FEATURES VERSUS STATISTICAL PARAMETRIC MAPPING ANALYSIS TO ASSESS ELBOW MOTIONS IN HEMIPARETIC AND HEALTHY SUBJECTS DURING DRINKING TASK

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Abstract. *Based on three-dimensional analysis, the present study compared two statistical approaches (features and Statistical Parametric Mapping, SPM) to verify differences in the elbow flexion/extension between hemiparetic (non-paretic UL) and age-gender matched healthy subjects (dominant UL) during drinking task. Thirteen chronic hemiparetic and age-gender matched healthy subjects performed drinking task at self-selected speed, which was divided into four phases (reaching, transporting the glass to mouth, transporting the glass to table, returning to initial position). Independent t test was used to compare scalar parameter (starting angle in the reaching phase, point to task achievement - PTA, maximum and minimum angles, and range of motion - ROM) of elbow motion. SPM two-sample t test was used to compare mean kinematic waveforms of elbow for each time-normalized phase between groups. An alpha level of 0.05 was considered. SPM analyses provided a more comprehensive understanding about the elbow motion strategies throughout all phases of task.*

Keywords*: Physical Therapy Modalities, Biostatistics. Nervous System Diseases. Upper extremity.*

1. INTRODUCTION

Stroke is the main cause of neurologic disability in adults worldwide (Murray *et al.*, 2012; Feigin *et al.*, 2014). Approximately 50-70% of stroke survivors have some loss function and disuse of upper limb (UL) contralateral to injury, called as paretic limb, even in chronic phase (Hunter e Crome, 2002; Alt Murphy *et al.*, 2011), which can contribute enormously to reduction in functional independence involving activities of daily living (ADL) (Desrosiers *et al.*, 2003; Faria-Fortini *et al.*, 2011). Although the post-stroke patients became more reliant to ipsilateral UL (non-paretic), there is growing evidence that this UL also exhibits sensorimotor impairments (Niessen, M. *et al.*, 2008; Niessen, M. H. *et al.*, 2008; Robertson *et al.*, 2012; Avila *et al.*, 2013; Kitsos *et al.*, 2013; Dos Santos *et al.*, 2015; Bustren *et al.*, 2017; Hsu *et al.*, 2017; Lixandrao *et al.*, 2017), which can be related to reduced functional capacity and may impact patient outcomes (Kitsos *et al.*, 2013).

According to literature review, during a variety of UL tests, hemiparetic subjects performed slower, less coordinated and accurate movements when performed with non-paretic UL (Kitsos *et al.*, 2013). Moreover, in order to obtain a better understanding of the ipsilateral changes during the ADL, recent studies evaluated the strategies used by the non-paretic UL during the activity of drinking and combing hair using the three-dimensional motion analysis (3DMA) (Bustren *et al.*, 2017; Lixandrao *et al.*, 2017). Thus, by using 3DMA, Bustren *et al.* (2017) observed that movements of the non-paretic limb, in early first month after stroke, were slower, less smooth with a prolonged relative deceleration time, and higher maximal of arm abduction during the drinking, which reached a level comparable with healthy subjects at 3 months post-stroke (Bustren *et al.*, 2017). Moreover, Lixandrão *et al.* found no alterations in the scapula motions of non-paretic limb of chronic hemiparetic subjects at 30°, 60°, and 90° of elevation and lowering of arm during combing hair task (Lixandrao *et al.*, 2017).

Although kinematic scalar parameters bring important information about the joint angles, they hind a understanding of the entire UL motion pattern and summarize the movement strategies to a single value extracted from the kinematic waveform at a specific time instant of the UL motion (Nieuwenhuys *et al.*, 2017; Santos *et al.*, 2017; Simon-Martinez *et al.*, 2017). Moreover, according to non-directed hypotheses testing, the scalar extraction is susceptible to two non-trivial bias sources: post hoc regional focus bias and inter-component covariation bias Type I or Type II error (Pataky *et al.*, 2013). In this sense, an critical and promising approach for continuous field analysis, originally developed to analyze 3D brain function, called Statistical Parametric Mapping (SPM), has been implemented in biomechanics (Friston *et al.*, 1994; Pataky, 2010; Penny *et al.*, 2011; Pataky *et al.*, 2013). SPM is a statistical method that investigate kinematic data in a continuous way, taking into account the interdependence of the data points (time instances of the movements) using random field theory (Pataky *et al.*, 2013; Santos *et al.*, 2017; Simon-Martinez *et al.*, 2017). Thus, this analysis provides a better understanding of movement strategies throughout the task looking for entire motion and reduces the risk of Type I and II error (Nieuwenhuys *et al.*, 2016; Santos *et al.*, 2017).

Nevertheless, to the best of our knowledge, SPM analysis has not yet been used to study the kinematic differences of functional UL activities between non-paretic limb of chronic post-stroke patients, which can contribute to understanding the movement strategies and impairments observed in non-paretic UL. Hence, the aim of this study was to compare the sitting posture and movement strategies between chronic hemiparetic subjects (non-paretic UL) and age-gender matched healthy subjects (dominant UL) during drinking task using feature and SPM analyses of elbow kinematics. We hypothesized that SPM analysis would provide additional results during different motion parts of the drinking task in relation to comparison between hemiparetic and healthy subjects.

2. METHODS

Post-stroke survivors with chronic hemiparesis (Hemiparetic Group: HG), and healthy subjects matched for age and gender (Control Group: CG) were recruited from community. To be included, hemiparetic subjects had to be diagnosed with unilateral stroke of any hemisphere; be able to performed the drinking task without trunk and arm support; and have spasticity level lower than 3 for elbow muscles quantified by Modified Ashworth Scale. In addition, both groups should have minimum score on the Mini Mental State Examination. The following exclusion criteria were considered: cognitive or communication deficits, visual deficits without correction, other neurological diseases (such as, Parkinson), shoulder pain during the tests, any history of joint or muscles injuries of shoulder complex or cervical; and unilateral neglect.

All subjects were underwent a 3DMA (Qualisys Medical AB, Gothenburg, Sweden) of a drinking task. Initially, four anatomical landmarkers were place on medial and lateral epicondyle, and radial and ulnar styloid (Wu *et al.*, 2005) in seated position with knees and ankles flexed at 90°, without trunk and with arms pronates on thigh (staring position). In addition, one cluster with markers was positioned on arm and also located as technical markers. A static trial was performed to determine the reference position and to calibrate the anatomical landmarkers (Cappozzo *et al.*, 1995). Afterwards, the anatomical landmarks were removed (Cappozzo *et al.*, 1995) and the participants were instructed to reach for a glass of water, take to the mouth (including a small sip), take on the table, and return to starting position at self-selected speed. The glass was positioned on a table at a distance of 80% of the UL-length (Santos *et al.*, 2017). Post-stroke subjects performed the task using the non-paretic limb, and healthy subjects using dominant limb three times. One trained physiotherapist performed standardized assessment protocol for all participants. Kinematic data are collected using a sample frequency of 120 Hz.

Data analysis was performed using Qualisys Track Manager by one single evaluator. Initially, drinking task was divided into four phases: (1) reaching for the glass (including grasping), (2) transporting the glass to the mouth (including sipping), (3) returning it to the table (including releasing the grasp), and (4) returning the starting position (Santos *et al.*, 2017). The onset and end of each phase were visually identified by this evaluator using a frame-by-frame movement inspection. Elbow motions at sagittal plane were computed with U.L.E.M.A. software (Jaspers *et al.*, 2014) according to International Society of Biomechanical recommendations (Wu *et al.*, 2005). For feature analysis, the following scalar parameters were calculated: starting angle only for reaching phase, point of task achievement (PTA, angle at the end of each phase) (Petuskey *et al.*, 2007), maximum and minimum angles, and range of motion (ROM, difference between minimum and maximum angle) for all phases (Santos *et al.*, 2017). For SPM analysis, time-normalized kinematic waveforms of elbow flexion/extension were generated.

All scalar parameters showed normality and homogeneity tested by Shapiro-Wilk and Levene tests, respectively. To compare groups for scalar parameters, independent t-test was performed using SPSS software version 17.0 (SPSS Inc, IL, USA). In addition, the effect size was estimated by Cohen's d, mean difference (CG *minus* HG) and 95% confidence interval (Cohen, 1988; Faraone, 2008). By convention, an Cohen's d around 0.2, 0.5, and 0.8 was considered small, medium, and large, respectively (Cohen, 1988). In addition, SPM two-sample t test was used to compare mean kinematic waveforms of elbow flexion/extension for each time-normalized phase between groups. All one-dimensional SPM analysis were implemented using the open-source spm1d code (v.M01, http://www.spm1d.org) in the MATLAB (R2017b, The Mathworks Inc, Natick, MA). For each SPM t test, a statistical parametric map (SPM {t}) created by calculating the conventional univariate t-statistic at each point in the normalized time series, indicating the magnitude of differences. Field smoothness was estimated from temporal gradients of the residuals. Thereafter, given this smoothness, RFT was used to determine an estimation of the critical threshold (t*) for which only 5% (α=0.05) of the equally smooth data would be expected to exceed. After this, the probability which suprathreshold regions could have been produced by a random field process with the same temporal smoothness was calculated (Adler e Taylor, 2009; Pataky, 2010; Pataky *et al.*, 2013; Santos *et al.*, 2017). An alpha level of 0.05 was considered for all analysis.

3. RESULTS

Thirteen post-stroke subjects in chronic phase (10 men and 3 women, 59.46 ±8.88 years old) with moderate UL impairment (Fugl-Meyer UL median score of 43 with range of 28-51) and 13 healthy subjects (10 men and 3 women, 60.69 ±8.13 years old) were included in the study. No differences between groups were observed for starting angles and range of motion (Table 1). However, for all phases, HG showed less extension at end of each phase and higher values of maximum angles, except when they returning to initial position (Table 1). In addition, they also presented higher values of minimum angles for all phases (Table 1).

Table 1. Starting angles, PTA, Maximum angles, Minimum angles and ROM for elbow flexion and extension during all the phases of the drinking task for both groups.

	HG (n=13) $M_1 \pm SD_1$	**CG (n=13)** $M_2 \pm SD_2$	**T (p-value)**	**Mean difference**	**95% CI**	**Cohen's d**
Starting angle (°)	65.95 (12.43)	61.22 (8.22)	-1.144 (0.264)	-4.73	-13.26 to 3.80	0.45
PTA (°)						
Reaching for the glass	71.11 (6.90)	61.78 (7.19)	-3.69 (<0.001)*	-9.33	-15.04 to -3.62	1.32
Transporting glass to mouth	126.69 (5.66)	119.45 (4.36)	-3.30 (0.003)*	-7.24	-11.33 to -3.15	1.43
Transporting glass to table	70.25 (9.34)	60.89 (7.49)	-3.48 (0.010)*	-9.36	-16.22 to -2.50	1.16
Returning to initial position	72.04 (14.50)	69.18 (11.60)	-0.55 (0.585)	-2.85	-13.48 to 7.78	0.22
Max angle (°)						
Reaching for the glass	89.77 (8.26)	81.33 (2.31)	-2.47 (0.021)*	-8.02	-14.74 to -1.31	1.39
Transporting glass to mouth	126.79 (5.60)	119.91 (4.14)	-3.56 (0.002)*	-6.88	-10..87 to -2.90	1.40
Transporting glass to table	125.80 (5.84)	118.79 (4.93)	-3.30 (0.003)*	-7.00	-11.39 to -2.63	1.30
Returning to initial position	88.64 (9.38)	81.59 (10.12)	-1.84 (0.078)	-7.04	-14.95 to 0.86	0.72
Min angle (°)						
Reaching for the glass	65.22 (10.38)	57.66 (5.90)	-2.28 (0.032)*	-7.56	-14.39 to -0.72	0.89
Transporting glass to mouth	71.72 (6.92)	61.64 (7.00)	-3.69 (0.001)*	-10.07	-15.71 to -2.88	1.45
Transporting glass to table	70.13 (9.35)	60.61 (7.49)	-2.87 (0.009)*	-9.52	-16.38 to -2.66	1.12
Returning to initial position	66.85 (12.54)	57.69 (7.53)	-2.26 (0.033)*	-9.17	-17.54 to -0.79	0.88
ROM (°)						
Reaching for the glass	24.55 (3.57)	24.08 (6.47)	-0.23 (0.823)	-0.46	-4.69 to 3.77	0.09
Transporting glass to mouth	55.07 (10.05)	58.26 (9.02)	-0.85 (0.403)	3.19	-4.54 to 10.92	0.33
Transporting glass to table	55.67 (11.32)	58.18 (8.36)	0.64 (0.526)	2.51	-5.54 to 10.57	0.25
Returning to initial position	21.78 (6.28)	23.91 (6.80)	0.83 (0.416)	2.12	-3.18 to -7.42	0.32

HG: Hemiparetic Group. CG: Control Group. M: mean. SD: standard deviation. 95% CI: 95% Confidence Interval. PTA: point of task achievement . Max: maximum, Min: minimum. ROM: range of motion. *Significant differences between groups.

According to SPM analysis, HG subjects showed more elbow flexion during 45-86% and 94-100% of reaching, 0-18% and 43-100% of transporting glass to mouth, 0-31% and 40-100% of transporting to glass to table, and 0-18% of returning to initial position.

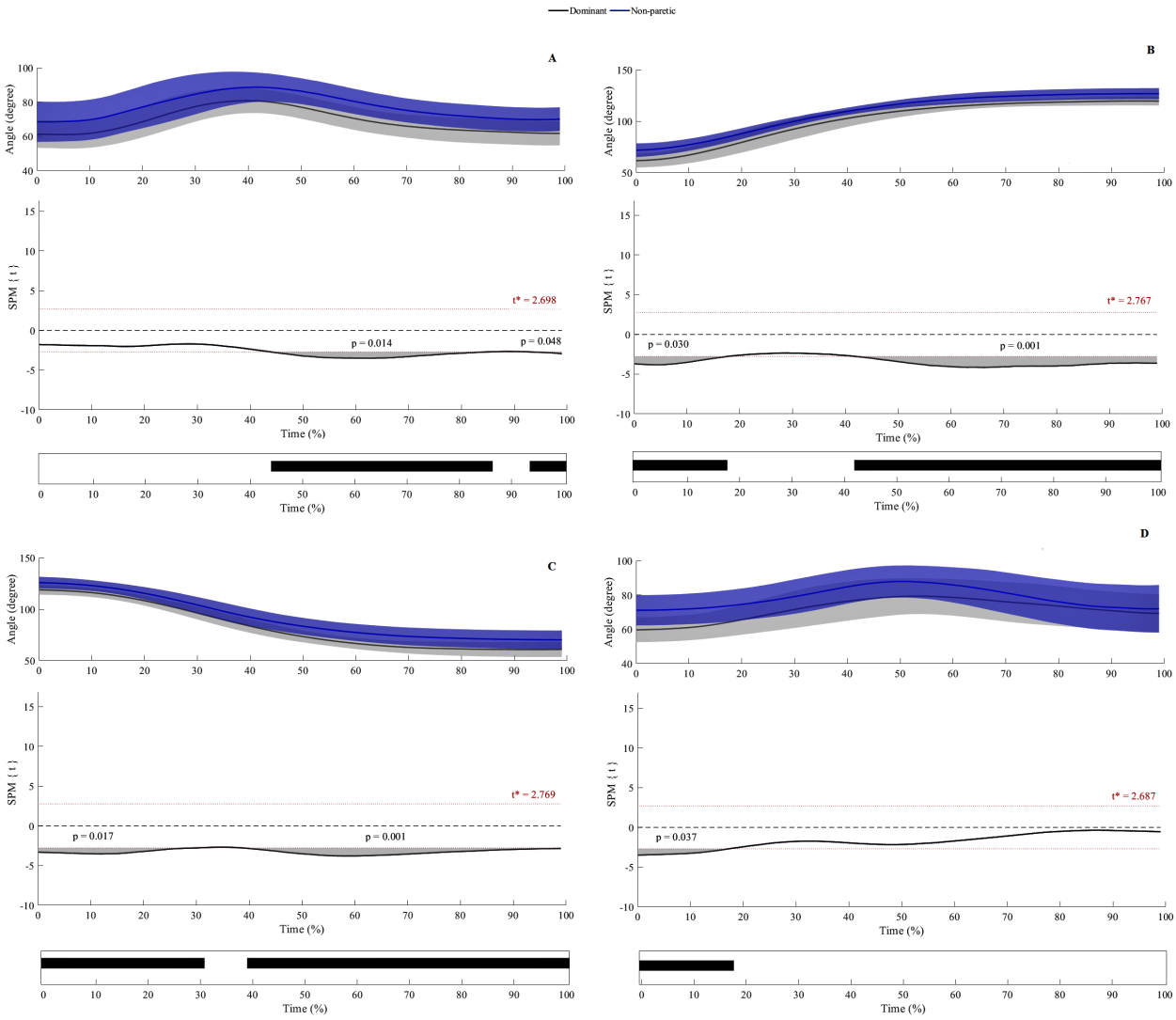

Figure 1. The graphics above show the mean kinematic waveforms of elbow extension/flexion during reaching for (a) reaching for the glass (A) reaching for the glass, (B) transporting glass to mouth, (C) transporting glass to table, and (D) returning to initial position, where the blue line represents non-paretic limb of hemiparetic group and black line, dominant limb of healthy subjects. Middle graphics present SPM {T} as function of the each phase with critical threshold (t*) and p-values of suprathreshold clusters. The black bars below the graphics represent the time during which the differences between groups occurred.

4. DISCUSSION

The present study compared movement strategies of elbow motion between chronic hemiparetic subjects (non-paretic UL) and age-gender matched healthy subjects (dominant UL) during drinking task using feature and SPM analyses. According to results feature analysis did not identified alterations in starting angle and ROM during all phases; however, a lower elbow extension at the end of each task phase was observed, except in the returning phase. Moreover, this analysis found higher values of maximum and minimum angles in each phase. Additionally, SPM provide other important information, for example, at 50% of reaching phase, when the healthy subjects start performing elbow extension in order to reach for the glass, hemiparetic subjects also performed this movement; however, whit less elbow extension. Moreover, when the hand was near glass or touching the glass as well as when the glass was near mouth or during the sip, patients kept their elbow more flexed, which can lead to other compensatory strategies to achievement the task. It was also possible to observe that during the transport to the mouth and to the table, patients performed more elbow flexion or less elbow extension during almost the entire phases, respectively. Therefore, the association of these analyses provided a comprehensive view of joint and motor control strategies during functional tasks

Moreover, these results are in line with previous studies that found deficits in ipsilateral UL. According to literature, the presence of bilateral deficits in post-stroke subjects can be explained by the presence of proprioceptive (Niessen, M. *et al.*, 2008; Niessen, M. H. *et al.*, 2008; Dos Santos *et al.*, 2015) and sensorimotor control deficits (Santos *et al.*, 2016), and muscle weakness (Avila *et al.*, 2013; Santos *et al.*, 2016). Moreover, neural mechanisms can be involved, such as the presence of 10-15% of the corticospinal pathways from cortex to end muscles that uncrossed (Mcnulty *et al.*, 2014), hemispheric lateralization and asymmetry (Kwon *et al.*, 2007) or maladaptive changes in the intact hemisphere (Madhavan *et al.*, 2010). In other words, during the planning and execution of targeted unilateral actions, and during more demanding and complex task, both hemispheres need to be activated, and when one hemisphere was injured, the task performance will be impaired (Haaland e Delaney, 1981; Sunderland, 2000; Mccombe Waller e Whitall, 2004; Bustren *et al.*, 2017).

Interestingly, our results revealed tow important aspects. First, findings underlined the benefits of including the SPM as complementary analysis to obtain a more complete view of movement strategies during UL functional tasks (Nieuwenhuys *et al.*, 2017; Santos *et al.*, 2017). Through the association of feature and SPM analysis, it was possible to identify that, although chronic hemiparetic patients did not present alterations in the initial angles of range of motion, they presented alterations at specific moment of the drinking task. Second, the results point to need to evaluate the ipsilateral UL and not consider it as non-affected side. In addition, if relevant, include bilateral activities during neurorehabilitation programs in order to maximize performance and motor function.

5. REFERÊNCIAS

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7. RESPONSABILITY FOR INFORMATION

The authors are only ones responsible for the information included in this work.