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Upper-limb movement smoothness after stroke and its relationship with measures of body function/structure and activity – A cross-sectional study

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ABSTRACT

Introduction: After a stroke, upper limb (UL) motor impairments interfere with functional activities and quality of life. Even though a range of assessment tools has been developed to assess UL, few studies explore the interfaces between different levels of functioning after stroke.
Objectives: (a) verify the correlation between movement smoothness and other measures of body function/structure [UL - Fugl-Meyer Assessment (FMA), and handgrip strength]; (b) verify which body function/structure [UL-FMA and/or handgrip strength] could predict UL movement smoothness; and (c) verify if movement smoothness could predict levels of activity, as assessed by the Box and Block Test (BBT).
Materials and methods: Cross-sectional study. Thirty-four individuals with chronic hemiparesis after stroke were enrolled. Measurements of body function/structure included FMA, handgrip strength and kinematic measure of movement smoothness. Levels of activity were measured using the Box and Block Test (BBT).
Results: Movement smoothness showed strong correlation with FMA ($r = 0.70$, $p < .001$) and moderate correlation with handgrip strength ($r = 0.63$, $p < .001$). FMA explained 46.4% of the variation in movement smoothness. Movement smoothness was moderately correlated with BBT ($r = -0.560$, $p < .005$) and predicted 31% of the variation in BBT.
Conclusion: We recommend the use of UL-FMA to predict movement smoothness in chronic post-stroke subjects. This study also showed that movement smoothness influences the level of activity. Then, movement smoothness may be emphasized during stroke rehabilitation to enhance the UL level of activity in chronic post-stroke subjects.

1. Introduction

After a stroke, upper limb (UL) motor impairments significantly affect functional activities and quality of life [1]. UL disability includes different degrees of reduction in motor control, muscle strength and movement smoothness [2,3]. Post-stroke subjects often perform their movements with oscillations and interruptions [4,5] as a result of the lack of movement smoothness. Spasticity, muscle weakness and poor motor coordination interfere with movement smoothness [5,6]. Likewise, improvements in movement smoothness are related to learned coordination and are a good sign of recovery after stroke [4,6,7].

Even though a range of assessment tools has been developed to assess UL impairments, few studies explore the interfaces between different levels of functioning after stroke. The International Classification of Functioning, Disability and Health (ICF) was developed to identify and measure levels of health and disability [8,9]. This classification has three primary levels of human functioning: body function/structure, activities and participation [10]. Clinical scales and analogic equipment are accessible ways by which clinicians can quantify body function/structure. More specifically, UL Fugl Meyer Assessment (FMA) is a clinical scale used to quantify motor impairment [11,12] and analogic dynamometers are commonly used to quantify handgrip strength [13]. These two measures are related to UL motor function after stroke [14–17]. On the other hand, kinematic analysis is

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an instrumented measure of movement smoothness [5,18] and requires specific equipment to quantify body function/structure [5,19].

The Box and Block Test (BBT) is a performance-based measure of gross manual dexterity that allows clinicians to infer about levels of activity [20,21]. Levels of activity and participation are ICF dimensions that are still scarcely assessed in clinical trials. Even though previous studies have shown that motor impairment [14,22,23] and muscle weakness [14] are related to movement smoothness, it is still unclear how these variables interact in post-stroke individuals. Also, it remains uncertain if movement smoothness interferes with the levels of UL activity.

Considering the importance of movement smoothness for the quality of movement after stroke, we aimed with this study: (a) verify the correlation between movement smoothness and other measures of body function/structure (UL-FMA and handgrip strength); (b) verify which body function/structure (UL-FMA and/or handgrip strength) could predict UL movement smoothness; and (c) verify if movement smoothness could predict levels of activity, as assessed by the BBT. We hypothesized that other measures of body function/structure (UL-FMA and handgrip strength) would correlate and predict movement smoothness. We also believed that movement smoothness would predict the levels of activity in post-stroke individuals.

2. Materials and methods

2.1. Study design

This cross-sectional study was approved by the Federal University of Health Sciences of Porto Alegre (UFCSPA) ethical committee (CAAE: 43503615.7.0000.5345) and followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist [24]. This research was conducted at the Movement Analysis and Rehabilitation laboratory at UFCSPA between 2017 and 2018.

2.2. Participants

We recruited volunteers through institutional website and social media. Subjects were eligible to participate if they: a) have had ischemic or hemorrhagic stroke (at least six months before the recruitment); b) were aged between 18 and 80 years; c) were able to reach forward with both UL. Subjects presenting cerebellum or brainstem injury, reporting painful shoulder, adhesive capsulitis or glenohumeral luxation were excluded from this study. All participants signed the informed consent form.

2.3. Upper limb motor impairment

We used the UL-FMA to evaluate UL motor impairment. This scale has nine domains and measures: reflex activity, flexor and extensor synergy, movement combining synergies, movement out of synergy, reflex activity, wrist, hand and coordination/speed. Each item has three possible scores: 0 (not performed); 1 (partially performed) and 2 (performed completely). Total UL score ranges between 0 and 66 points [25].

2.4. Handgrip strength

Handgrip strength was measured using a Jamar® hydraulic hand dynamometer (JA Preston Corporation, USA). Subjects were kept seated, with the shoulder placed at approximately 30° of abduction and 0° of flexion, elbow flexed at 90° with wrist in neutral position. Maximal voluntary handgrip forces were established as the highest values recorded during three maximal voluntary exertions separated by 2-minute rest intervals [16].

2.5. Movement smoothness

We used kinematic analysis during a reaching forward task to evaluate movement smoothness. To acquire data, we used a synchronized optoelectronic system composed by six infrared cameras with acquisition frequency of 100 Hz (BTS SMART DX 400 System, Italy) and two digital video cameras (BTS eVIXTA, Italy). Kinematic analysis was done using an adapted version of the Rab protocol [26]. Fourteen reflecting markers were positioned on the subject's body: three in the head (nasion, right and left zygomatic protuberances), three in the trunk (midsternum, right and left acromions), three in each forearm (right and left olecranon, right and left radial styloid process, and right and left ulna styloid process), and one in each hand (right and left third metacarpal head) [27]. An additional marker was used as a target and placed in the mid-sagittal plane at 80% of subject's arm length [28]. Participants were instructed to lean back on the backrest, keeping the back as straight as possible, with elbows flexed at approximately 90° and palms of hands placed on the table surface. A beep sound was used to trigger the reaching movement and the subject was asked to move one limb at a time as quickly and precise as possible, touch the target and return to the initial position. All subjects started the task with the non-paretic UL and repeated it three times [28].

An algorithm developed in the software Smart Analyzer (BTS Bioengineering Corp. NY, USA) was used to filter the raw data and define the reaching movement phases as follows: 1) going phase, 2) adjusting phase, and 3) returning phase. These parameters were calculated considering the hand marker velocity. The beginning and the end of each phase were defined as the moment in which the hand velocity exceeded (going and returning phases) or dropped (adjusting phase) a threshold of 0.05 m/s [28].

We used the Number of Movement Units (NMU) to quantify movement smoothness. NMU was computed as the number of velocity peaks that exceeded 10% of peak velocity [28]. A movement unit is a set of acceleration, velocity peaks, and deceleration [27]. NMU gives us an indication of the number of online corrections the subject performs during the ongoing phase of a task. Participants who performed more corrections presented higher NMU and, consequently, less movement smoothness [29].

2.6. Box and block test

The BBT was used to assess manual dexterity and evaluate the level of activity. This test is composed of one wooden box divided in two compartments and 150 little cubic blocks (2.54cm^2) [30]. All participants were kept seated and were instructed to move the highest number of blocks from one compartment to another within 60 s. The test score was computed by counting the number of blocks transferred using the affected arm in 60 s. A higher number of blocks transferred indicates better hand dexterity.

2.7. Muscle tone

Modified Ashworth Scale (MAS) assesses the resistance to the passive motion. We used the MAS as an indirect assessment of muscle tone of the paretic UL (shoulder adductors, elbow, wrist, fingers and thumb flexor muscles) [31]. This scale comprises 6 ordinary values ranging from 0 (no tonus increase) to 4 (stiffness) [32]. MAS was used only to characterize the sample.

2.8. Procedures

All subjects performed the full test battery in the following order: (1) UL-FMA; (2) MAS; (3) Kinematic analysis of reaching task; (4) Handgrip strength; (5) BBT. The same trained examiner conducted all the evaluations on the same day.

3. Data analysis

Sample size was determined based on a previous study [22] using a tool available at www.sample-size.net/correlation-sample-size/. The enrollment of 36 participants would ensure that this trial was powered to detect significant correlation between movement smoothness (NMU) and motor impairment (FMA) ($r = 0.45$) with 80% power and alpha value of 0.05.

Data were expressed as mean, median, interquartile range (IQR), standard deviation or 95% confidence intervals (continuous variables) and frequency distribution (categorical variables). Shapiro-Wilk tests were used to evaluate the normality of the continuous variables. Pearson's and Spearman's correlation coefficients were used to verify correlations of parametric and non-parametric variables, respectively. We interpreted the strength of correlations as follows: 0.26–0.49 = weak; 0.5–0.69 = moderate; 0.7–0.89 = strong; and 0.9–1.0 = very strong. Two regression analyses were performed using the stepwise method. First, a multiple linear regression was conducted to determine which predictor (motor impairment or handgrip strength) would better explain the variance in movement smoothness. Then, a single linear regression determined if smoothness could predict the variance in the BBT. All analysis was done using the IBM SPSS statistical software version 21.0. The significance level was set at $p < .05$.

4. Results

Fifty-one subjects with chronic hemiparesis after stroke were recruited. Sixteen were excluded because they did not attend all the eligibility criteria: cerebellar stroke ($n = 4$) and incapacity to perform the reaching task ($n = 12$). Thus, thirty-four participants were included. Table 1 shows demographic data, clinical characteristics and kinematic measures.

Table 2 depicts correlation analyses. Movement smoothness was strongly correlated with UL motor impairment ($r = 0.70$, $p < .001$) and moderately correlated with handgrip strength ($r = 0.63$, $p < .001$). UL-FMA and handgrip strength were inputted into a multiple linear regression model to predict variations in movement smoothness during the reaching task. The only significant predictor was the UL-FMA score, which explained 46.4% of the movement smoothness variance (F = 26.85; p < .001; $r^2 = 0.464$). The corresponding regression equation was: ln *Smoothness* = 1.946 − 0.02*x FMA*.

Movement smoothness was moderately correlated with BBT ($r = -0.560$, $p < .005$). To predict BBT results, we performed a single regression model with movement smoothness as a potential predictor. Simple linear regression showed that movement smoothness was able to explain 31% of the variance in BBT (F = 6.29; $p = .025$; $r^2 = 0.310$). The corresponding regression equation was: $\sqrt{BBT} = 7.465–4.144\,x\ \ln Smoothness$.

Note that the smoothness variable entered in both equations requires the appropriate transformation using the natural log. The BBT measure used in the second equation also needs transformation using the square root.

Table 1
Clinical characteristics.

Characteristics	Min	Max	Median	IQR	$n = 34$
Age, yr	29	89	59	47–69	58.81 (52.22–67.40)
Sex (F/M)					10/25
Time after-stroke, (months)	6	60	23	15–39	20.12 (14.07–26.18)
Type of Stoke (I/H)					31/4

	Min	Max	Median	IQR	Mean (CI)
Muscle tone (MAS)					
Shoulder adductors	0	4	1	1–3	1.69 (0.99–2.38)
Elbow Flexors	0	4	1.5	1–2	1.63 (1.11–2.14)
Wrist Flexors	0	3	1	0–2	1.44 (0.96–1.91)
Smoothness, NMU (units)	2	0.33	3.33	2.3–4.7	3.50 (2.85–4.14)
Motor Impairment, FMA-UL (score)	18	46	31.5	23–51	32.93 (28.81–37.05)
Handgrip strength (Kgf)	2	20	12	8–19	11.06 (8.27–13.85)
Box and Block Test (number)	0	45	2	0.2–20.7	11.50 (3.23–19.76)

Note. Data are 95% Confidence Intervals, Minimum (Min), Maximum (Max), Median and Interquartile Range (IQR). n: Number of participants; yr: years. F: Female; M: Male; I: Ischemic, H: Hemorrhagic; MAS: Modified Ashworth Scale; NMU: Number of Movement Units; FMA-UL: Upper Limb section of the Fugl Meyer Assessment.

Table 2
Correlations.

A. Correlations		UL-FMA	Movement smoothness – NMU	Handgrip strength	BBT
UL-FMA, score	R		**−0.70**	**−0.72**	**0.78**
	p-value		**> .001**	**> .001**	**> .001**
Movement smoothness – NMU, unit	R	**−0.70**		−0.62	−0.56
	p-value	**> .001**		**> .001**	**.025**
Handgrip strength – KgF	R	**−0.72**	**−0.62**		0.09
	p-value	**> .001**	**> .001**		.772
BBT, unit	R	**0.78**	**−0.56**	0.09	
	p-value	**> .001**	**.025**	.772	

Note. BBT, box and block test. NMU, Number of movement units. UL-FMA, Upper limb-Fugl Meyer Assessment. Significant correlations are highlighted in boldface.

5. Discussion

Movement smoothness is an important parameter used in UL rehabilitation. An adequate smoothness denotes the movement has good quality [33]. Unfortunately, equipment needed to measure smoothness is not available to all clinicians. To explore this issue, this study aimed to investigate the relationship between smoothness and other measures of body function/structure and activity in chronic post-stroke subjects. To the best of our knowledge, this is the first study that explores UL movement smoothness - a measure of body function/structure according to ICF assessed by kinematic analysis – and its relationship with other measures that are commonly used in the clinical practice.

Our results indicated that worse the UL movement smoothness, worse is the motor impairment and handgrip strength. Previous studies corroborate with our findings [19,22]. These three variables belong to the same ICF component. Then, the correlation between them was expected. Even though motor impairment and handgrip strength presented similar correlations with movement smoothness, motor impairment (i.e. UL-FMA) was the only predictor able to explain the variance in smoothness. According to our multiple regression results, scores of UL-FMA predicted a large part of the movement smoothness variance (46.4%). Considering that smoothness is a measure of movement quality [14,33], this result shows that an evaluation of motor impairment [12] could be used to infer about movement quality.

Different elements that affect motor coordination may interact with gross manual dexterity. According to our study, the lack of smoothness is one of these elements and could predict almost one-third of the performance in the gross manual dexterity test (BBT). This result means that a measure of body function/structure can determine a significant part of a functional test related to the UL levels of activity. These findings reinforce the clinical relevance of movement smoothness and demonstrate its importance in determining the level of activity. In agreement with our results, a previous study compared movement smoothness with the activity capacity level evaluated by the Action Research Arm Test in acute and subacute post-stroke subjects. Authors found strong correlations between movement smoothness (ICF body function/structure) and the activity capacity level (ICF level of activity) [19].

UL movement smoothness is an important marker of motor control and coordination [4,5,7], and can be influenced by spasticity, muscle weakness and poor motor coordination [5,6]. Our results highlight the importance of using therapeutic strategies to improve this outcome. Sensorimotor, spatiotemporal coordination training [4] and task-specific exercises focusing on minimizing the effort [5] are approaches that must be included in rehabilitation programs to improve movement smoothness in chronic post-stroke subjects.

This study has some limitations that must be considered. Firstly, we used a target without a functional aim to evaluate kinematic smoothness. Affordance perception is critical to adaptive behavior [34]. Then, object affordance may influence movement smoothness. Also, we only assessed the gross manual dexterity as part of the ICF activity domain. Other impairments than gross manual dexterity may interfere with UL activity and lead to participation restrictions. Finally, we did not use any measure of the level of participation. Future studies should focus on smoothness evaluation and its impact on ICF multiple dimensions.

6. Conclusion

This study showed that movement smoothness is correlated with other measures of ICF body function/structure (UL-FMA and handgrip strength). Based on our results, we recommend the use of UL-FMA to predict UL movement smoothness in chronic post-stroke subjects. Still, movement smoothness predicted around 30% of BBT results – a measure classified as ICF activity level. Thereby, movement smoothness influences the level of activity after stroke. Movement smoothness implies motor control and coordination. Then, this variable should be emphasized during stroke rehabilitation to enhance the UL level of activity of chronic post-stroke subjects.

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Declarations of interest

Authors have no conflict of interest to disclosure, including personal relationships, interests, and affiliations over the past 12 months. This information also includes, but is not limited to, grants or funding, employment, affiliations, patents, inventions, honoraria, consultancies, royalties, stock options/ownership, or expert testimony.

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