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Proximal arm non-use when reaching after a stroke

K.K.A. Bakhti^{1,2}, D. Mottet¹, N. Schweighofer^{1,3}, J. Froger^{1,4}, I. Laffont^{1,2}

¹Euromov, University of Montpellier, Montpellier, France

²Physical Medicine and Rehabilitation, Montpellier University Hospital, Montpellier,
France

³Biokinesiology and Physical Therapy, University of Southern California, Los
Angeles, USA

⁴Physical Medicine and Rehabilitation, Nîmes University Hospital, Le Grau du Roi,
France

Key Words:

Kinematic analysis; non-use; reaching; stroke; upper-limb

Highlights

- Arm non-use when people “can but do not” likely contributes to disability after stroke
- A hand-reaching test in seated position identifies persons with proximal arm non-use
- Among post-stroke individuals with low impairment, 61% have proximal arm non-use
- Proximal arm non-use is tantamount to a motor reserve for recovery post-stroke

Abstract

After a stroke, many people “cannot and do not” use their paretic upper limb. With recovery, some people “can but do not” use their paretic upper limb and this non-use should be counteracted with specific rehabilitation.

The aim of the study was to quantify one aspect of the non-use: proximal arm non-use when reaching within one’s arm length in 45 post-stroke and 45 age matched controls. Arm use refers to the contribution of the shoulder and elbow motion to the hand movement towards the target. Proximal arm non-use is calculated as the ratio of the difference between spontaneous arm use and maximal arm use.

We found that proximal arm non-use has very good test-retest reliability, does not depend on time since stroke, increases with impairment (Fugl-Meyer) and loss of function (Box & Block), and most importantly, that 61% of patients with lower impairment (Fugl-Meyer >28/42) exhibit proximal arm non-use.

We conclude that quantifying proximal arm non-use in post-stroke individuals provides novel information that complements routine clinical measures. It is likely that proximal arm non-use quantifies one aspect of the motor reserve that therapists can target in patient specific rehabilitation programs.

Keywords: Kinematic analysis; non-use; reaching; stroke; upper-limb

Introduction

About 80% of stroke survivors suffer a reduced ability to use their paretic upper limb, and this is a challenge for therapists [1,2]. Among people with stroke, some “can but do not” use the paretic arm, to paraphrase the title of the first paper that discussed this non-use phenomenon [3], and this non-use should be counteracted with specific rehabilitation [4,5].

The most classical form of non-use after stroke is the non-use of the paretic arm in daily life. Individuals post-stroke often under-use their paretic arm, and compensate for this with excessive use of the non-paretic arm [5]. Using clinical tests, therapists can detect the non-use of the paretic arm by comparing the spontaneous use of the paretic arm in daily life activities (Actual Amount of Use Test or the Motor Activity Log) with the maximal use of the paretic arm when requested to do so in clinical settings [6]. Using a bilateral arm choice test, in which one reaches 100 targets at various distances and directions, researchers can quantify the non-use of the paretic arm by subtracting its probability of use in a spontaneous choice condition from the probability of its use when forced to do so [7]. From the previous measures, it comes that the non-use is not a mere measure of use, but a difference in use. Non-use is the result of the comparison of spontaneous use and maximal use [6], and it is quantified as maximal use minus spontaneous use [7], patient by patient.

Besides paretic arm non-use, a prevalent form of non-use occurs during reaching movements with the paretic arm. Individuals post-stroke often under-use shoulder and elbow joints when reaching within one’s arm length, and compensate with excessive trunk movements [8–10]. Proximal arm non-use is the persistence of such under-use of shoulder and elbow joints for patients with sufficient recovery of arm function. As with all non-use measures, proximal arm non-use is the result of the comparison of spontaneous use and maximal use, which entails two measurements of proximal arm use [5–7]. In the specific case

of seated reaching, trunk compensation can inform about proximal arm use, because the hand is the end effector of the kinematic chain formed by the trunk, the arm and the forearm [11]: patients can compensate for under-use of one joint with over-use of another joint, within certain limits. Using clinical tests, therapists can identify trunk compensation and its counterpart in terms of under-use of shoulder and elbow joints. The Reaching Performance Scale, in which the therapist visually decomposes the reaching movement into its sub-elements, is best suited for that [12]. Using kinematic analysis in a seated reaching movement, researchers can quantify trunk compensation, as well as shoulder and elbow joint contributions [13]. In fine, proximal arm non-use will be given by comparing the spontaneous use of the arm with the maximal use of the arm.

Though measuring proximal arm non-use seems doable, it received little attention up to now, most likely because researchers focused on only measuring trunk compensation per se [9–11,14]. From a rehabilitation point of view, because paretic arm non-use can persist at various stages of impairment [5], measuring proximal arm non-use is important to distinguish recovery from compensation [15] and to quantify the amount of shoulder and elbow movements that a post-stroke individual can relearn to use over therapy [16].

In this study, we aimed to quantify proximal arm non-use when reaching within one's arm length in a seated position, for patients post-stroke and for healthy age-matched individuals. We use kinematic analysis to define a score of proximal arm non-use (PANU), assess test-retest reliability and relation to arm function (Box & Block Test) and impairment (Fugl-Meyer). First, we hypothesize that PANU will be higher for the paretic hand than for the non-paretic hand or for control participants. Second, we hypothesize that PANU will be strongly related to function and weakly related to impairment, because paretic arm non-use can persist at various stages of impairment [5].

Methods

Participants

After preliminary tests to estimate effect size, a total of 45 people who had suffered a stroke (29 men, 16 women) participated in the study. In addition, 45 age-matched participants with no neurological or orthopedic disease were recruited (Table 1). For individuals post-stroke, the inclusion criteria were: first supratentorial hemorrhagic or ischemic cerebral vascular accident; anytime after the cerebral vascular accident; either left or right affected hemisphere; aged ≥ 18 and ≤ 90 ; able to carry out a seated forward reaching task with the paretic arm without trunk compensation (see details of reaching task in Figure 1); had health insurance. Exclusion criteria were: severe cognitive disorders (Mini Mental Status Examination score < 24); severe aphasia with impaired comprehension (Boston Disability Aphasia Quotient $< 4/5$); strong neglect (Bell's test > 15 bells). Out of 68 patients screened for inclusion, 16 could not achieve the hand-reaching task with their paretic arm, 5 could not perform the reaching task without excessive trunk compensation, and 2 had too much spasticity. That left 45 patients included in the analysis.

The Ethics Committee of Nimes approved the study protocol (N°ID-RCB: 2014-A00395-42, Clinical Trial: NCT02326688). The research was carried out in two Physical and Rehabilitation Medicine Departments. All participants provided written consent before inclusion. Participants were not informed about the precise aim of the study to minimize bias.

Experimental setup

The movements of the hand and of the trunk were recorded during a seated reaching task with a CMS 20s system (Zebris Medical GmbH, Isny, Germany). Sensors were placed at the head of the second metacarpal of each hand and at the middle of the sternum. Sampling frequency was 50 Hz and spatial accuracy was better than 1.5 mm. The participant's back

was against the backrest of the chair and both feet were on the floor. The initial hand position was on the middle edge of the table in front of the participant's navel, with fingers of the two hands drawn on the table. The height of the table was modified in accordance with the height of the sitting participant.

Procedure

Participants had to reach a cone (17 cm high, 7.2 cm base diameter, 3 cm upper diameter) placed on the table in front of them just within the anatomical reaching distance for the hand [17]. This task was always performed 5 times with one hand (paretic hand for patients, and right hand for controls), then 5 times with the other hand. The pace was self-selected. In the spontaneous arm use condition, after a “go” signal, the participant was free of constraint and reached the cone in a spontaneous manner. In the maximal arm use condition (Figure 1), the therapist explicitly informed the participant to self-minimize trunk movement so to “force” the patient to maximize arm use. The light touch by the therapist served as an external feedback to maximally use shoulder and elbow active motion to reach the cone [18]. Mandatory and thus “non avoidable” trunk movements for task success were allowed [19]. The total measurement session lasted about ten minutes. The same assessor evaluated each participant twice (24h between the two assessments).

In the left and right panels, the upper panel illustrates the experimental setup and the graph below shows the corresponding distance to the target (mm) as a function of time (s). The blue line represents the hand movement and the red line represents the trunk movement. Δ_{Trunk} and Δ_{Hand} are the changes in distance to the target due to the reaching. Proximal arm use (PAU) in the two conditions (spontaneous-use S_{PAU} , maximal-use M_{PAU}) is computed

from Δ_{Trunk} and Δ_{Hand} following the equation below each panel. PANU is calculated as M_{PAU} (right panel) minus S_{PAU} (left panel).

Kinematic analysis

During seated reaching, the hand is the end effector of the kinematic chain formed by the trunk, upper arm and forearm [11]. Moreover, when reaching at a target, the Euclidian distance from the hand to the target defines the so-called “task space”, which summarizes the subspace that ensures task success [20]. In the task space, the displacement of the hand is the sum of the trunk, shoulder, and elbow movements. As a consequence, proximal arm use was computed from the 3D Euclidian distance from the hand to the target (Figure 1).

In a first step, the start and the end of each reaching movement were determined. The start of the movement was defined when velocity in task space became positive and stayed positive up to peak velocity. The end of the movement was defined when the distance to the target was minimal. Then, the change in distance to the target during the reaching movement was measured, for the trunk and for the hand (Δ_{Trunk} and Δ_{Hand} in Figure 1). Finally, using Δ_{Trunk} and Δ_{Hand} , proximal arm use (PAU) was computed, which was equal to hand movement minus trunk movement relative to hand movement (equation in Figure 1) and refers to the contribution of the arm to the hand movement toward the target.

In a second step, PANU was computed as the difference in arm use between the spontaneous arm use (S_{PAU}) condition and the maximal arm use (M_{PAU}) condition (i.e., $\text{PANU} = M_{\text{PAU}} - S_{\text{PAU}}$, see details in Figure 1).

Finally, PANU was calculated for the paretic and the non-paretic hand, and for the right and left hand in the control group, using the median of the 5 reaching movements in each condition.

Clinical assessments

The patient's upper limb sensorimotor impairment was assessed with the upper limb proximal Fugl-Meyer score, allowing a maximal score of 42 [21]. The patient's upper limb functional capacity was assessed using the Box & Block test, with scores expressed as the number of blocks transferred using the paretic arm compared to the non-paretic arm [22]. Data are summarized in Table 1.

Statistical Analysis

In all analyses, the significance level was set to $\alpha = 0.01$. A Shapiro-Wilk test indicated that patient's data often departed from a normal distribution. As a consequence, the effects of the four experimental conditions (Patient-Paretic, Patient-Non-paretic, Control-Right, Control-Left) were assessed using non-parametric methods [23]. The non-parametric Spearman correlation coefficients were used to assess the relationship between the PANU on the paretic side and arm impairment (proximal Fugl-Meyer score), arm function (Box & Block test) and time since stroke. We also used Spearman correlation to measure the reliability of PANU scores assessed between day 1 and day 2, in patients and controls. With the Bland & Altman graphical method [24], we found that the PANU difference values (retest minus test) were normally distributed so that we report the mean \pm standard deviation.

Results

Proximal arm non-use is reliably assessed on test-retest

The test-retest analysis using the Spearman correlation coefficient indicated that PANU measurements were very reliable for the Patient-Paretic condition ($r_s = .82$, $p = .0000$), but less for the other conditions (Patient non-paretic: $r_s = .53$, $p = .0001$; Control right: $r_s = .66$, $p = .0000$ and left: $r_s = .65$, $p = .0000$).

Using the Bland & Altman graphical method [24], we found that the bias in PANU was: -2.62 ± 7.24 , 0.96 ± 3.37 , 0.38 ± 1.59 and -0.35 ± 1.38 , respectively for the Patient-Paretic, Patient-Nonparetic, Control-Right, Control-Left hand conditions. As illustrated in Figure 2, the PANU difference values between test and retest were closer to zero and less variable for the control participants and the non-paretic hand, in comparison to the paretic hand.

Overall, these results indicate that the PANU assessment was very reliable for the paretic hand, yet with a constant bias towards lower values on the retest one day later.

Proximal arm non-use is higher for the paretic hand

A Kruskal-Wallis H test showed a significant difference in PANU scores between hand conditions ($\chi^2(3) = 54.90$, $p = 0.000$), with a mean rank of 140.19 for Patient-Paretic, 76.19 for Patient-Nonparetic, 73.03 for Control-Right and 72.68 for Control-Left. Post-hoc comparisons using Mann-Whitney U tests (interpreted with Bonferroni corrections) indicated that PANU was higher in Patient-Paretic than in the other 3 conditions (Patient-Nonparetic: $U = 308$, $p = .0000$; Control-Right: $U = 245$, $p = .0000$; Control-Left: $U = 248.5$, $p = .0000$) which did not differ significantly from one another (Patient-Nonparetic vs. Control-Left: $U = 981.5$, $p = .4012$; Patient-Nonparetic vs. Control-Right: $U = 985$, $p = .4122$; Control-Right vs. Control-Left: $U = 1004$, $p = .4727$). Therefore, in agreement with our first hypothesis, the median Patient-Paretic PANU score of 11.7% was significantly higher than in the other conditions, where median PANU scores were similar for the Patient-Nonparetic (2.4%), Control-Right (2.5%) and Control-Left (2.3%) conditions (see Figure 3).

In healthy participants, 99 percent of the PANU distribution lied between -0.5 and 6.5%. This value of 6.5% was considered as a threshold of significant difference from the control group. On the paretic side of participants post-stroke, 99 percent of the PANU distribution lied between 1.3 and 40.5%, with 69% of participants with a PANU value higher than in the control group.

The boxplot represents proximal arm non-use (PANU) for the paretic and non-paretic hand of post-stroke participants (Patient Paretic; Patient Nonparetic) and for the left and right hand of age-matched control participants (Control Right; Control Left). The box represents the interquartile range of PANU scores with the internal horizontal line representing the median score. The “whiskers” extend to the highest and lowest (non-outliers) values. The circles indicate outliers.

Proximal arm non-use relations with clinical assessments

PANU scores were not significantly related to the time since stroke ($r_s = -0.26$, $p = .0897$). Higher PANU scores were related to lower proximal Fugl-Meyer scores ($r_s = -0.51$, $p = .0004$) and to lower Box and Block scores ($r_s = -0.69$, $p = .0000$) scores. Box and Block and Fugl-Meyer scores were related ($r_s = 0.63$, $p = .0000$). All in all, PANU scores were strongly related to hand function (Box and Block test), and moderately related to sensorimotor impairment (Fugl-Meyer score). Therefore, confirming our second hypothesis, PANU increased with loss of function and less so with sensorimotor impairment.

In addition, among the 23 post-stroke individuals with high proximal Fugl-Meyer score ($> 28/42$), 14 were found with PANU $> 6.5\%$ (where 6.5% was the 99th percentile of PANU distribution in controls). Hence, 61% of the less impaired post-stroke individuals had proximal arm non-use.

Discussion

In the present work, we quantified proximal arm non-use in people post-stroke when reaching within one's arm length in a seated position. The score of proximal arm non-use (PANU) was obtained from the difference between the spontaneous use of the arm and the maximal use of the arm. We found that PANU has very good test-retest reliability, does not depend on time since stroke, increases with impairment (Fugl Meyer) and loss of function (Box & Block Test), and most importantly, that 61% of patients with lower impairment (Fugl-Meyer >28/42) exhibit proximal arm non-use.

Proximal arm non-use measures functional motor reserve

Proximal arm non-use quantifies the amount of shoulder and elbow movements that a post-stroke individual does not use spontaneously, but can use when forced to do so. Therefore, PANU measures what a person mobilizes in order to increase “near-to-healthy” recovery of paretic arm function [25] that is, the “functional motor reserve” available to improve reaching movements. Generally speaking, the concept of reserve captures the ability to perform the same task with a damaged central nervous system, provided that damage to the basic control centers remain below a critical threshold [26]. Here, we focus on the motor expression of the reserve [27]. In the maximal arm use condition, patients have no option but to recruit the motor reserve of their paretic arm to complete the task (i.e., they recruit as much shoulder flexion and elbow extension as available). From a rehabilitation point of view, measuring proximal arm non-use is important because it can reveal an “unused potential” of the paretic arm after a stroke [28], with therapeutic consequences [16].

Proximal arm non-use complements classical clinical assessments

The significant negative correlations of the PANU scores with the Fugl-Meyer and the Box & Block scores were expected. Because a higher PANU score implies higher trunk compensation (Figure 1), and because trunk compensation increases with impairment and loss of function [8,10,29], it is logical that higher impairment and lower function result in higher non-use [5], hence higher PANU. However, although PANU provides information related to the Fugl-Meyer and the Box & Block tests, PANU goes beyond the clinical assessment of arm deficit and function. The fact that 61% of the less impaired patients (Fugl-Meyer >28/42) exhibit proximal arm non-use indicates that PANU provides novel information, which can help therapists to better personalize the strategy of post-stroke rehabilitation.

First, PANU directly informs about the non-use, and it focuses on the non-use phenomenon *intrinsic* to the paretic upper limb. Measures of non-use are important to complement clinical assessments and organize the therapeutic strategy [5,7]. PANU provides an objective quantification of the functional motor reserve, patient by patient. For a therapist, PANU directly quantifies the potential of progress that one can expect with specific rehabilitation to promote arm use [25]. Measuring PANU could help therapists deciding which patients would best benefit from specific rehabilitation targeting the use of shoulder and elbow [5,25]. Throughout the course of treatment, the PANU measure could complement conventional clinical assessments to monitor post-stroke upper limb recovery and better evaluate treatment efficacy.

Second, PANU is fast and easy to quantify. Obtaining a PANU score takes about 10 minutes per patient, and the score is more fine-grained and objective than clinical

assessments such as the Fugl-Meyer or Box & Block tests. Moreover, training a therapist to score PANU requires only 15 minutes.

All these make PANU a useful measure to complement classical clinical assessments of the upper arm after a stroke.

Limitations

First, measuring PANU currently necessitates a 3D movement capture system, making the method more suitable for research centers or large hospitals, although, in the future, low-cost movement capture systems from the video game industry could make the method more accessible [30].

Second, PANU remains to be compared to other methods to assess arm non-use after a stroke [5–7]. This impedes any generalization of its validity as a generic measure of the non-use. However, because forward reaching is the building block of many upper limb activities, it is likely proximal arm non-use co-varies with non-use in a larger variety of upper limb activities.

Third, measurement of arm use were set after summarizing all body movements in one dimension that represents task space [20]. This approach does not allow to assess arm joint rotations, scapular rotations or trunk rotations, and their synergistic organization during reaching [14,19].

Finally, sensitivity of PANU scores to change remains to be evaluated by future work.

Conclusion

The low rate of recovery of upper limb function post-stroke is a considerable challenge for therapists. Individualized assessment can help determining the best rehabilitation protocol for each patient. Here, we quantified one aspect of the non-use in people post-stroke: PANU when reaching within arm's length in a seated position. We found

that a high score of PANU identified the patients with a potential functional reserve of arm use. Consequently, we propose that PANU scores be used to select patients for specific rehabilitation programs focusing on the “forced-use” of shoulder and elbow movements as well as to monitor the recovery of upper limb post-stroke.

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Figure 1. Experimental setup and an example of high Proximal Arm Non-Use (PANU) on the paretic side of a post-stroke individual.

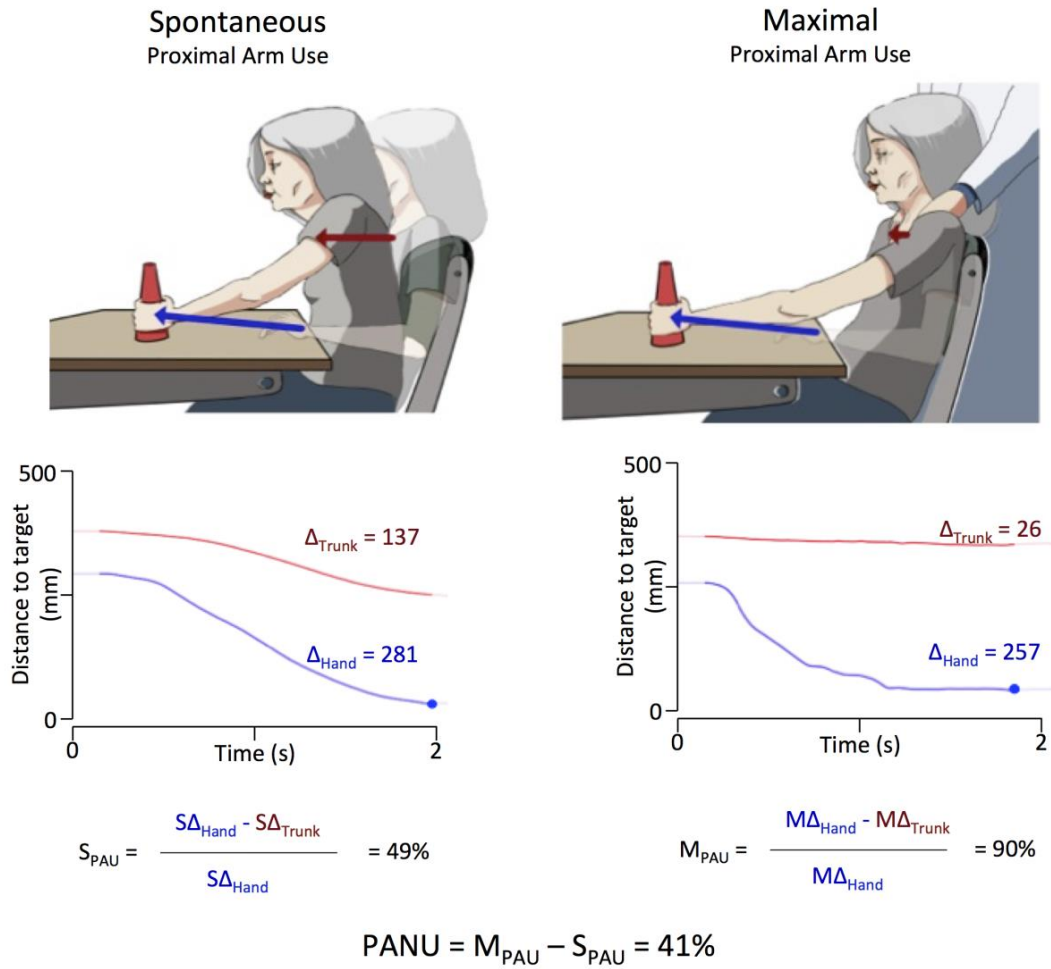
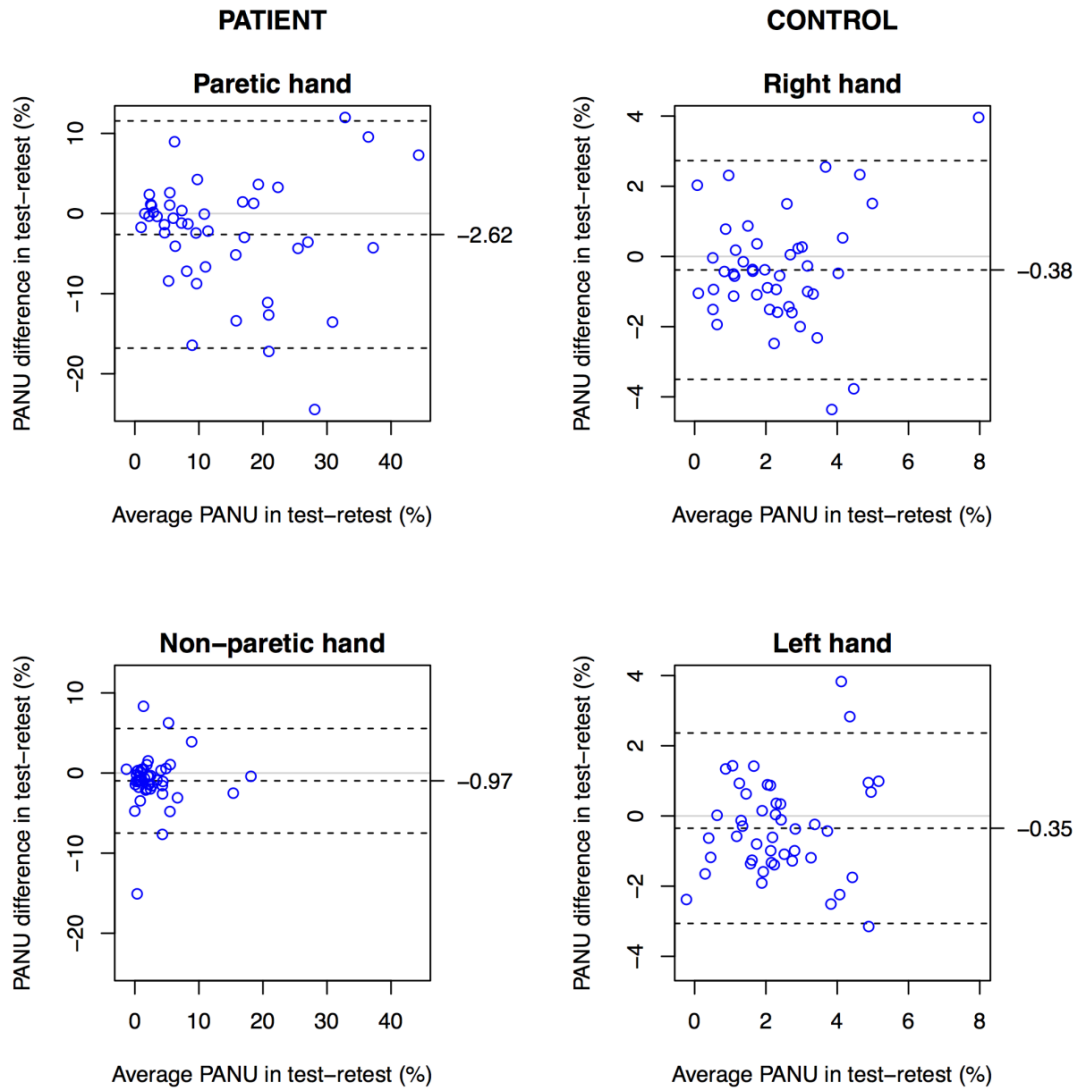


Figure 2. Bland-Altman plots of the repeatability of the measure of proximal arm non-use (PANU).



Note the difference in scale for the post-stroke participants (left panels) and for healthy participants (right panels). The number on the right of each graph is the mean PANU difference from test to retest.

Figure 3. Proximal arm non-use (PANU) for post-stroke and control participants.

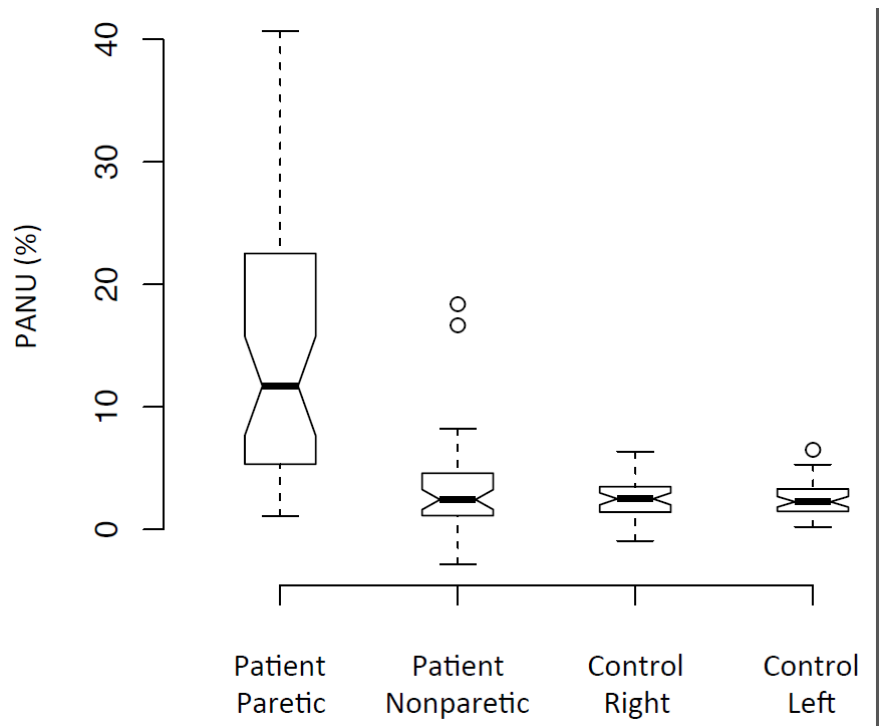


Table 1. Demographic and clinical characteristics of the post-stroke (N=45) and control (N=45) participants.

Domain		Patients Median (IQR) or Count (%)	Controls Median (IQR) or Count (%)
Gender	Women	16 (36.5%)	26 (58%)
	Men	29 (64%)	19 (42%)
Age (Years)		58 (21)	58 (20)
Hand Dominance	Right	40 (89%)	42 (93%)
	Left	4 (9%)	3 (7%)
	Ambidextrous	1 (2%)	
Side of stroke	Right	16 (36.5%)	
	Left	29 (64%)	
Etiology	Hemorrhagic	18 (40%)	
	Ischemic	27 (60%)	
Localization	Middle cerebral artery	17 (38%)	
	Other	28 (62%)	
Delay post-stroke (Months)		8 (31)	
Fugl-Meyer Score (/42)		29 (12,5)	
Box & Block Test (% of nonparetic)		21 (29)	