

The drawing test: A measure of spasticity in subjects with hemiplegia caused by stroke

Clemens Eder¹, Mirjana B. Popović^{1,2}, Dejan B. Popović¹, Aleksandra Stefanović³, Stevan Jović³

¹Center for Sensory-Motor Interaction, Department of Health Science and Technology, Aalborg University, Denmark; ²Institute for Medical Research, Belgrade; ³Institute for Rehabilitation “Dr Miroslav Zotović”, Belgrade

Introduction

Paraplegic and hemiplegic subjects often have motor limitations caused by spasticity, that is, the following: 1) decreased dexterity, 2) loss of strength, 3) increased tendon jerks, 4) increased resistance to slower passive muscle stretch, and 5) hyperactive flexion reflexes [Landau, 1980]. Studies applying refined biomechanical and electrophysiological measures have revealed a significant change in the passive properties of the subjects with expressed spasticity [Sinkjær *et al.*, 1993]. Based on such observations, the idea that changes in the intrinsic muscle properties are largely responsible for spastic hypertonia has been accepted [Dietz, 1997]. Other investigators conclude, however, that the major cause of spastic muscle hypertonus is the widely accepted pathological increase in the stretch reflex activity [Ashby *et al.*, 1987].

Measuring spasticity is complex, and not very reproducible. One of the widely accepted methods to measure spasticity is the modified Ashworth scale [Bohannon *et al.*, 1987] that assesses increase of muscle tonus to passive movements. In our clinical evaluations of new therapies in hemiplegic subjects [Popović *et al.*, 2002] we introduced a drawing test [Eder *et al.*, 2002] as a measure of the ability to coordinate the shoulder and elbow movements during simple point-to-point movements in the horizontal plane. We found very high correlation between the ability to perform daily tasks and the score of the drawing test [Popović *et al.*, 2002]. In parallel, we found that the gains in the drawing test scores coincided with the overall decrease in spasticity measures by the modified Ashworth scale [Bohannon *et al.*, 1987]. The purpose of this study was to analyze in details the drawing test, i.e., drawing on the digitizing board, of hemiplegic subjects with different levels of spasticity and establish the correlation between the spasticity and the scores in the drawing test.

Methods

Subjects and task. Sixteen hemiplegic patients with different levels of spasticity volunteered in the experiments. Hemiplegic subjects were seated in a comfortable chair so that their arm rested on a digitizing board positioned within their workspace. Subjects were asked to sequentially track the sides of a square (20 x 20 cm) on a digitizing drawing board. The trajectories were recorded (Calcomp III, precision of ± 1 mm, sampling rate 75 Hz) in parallel with the surface EMG from prime movers of the shoulder and elbow. The corners of the square were labeled with letters A, B, C, and D (Figure 1) starting from the left bottom corner in clockwise direction. Subjects were specifically instructed to “connect” two neighboring corners (e.g., AB, BC, CD, DA), to stop the hand at the corner, and to relax their muscles when the hand was at the corners. Before the recording sessions subjects practiced the drawing with the mouse for a short period of time. If a hemiplegic subject could not hold the magnetic mouse, then it was attached to the hand with a tape. Subjects were asked to move their paretic and non-paretic arms in clock wise and counter-clock directions for nine times. The local ethics committee approved the experiments, and the subjects signed the informed consent.

Outcome measures. The quality of recorded drawings was analyzed separately for every line connecting two neighboring corners. The measures of the quality were the timing and tracking errors. The beginning and end of movement were detected by setting a threshold to 15% of maximum movement speed within a trial. The lack of coordination contributed to a limited range of movement and was characterized as departures from the desired end-points. These were measured as distances from the y-margin and x-margin respectively (Figure 1).

Variations from straight movements were defined as the variance from the trajectories' geometric center in horizontal and vertical direction. We compared corresponding movements of the paretic and normal arm, e.g., a movement AB executed by the left arm with the right-arm movement along the side DC.

Results and Discussion

Here we only present representative shoulder flexion/elbow extension movement with normal and paretic arms for two hemiplegic subjects. Subject #4 had low spasticity. His modified Ashworth score was 1 in the left paretic arm. The movement along the square side AB was performed by the paretic arm, and the movement along the side DC by the normal arm (Figure 1, right panel). Subject #14 was more spastic compared with Subject #4, and his modified Ashworth score was 3 in the left paretic arm. The movement along the side AB was performed by the paretic arm, and the movement along the side DC by the normal arm (Figure 1, left panel). Subjects were asked to repeat the movement along both AB and DC sides of the square for nine times, and all trials were included in Fig. 1. Outcome measures for both subjects are presented in Table 1.

The movements with the normal arm were smooth and lasted between 0.5 and 1 seconds. Both hemiplegic subjects could follow the corresponding side of the square. The excursions from the desired path were small, that is, the movement could be characterized as accurate.

The movements with the paretic arm were slower (≈ 4 seconds) compared with the movement by the normal. Subject #14 could not move the arm along the side of the square. Figure 1 shows that there were substantial differences between nine trials to move the paretic arm along the side AB of the square. During the drawing test subjects were not able to see their previous trajectories.

Future work

The results presented here are a part of the validation of the drawing test as a measure of functional abilities of humans with impact on reaching and grasping. The drawing test was evaluated in able bodies humans, and excellent reproducibility of the test confirmed [Eder et al., 2002]. The drawing test was used for assessment of functional gains resulting from new rehabilitation therapies in hemiplegic subjects [Popovic et al., 2002]. The improvement in functioning of hemiplegic subjects was followed by the over all decrease of spasticity in the paretic arm; thus, the hypothesis was developed that there is a correlation between the spasticity measures, that is, Ashworth and modified Ashworth scale grades and the results from the drawing test.

The validation of the drawing test will be continued in order to collect sufficient statistically significant evidence that the drawing test could be used as a quantitative measure of arm spasticity. In parallel, the validation of the drawing test included the recordings of EMG activity of the shoulder and elbow prime movers. These results will be in future correlated with the Ashworth scale grades, and more detailed analysis of the physiological changes that are responsible for spasticity.

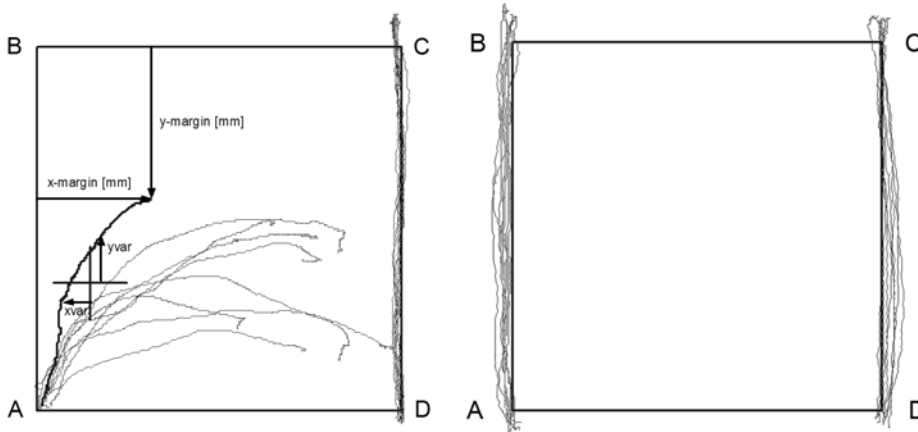


Figure 1. *Left panel:* Nine repetitions of shoulder flexion/ elbow extension movement along the 20 cm long sides of the square ABCD with paretic and normal arms. Left panel shows movements of Subject #14 (modified Ashworth grade 3), while the right panel shows movements of Subject #4 (modified Ashworth grade 1). Subject #14 was right-handed with affected left side, and Subject #4 right handed with the affected left side. The measures used for analysis in Table 1: x-margin, y-margin, xvar and yvar are only depicted for the first trajectory. The x-margin and y-margin describe the distance of the trajectory end-position to the desired corner B or C, whereas xvar and yvar show the variance in x- and y-direction respectively, measured relative to the geometric center of the trajectory (cross in left panel).

Table 1. Outcome measures for Subject #14 (first two rows) and Subject #4 (last two rows). ASW indicates modified Ashworth grade. Data are separated for movements DC (normal arm) and AB (paretic arm). Numbers represent average measures for nine trials, numbers in brackets indicate the standard deviation.

| Pat/ASW | DC/AB | t [ms] | xmargin [mm] | ymargin [mm] | xvar [mm ²] | yvar [mm ²] |
|---------|-------|----------------|---------------|----------------|-------------------------|-------------------------|
| 14/3 | DC | 1222 (110) | 5.3 (1.8) | -9.4 (5.6) | 2.4 (1.7) | 4459 (243) |
| | AB | 4477 (3425) | 114 (57.3) | 128 (26.6) | 1799 (1609) | 490 (436) |
| 4/1 | DC | 518 (125) | 5.7 (3.2) | -0.2 (20.7) | 3 (3.7) | 4192 (928) |
| | AB | 663 (122) | 10.2 (3.3) | 9.6 (20.3) | 10.6 (6.6) | 3782 (819) |

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