strength. This is in accordance with findings from previous studies in patients with stroke (21) and CRPS-1 (9). However, as can be deduced from Fig. 1, the results of the present study show an outlier with an almost maximal score at the ABILHAND, and a score of only 40% on the Stroke-ULAM. This result is possible because of the subjective nature of the ABILHAND questionnaire, and its allowance for compensation strategies. The size of the correlation coefficient found in the present study between ABILHAND and Stroke-ULAM will of course be influenced by this outlier (even more so given the small sample size). However, this outlier can also be viewed as an extreme example of how large the discrepancies between actual and self-perceived performance actually can be. The former emphasizes how self-reported scores are prone to over- or under-estimation, depending on either motivation and/or cognitive skills (17). When evaluating a rehabilitation intervention aimed at improving actual performance this is an important issue to take into account, as such "psychosocial factors" are not expected to respond to regular rehabilitation interventions, and might conceal possible improvements in actual performance.

The present study has some potential limitations. First of all, as already mentioned, its sample size was rather small, requiring caution before generalizing results or drawing strong conclusions. Secondly, it is important to note that the aim of the present study was not to validate whether or not the used measurements tools indeed measure in their specific domain of functioning. All used tools have been tested for that previously, but it is still important to keep in mind that the same domain or construct can be validly operationalized in different ways and therefore be measured with different tools. Finally, when measuring actual performance for a longer period of time in daily living situations, the question always remains to what extent the measured period is representative for someone's overall activity pattern. However, in this study the proportion of the level of usage of the affected upper limb in comparison with the level of usage of the unaffected upper limb was used to index actual performance. As this is a measure that is not very susceptible to changes in overall activity (as such changes will affect the activity of both arms equally), it makes the issue of representiveness of the data of less concern.

The main finding of the present study was that even though actual performance and function and capacity of the upper limbs following stroke are strongly related, this relationship appears not to be of a linear nature. This indicates that the size of discrepancies between function, capacity and actual performance can be dependent on the degree of recovery. Furthermore, the present study provided insight into possible differences between actual performance and self-perceived performance. In planning as well as in evaluating the effect of post-acute rehabilitation programmes aimed at hand function it is pivotal to understand that there is no one-to-one relationship between function, capacity, self-perceived performance and actual performance, and that improvements on any of those levels might not occur simultaneously. For future research, it would be interesting to examine both the strength and the nature of the relationships between recovery at the different levels of functioning in a longitudinal design.

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