Recovery of objectively measured arm use in daily life after stroke and its relationship with arm function

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ABSTRACT

Background: A stroke often results in functional impairment and in decreased daily-life use of the affected arm. However, it remains unclear how actual arm use recovers after a stroke and how this relates to arm function.

Objective: To investigate the recovery of objectively measured arm use and its relationship with arm function during stroke rehabilitation.

Methods: In fifteen individuals with initial arm paresis after a stroke and receiving usual care in a rehabilitation center, arm use and function were assessed at 3, 12, and 26 weeks after a stroke. Arm use was repeatedly measured for one consecutive week using an accelerometry-based arm use monitor. The primary outcome was the ratio of movement counts of the affected arm divided by those of the unaffected arm, calculated during sitting and standing, as assessed by the activity monitor. Arm function was measured with the Fugl-Meyer Assessment scale.

Results: On average, the arm use ratio increased from 0.25±0.14 (3 weeks) to 0.42±0.25 (12 weeks; 3-12 weeks $p=0.002$) and to 0.51±0.24 (26 weeks; 12-26 weeks $p=0.009$), but still remained low and with large inter-individual variability. The arm use ratio was positively related to arm function and this was more clearly observed at higher levels of arm function.

Conclusions: This study shows that daily-life arm use remains asymmetrical up to six months after a stroke. Since this arm use is essential in daily-life activities and to prevent non-use, interventions are needed to stimulate use of the affected arm in individuals with an asymmetrical pattern of arm use after a stroke.

INTRODUCTION

After stroke, individuals often suffer from impairment of the affected arm; initially, 75% suffers from impaired arm function, improving to 65% after 6 months[1,2]. Besides this impairment, individuals experience decreased actual use of their affected arm in daily life, leading to limitations in daily-life activities, greater dependency, and restrictions in social participation[3,4]. Practicing arm movements with the affected arm is a key element during motor rehabilitation after a stroke. However, from the patient's perspective, it is not so much the ability to move the affected arm (hereafter called 'arm function') that is the ultimate goal of stroke rehabilitation, but to restore actual arm use in daily life (hereafter called 'arm use')[5,6].

Currently, it is unclear how actual arm use during daily life recovers after a stroke and how this relates to arm function. Cross-sectional data of previous studies have shown that objectively measured (accelerometry) arm use, is correlated with several measures of arm function, e.g. the active range of motion of the shoulder, elbow and wrist, the Fugl-Meyer Assessment (FMA), and the Action Research Arm Test (ARAT)[7-11]. However, being able to move the affected arm and having the potential to use this arm does not necessarily lead to actual arm use in daily life[12-14], which may lead to so-called 'non-use' of the affected arm[4,15]. Therefore, it is important to assess not only arm function with clinical measures (such as the FMA or the ARAT), but to also objectively measure actual arm use during stroke rehabilitation[16]. Using data on arm use and on arm function allows to quantify the 'gap' (the so-called non-use of the affected arm) between these two parameters. New insight in patterns of non-use provide opportunities for more appropriate therapeutic options and may help improve stroke rehabilitation.

Several methods are available to measure arm use; of these, accelerometry is generally considered the most suitable because it is objective, easy to use, widely available and has previously been applied[4,10,16,17]. However, measuring arm use during stroke rehabilitation is much less common than measuring, for example, general physical activity[18]. This might be due to practical issues, such as the commercial availability of sensors measuring general physical activity as compared to sensors measuring arm use. However, objectively measuring arm use is also hampered by the complexity of the interpretation of the measured arm movements to describe arm use. For interpreting arm movements, it is necessary to distinguish between arm movements caused by walking or other whole-body movements and arm movements occurring during other body postures (e.g. sitting and standing) since, in these latter postures, arm movements are more likely to be arm use and not the result of body movement (such as arm sway during gait). To enable this, our group developed and validated an easy-to-use arm use monitor to objectively measure arm use with accelerometry[19]. This device measures accelerations of both arms simultaneously and combines these data with body postures and movements (hereafter called 'postures/movements') to obtain a more accurate estimation of arm use. Moreover, this monitor is easy-to-use, non-invasive to wear and relatively inexpensive, making it a clinically applicable monitor.

In this longitudinal study, the new monitor was used to repeatedly measure arm use to examine the recovery of arm use during the first 26 weeks after a stroke. Also investigated was the relationship between arm use and arm function during the first 26 weeks after a stroke.

METHODS

Participants

The present study was part of a larger longitudinal cohort study (PROFITS) aimed to improve prognostic models for motor recovery poststroke. All individuals entering Rijndam Rehabilitation (Rotterdam, the Netherlands) between September 2016 and April 2017 after an ischemic or hemorrhagic stroke were screened by a research assistant. Inclusion criteria were a paretic arm or leg at admission to the rehabilitation center (defined as NIHSS 5A/B or 6A/B 4 ≥ score > 0), aged ≥18 years, a Mini–Mental State Examination of at least 20, and the ability to sit at least 30 min with back support. Excluded from the study were individuals who were ≥ 3 weeks after the stroke. The study was approved by the Medical Ethics Committee of Erasmus Medical Center Rotterdam, the Netherlands (MEC-2015-687) and all participants gave written informed consent.

Procedure

At the start of the study, all participants were inpatients at Rijndam Rehabilitation where they received 'usual care' stroke rehabilitation. Here, the 'usual care' for arm rehabilitation is based on the principles of the Concise Arm and Hand Rehabilitation Approach in Stroke (CARAS)[20]. As the present study was purely observational, this 'usual care' was not adapted, neither the amount nor the content of the rehabilitation. Arm use as well as clinically-assessed arm function was measured at fixed time points after the stroke i.e. at 3 weeks (T1), 12 weeks (T2), and 26 weeks (T3). At T1, the following information was collected on participants and their stroke characteristics. The type, location, and side of the stroke were extracted from the medical records, as was the score on the Montreal Cognitive Assessment[21], assessed by a physician on admission to Rijndam Rehabilitation. The left-right handedness before stroke was determined by asking the participants. Due to the individual goal setting in 'usual care', some participants were still at the rehabilitation center at T2, whereas at T3 all participants were at home and were visited by a research assistant for the follow-up measurements.

Instruments: arm use

Arm use was measured by the Activ8 arm use monitor (Activ8-AUM); participants were asked to wear the monitor for one consecutive week. The Activ8-AUM consists of three Activ8 Physical Activity Monitors (Remedy Distribution Ltd, Valkenswaard, the Netherlands). One of these single-sensor, triaxial accelerometers was attached to the unaffected thigh and the two others to each wrist. This configuration was developed and validated in a previous study[19]. In short, movement counts of the arms (expressing the amount and intensity of movement) are determined based on the acceleration data measured with the sensors on the wrists, while postures/movements are determined based on the leg sensor. The posture/movement detection of the Activ8 in people after stroke was previously validated as well[22]. After the measurement, all data were combined to quantify arm use (described below in Data analysis Activ8-AUM). The sensors on the wrists were attached to the dorsal side with watch-type wristbands and were taken off during the night and during activities involving water, e.g. showering, bathing, and swimming. The leg sensor was attached on the ventral side of the thigh between hip and knee with water resistant, anti-allergic skin tape, and was worn continuously for seven days.

Instruments: arm function

Arm function was measured by the Fugl-Meyer Assessment of the arm (FMA-UE). The FMA-UE consists of nine components examining voluntary movements and the ability to perform arm movements outside of patterns of abnormal joint coupling (flexion synergies)[23,24] outside of synergies. Scores on the FMA-UE range from 0-66, with higher scores indicating better motor function of the affected arm[23,25]. The FMA-UE is often considered a measure of behavioral restitution reflecting the amount of neurobiological recovery of motor function[26].

Data analysis

After each measurement, data from all three Activ8s were downloaded to a PC and were the input for an in-house MATLAB (MathWorks, Natick, MA, USA) program determining arm use. The first step was to synchronize the Activ8s based on the time stamps within the data files. Then, the measurement period was selected. Only waking hours were analyzed, for which we chose 7 am to 10 pm. Within this period, nonwear of the arms was detected when at least one of the two wrist sensors measured zero movement counts for at least one hour. Data were used for analysis when at least three valid days of data were available, defined as at least ten hours of data without nonwear. Then, epochs were selected during which participants were in a sitting or standing position as assessed by the leg sensor. Of these selected data, outcomes were calculated per valid day and then averaged to a mean value per measurement. The primary outcome measure of the present study was arm use defined as the ratio of the movement counts of both arms, calculated as the sum of the movement counts of the affected arm during sitting and standing divided by the sum of the movement counts of the unaffected arm during sitting and standing. The secondary outcome measure, the total movement counts during sitting and standing, was calculated for each arm separately to be able to attribute changed arm use ratio to a change in use of the affected arm, or of the unaffected arm, or a combination of both.

Statistical analysis

In this longitudinal study, most data were presented in a descriptive way on individual level. Generalized estimating equation was used to determine the effect of time on the arm use ratio and the movement counts of each arm, and to calculate the mean arm use ratio for each time point. The measurement occasion (as the factor time) was added to the model as the only independent variable. To assess whether the arm use ratio deviated from the value for healthy persons (reported in literature to be 0.95[27]),

Table 6.1 Characteristics of the participants and information related to their stroke.

Participant ID number	Gender	Age at stroke (years)	Type of stroke	Supra or infra tentorial stroke	Side of stroke	Dexterity before stroke	MOCA score at start of inpatient rehabilitation	End of inpatient rehabilitation (weeks after the stroke)
1	Male	37	Infarct	Supra	Right	Right	27	8
2	Male	66	Venous hemorrhage infarct	Supra	Left	Right	11	6
3	Male	62	Infarct	Supra	Right	Left	27	3
4	Female	38	Infarct	Supra	Right	Right	21	13*
5	Male	61	Infarct	Supra	Right	Right	23	11
6	Male	54	Infarct	Infra	Left	Right	22	14*
7	Female	57	Infarct	Supra	Left	Right	25	12*
8	Male	47	Infarct	Supra	Right	Right	20	10
9	Female	62	Infarct	Supra	Left	Right	27	10
10	Male	58	Infarct	Supra	Right	Right	23	23*
11	Male	65	Infarct	Supra	Right	Right	22	4
12	Male	60	Infarct	Supra	Left	Left		17*
13	Male	48	Infarct	Supra	Right	Right	29	6
14	Male	39	Infarct	Supra	Left	Right	9	11
15	Female	59	Infarct	Supra	Left	Right	25	10

**These participants were measured at the rehabilitation center at T2 (12 weeks after the stroke). MOCA = Montreal Cognitive Assessment.*

a one-sample t-test was performed with 0.95 as test value. All statistical analyses were performed with SPSS for Windows version 24 (SPSS Inc., Chicago, IL, USA) and a p-value ≤ 0.05 was considered statistically significant.

RESULTS

Participants

Included were 15 individuals after a stroke (11 males; mean age 54.6±9.9 years, FMA-UE 23±21 at T1) (Table 6.1). At T1, Activ8-AUM data were missing for three participants: for two because of device failures while the other participant had insufficient valid days (≤ 3 days) both at T1 and T2. At T3, data on arm use were missing for two other participants: for one because of insufficient valid days while the other participant was lost to follow-up. Scores for the FMA-UE were missing for three participants (each at one time point).

Change in arm use

Figure 6.1 shows the course of the arm use ratio during the first 26 weeks after the stroke. At T1, the mean arm use ratio was 0.25±0.14 and showed a significant increase at T2 to 0.42±0.25 (T1-T2 p=0.002) and at T3 to 0.51±0.24 (T2-T3 p=0.009). Figure 6.2 shows the course of the movement counts of the affected and unaffected arm after the

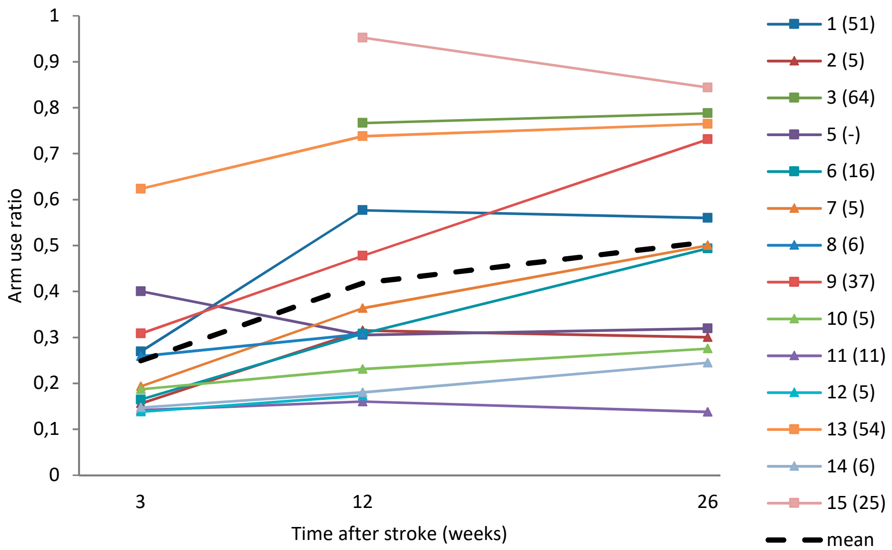
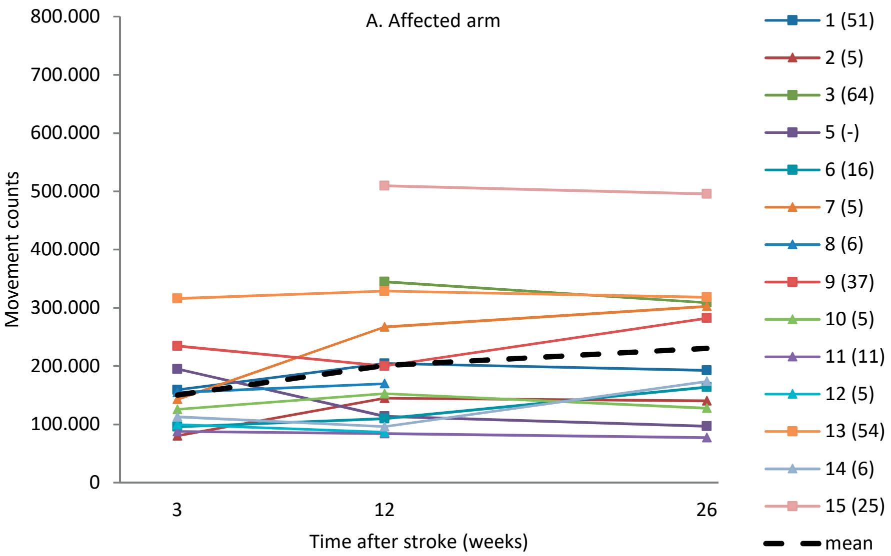


Figure 6.1 Change in arm use ratio in the 26-week period after the stroke. The ID numbers of the 15 participants (right panel) correspond to those in Table 6.1. The numbers between brackets are the scores on the Fugl-Meyer Assessment of the affected arm at 3 weeks after the stroke. Of all participants, the half with the lowest FMA scores are indicated by ▲ and the remainder by n.

stroke. The movement counts of the affected arm were on average lower than those of the unaffected arm; at baseline this was about a four-fold difference while, over time, the



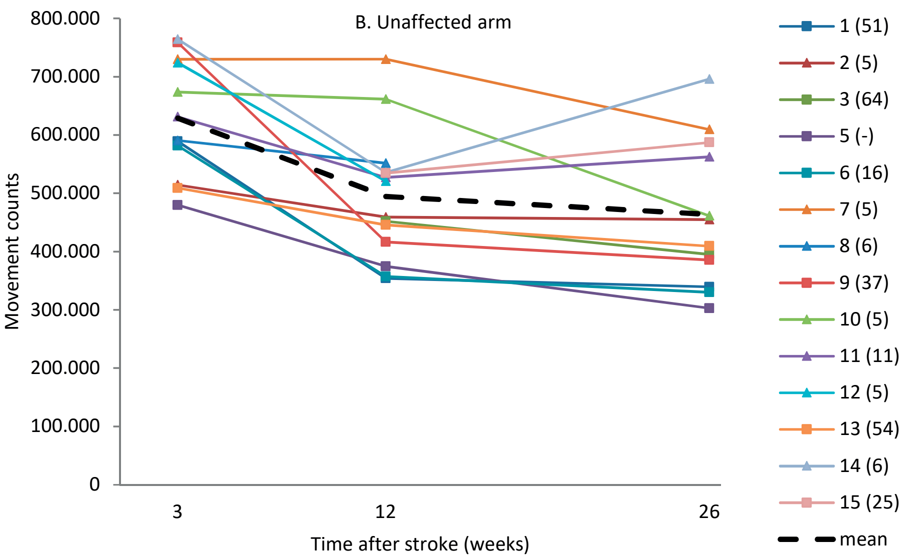


Figure 6.2 Change in movement counts of (A) the affected arm, and (B) the unaffected arm in the 26-week period after the stroke. The ID numbers of the 15 participants (right panel) correspond to those in Table 6.1. The numbers between brackets are the scores on the Fugl-Meyer Assessment of the affected arm at 3 weeks after the stroke. Of all participants, the half with the lowest FMA scores are indicated by ▲ and the remainder by n.

difference decreased to a two-fold difference. The increase of movement counts of the affected arm and the decrease of movement counts of the unaffected arm were significant over time (affected arm T1-T3 p<0.01; unaffected arm T1-T3 p<0.01). The amount of time that participants were sitting and standing, during which arm use was analyzed, showed a significant decrease over time (T1-T3 p<0.01). On average, at T1 participants sat 785 min per measurement day compared with 712 min per measurement day at T3. Even when taking this decrease in sitting/standing into account, the decrease in movement counts of the unaffected arm was still significant (T1-T3 p<0.01). Figure 6.2 also shows that the increased arm use ratio was a combined effect of increased use of the affected arm and decreased use of the unaffected arm. Both figures show large variability between participants, in both level of arm use and in change over time. Although the arm use ratio increased, it remained significantly lower than the average ratio of 0.95 reported for healthy persons[27] (p<0.001 for T1, T2 and T3).

Relationship between arm use and arm function

Figure 6.3 shows the relationship between the arm use ratio and arm function; participants with a better arm function had a larger arm use ratio. However, this is clearer above a FMA-UE of 40.

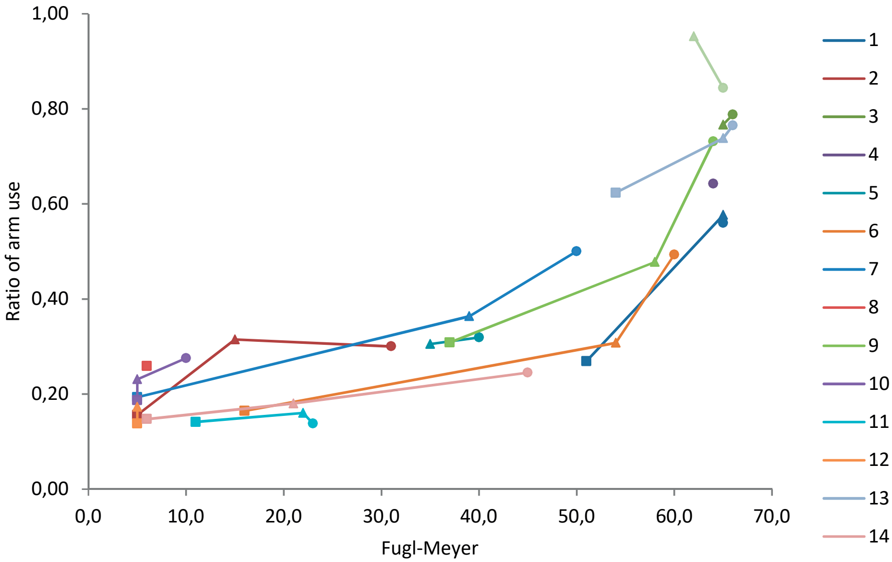


Figure 6.3 Relationship between scores on the Fugl-Meyer Assessment of the affected arm and the arm use ratio. The ID numbers of the 15 participants (right panel) correspond to those in Table 6.1. Symbols: n scores at 3 weeks after the stroke, ▲ scores at 12 weeks after the stroke, and l scores at 26 weeks after the stroke.

DISCUSSION

This longitudinal study with repeated measurements at fixed time points after the stroke, examined the recovery of arm use in daily life and its relationship with arm function during stroke rehabilitation. During the first 26 weeks after the stroke, although the arm use ratio increased caused by an increased use of the affected arm and by a decreased use of the unaffected arm, the unaffected arm was still highly dominant (mean ratios ranging from 0.25 to 0.51). Despite large variability in arm use ratio and recovery pattern, at 26 weeks after the stroke the mean arm use ratio was still lower than that reported for healthy persons[27]. The arm use ratio was positively related to arm function and this was more clearly observed at higher levels of arm function (FMA-UE score >40).

The results of the present study show that the mean arm use ratio was strongly decreased at 3 weeks after the stroke but improved over time, indicating increased symmetrical arm use. However, although the mean arm use ratio increased from 0.25 (T1) to 0.51 (T3), this is still considerably less than the almost symmetrical 0.95 reported for healthy persons[27]. Comparable results on symmetry of arm use after a stroke were found in previous cross-sectional studies: participants (in both the sub-acute and chronic phase) used their affected arm two to four times less than their unaffected arm[4,8,9,12,13]. The only available longitudinal study reported arm use ratios of around 0.6, with large inter-individual variability[14]. The increased mean arm use ratio of the present study indicates a recovery towards a more symmetrical pattern of arm use, resulting from both an increased use of the affected arm and a decreased use of the unaffected arm (Figure 6.2). This indicates that, early after a stroke, individuals compensate for the decreased use of their affected arm by increased use of their affected arm and that this compensatory behavior starts to decrease in the first months after stroke. However, in the present study, the type of rehabilitation that participants received may have played a role in their changed behavior, i.e. during rehabilitation, our participants were stimulated to re-use their affected arm to perform daily-life activities and to use both arms to perform bimanual activities.

In this study, recovery of the arm use ratio in the first 26 weeks after the stroke was highly variable. Although the arm use ratio was considerably affected at 3 weeks after the stroke, some participants had more symmetrical arm use than others, and the significant increase of the arm use ratio over time did not occur in all participants. In some, the ratio increased over the entire 26-week period, whereas in others it increased only in the first 12 weeks after the stroke, or there was no increase at all. Reasons for this variability might include: i) individual stroke characteristics (e.g. initial arm function, dominant arm affected or not, cognitive impairments, etc.) or ii) personal and/or psychological issues (e.g. motivation and self-efficacy)[28-30]. Although we did not assess these types of characteristics, we recommend to include them in future research.

The present results also demonstrate a relationship between arm use and arm function; however, both the overall data and individual data show that this is a nonlinear relationship. This indicates the need for a threshold in arm function before the affected arm is functionally used in daily life and thereby the arm use ratio starts to increase during rehabilitation, irrespective of normalization of arm use ratio. This nonlinear relationship between arm use and arm function was found in earlier cross-sectional studies[11]. Although other studies assessing arm use and arm function also found some relationship they: i) only calculated Spearman's correlation coefficients and did not examine the nature of the relationship, and ii) although accelerometry was used to measure arm use, this was for a maximum of 24 h only[8,9].

Strengths of the present study were its longitudinal design with repeated measurements at fixed time points up to 26 weeks after the stroke encompassing objectively measured arm use in daily life using a validated and standardized accelerometry based paradigm with a one week consecutive observational period. There are also some limitations. First, the sample size is small and some data are missing. Second, received therapy at the rehabilitation center was not standardized, nor recorded, but rather reflected 'usual' care. Therefore, the influence of therapy on arm use cannot be determined. Future studies should take into account the amount, duration, frequency and type (unimanual/bimanual) of therapy that each participant receives.

From a clinical perspective, there is added value for measuring actual arm use in daily life next to assessing arm function and capacity by e.g. FMA-UE or ARAT. The present study shows that there are individuals with a gap between arm use in daily life and arm function within the first 26 weeks after the stroke, indicating being at risk to develop non-use of the affected arm. It is important to target those individuals at risk and develop specific strategies to prevent non-use of the affected arm. We hypothesize that stimulating arm use without having sufficient arm function could be demotivating, while stimulating arm use too late could trigger the development of non-use. Since arm use in daily life and the recovery of arm use after a stroke were found to be highly variable, rehabilitation programs targeting arm use should be preferably be patient-specific to stimulate arm use at the appropriate moment in the aim to optimize stroke rehabilitation.

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