The Drawing Test as a Tool for Evaluation of Motor Impairment: Correlation with the Wolf Motor Function Test

Milica S. Isaković, Andrej M. Savić, Miloš D. Kostić, Ljubica M. Konstantinović, and Mirjana B. Popović

***Abstract*—The aim of this study was to examine the correlation between the measures based on the Drawing Test (DT) in horizontal plane and the score on the shoulder-elbow tasks of the Wolf Motor Function Test (WMFT). Fourteen stroke survivors who participated in the study performed the two tests before and after the four-week rehabilitation program. The DT task included drawing a square in the predefined template and was performed using a digitizing board and a mechanical manipulandum. Two outcome measures of the DT were evaluated: movement duration and the distance of the movement endpoint from the target corner. Significant correlations were found between WMFT time and DT movement duration in contra lateral proximal to distal direction (before: r = 0.61, p = 0.019; after: r = 0.57, p = 0.034) and WMFT score and DT distance from distal ipsilateral corner (before: r = -0.69, p = 0.006; after: r = -0.58, p = 0.031).**

***Index Terms*—Stroke; Drawing Test; Wolf Motor Function Test; Shoulder/Elbow Movements.**

I. Introduction

STROKE survivors often suffer from motor impairment of one of the upper limbs (UL) caused by spasticity, muscular weakness and disturbed muscle synergies. Assessing the current condition of the hemiplegic UL and predicting the course of regaining dexterity is of great importance for the clinicians, in order to optimize the rehabilitation treatment [1]. The UL movement assessment is a qualitative and/or quantitative procedure which involves evaluating the level of a patient's functional and motor abilities. Commonly used clinical tests, such as Fugl-Meyer assessment of sensorimotor recovery after stroke (FMA) [2], Wolf Motor Function Test (WMFT) [3], Action Research Arm Test (ARAT) [4], and Barthel ADL Index (BI) [5], take 10-35 min to administer, represent a subjective evaluation of the clinician performing the test and may show a lack reproducibility. In order to obtain objective, consistent, reproducible and fast quantitative evaluation, haptic robot based methods for the assessment of the quality of UL movements have been investigated [6-9]. One of the proposed methods is the Drawing Test [9]

The *Drawing Test (DT)* was introduced as a measure of coordination of the elbow and shoulder joints in the clinical trial evaluating functional electrical therapy [9]. The subjects were asked to draw a square with a side length of 20 cm on a digitizing board in the horizontal plane. The reproducibility of the test was validated in able-bodied subjects [10]. Drawing the square was found to be cognitively demanding task since it included multiple changes in the direction of the movement, so the DT was simplified [11]. The modified DT required from subjects to make self-paced radial, point-to-point movements within their horizontal working space. The outcome metric, related only to the kinematics of the movement, correlated highly with Ashworth Scale score, standard clinical measure of spasticity. User-friendly software which enables testing using DT task and automatic detection of parameters that quantify the quality of movement (speed, smoothness and precision) was presented in [12]. The results from 10 patients showed significant increase of proposed metric scores after the rehabilitation therapy.

The results of the previous studies [9-12] suggested that the Drawing Test is a useful quantitative assessment tool of UL disability. Due to its comprehensiveness, simplicity and correlation with Ashworth Scale, DT may be included in the evaluation of efficacy of the rehabilitation treatment.

The aim of this study was to examine the correlation between the DT and the clinical measures assessing UL motor ability. The clinical outcome measures were based on the *Wolf Motor Function Test (WMFT)*, since it includes shoulder/elbow movements in the horizontal plane and is performed by a subject seated in front of the table, similar as the DT. The WMFT is an activity-based test that evaluates upper extremity performance via timed and functional tasks. The WMFT has shown high reliability and validity for activity-based evaluation of UL function [13]. Each item is rated on a 6-point Functional Ability Scale (FAS) and

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summed into total WMFT-FAS score. We used a 17-item WMFT, consisting of 15 function-based tasks and two strength tasks, each scored from 0 to 5 for a maximum score of 75 points [14]. We considered the subset of 7 WMFT tasks pertaining solely to shoulder/elbow movements – “forearm to table” (side and front), “forearm to box” (side and front), “extend elbow” (with and without weight) and “reach and retrieve”. To the best of our knowledge, this is the first evaluation of the correlation between the WMFT and the measurement of the UL movements using the drawing board.

II. Methods

A. Subjects

Fourteen stroke survivors (13/1 male/female, age 59±7 years, months after stroke 2.5±2.1) with right side hemiparesis evaluated in this paper were the participants in one broader study. The study was approved by the Ethics Committee of the Clinic for Rehabilitation “Dr Miroslav Zotović” affiliated with the University of Belgrade - Faculty of Medicine, Belgrade, Serbia. All participants signed the informed consent form and all research procedures were performed in accordance with the Declaration of Helsinki.

B. Rehabilitation program

The subjects were asked to perform the Modified Drawing Test and Wolf Motor Function Test before and after four weeks of conventional rehabilitation program, provided 5 days per week by a physiotherapist experienced in neurorehabilitation. The program involved two 30-minutes sessions of physical and occupational therapy (passive stretching within submaximal range of motion to inhibit spasticity, active-assisted movements, functional tasks, and daily living activities) and physiotherapy (range of motion exercises, gentle stretching, splinting/casting, facilitation of active voluntary movement, and exercises to improve endurance, balance, strength, and gait).

C. Measurement system for DT

The experimental hardware consisted of the mechanical interface and the signal recording system. The testing setup is shown in Fig 1. The planar manipulandum was a custom-made mechanical rig with low inertia and virtually no friction. The rig consisted of two pieces and a handle attached to the open end of one rig’s segment. The planar movement was performed by pushing/pooling the handle in various directions. The movement of the handle was recorded with the cordless mouse attached to the rig’s end and Intuos 4 XL drawing board (Wacom, WA, USA), with 100 Hz sampling frequency and 0.05 mm spatial resolution. The detailed description of the system is presented in [15].

D. The Drawing Test procedure

The testing procedure requires from subject to draw with their stroke affected hand a square within the two concentric squares (with side lengths of 19 cm and 21 cm) presented as a template, with maximal speed and precision. The subjects performed three trials before and after the rehabilitation program. The course of movements was from the proximal contra lateral corner (vertex A – Fig. 1), proceeding to the distal contra lateral corner (vertex B – Fig. 1), and continued to cover the complete rectangular path (vertices C, D, and A, respectively – Fig. 1). Subjects performed movements while seated in front of the drawing board, with their trunk secured in a harness in order to prevent compensatory body movements (Fig. 1). The testing procedure was supervised by an experienced therapist from the Clinic for Rehabilitation "Dr Miroslav Zotović", Belgrade, Serbia.

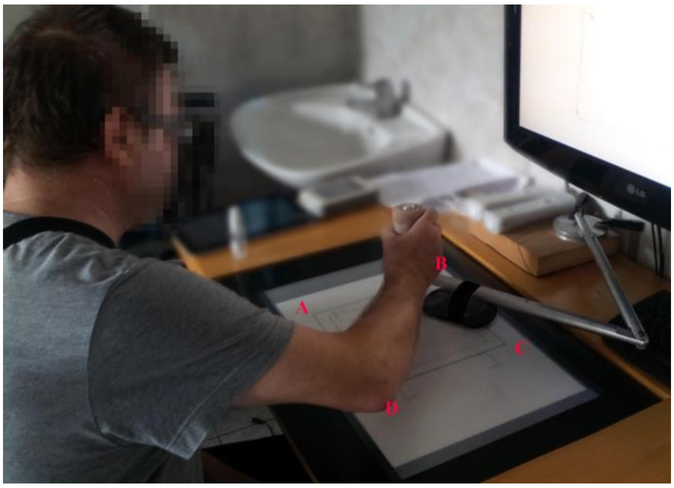

Fig. 1. Subject performing the Drawing Test procedure.

E. Outcome measures

Two outcome measures of the Drawing Test were evaluated: movement duration (T_{DT}) and the distance of the movement endpoint from the target corner (R_{DT}), computed separately for four directions of the movement, i.e. four sides of the square (AB, BC, CD, DA). In order to segment the square drawing into four sides, an algorithm for detection of square vertices presented in [12] was used. T_{DT} was calculated as the time between the beginning and the end of the movement along the desired direction. R_{DT} was calculated as the distance between the two points with known coordinates: the movement endpoint and the desired target endpoint (vertex). The outcome measures were averaged across three trials of the DT.

The clinical outcome measures were based on the 7-item subset of WMFT. WMFT time (T_{WMFT}) was calculated as the average time for performing 7 selected items. WMFT score (S_{WMFT}) was obtained as the sum of scores for 7 selected items, with maximum possible score of 35.

F. Statistical data analysis

The results of Kolmogorov-Smirnov test suggested that the three outcome measures (T_{DT}, R_{DT}, and S_{WMFT}) were normally distributed, while T_{WMFT} had to be log-transformed ($\log(T_{WMFT})$) in order to meet this assumption. Matched-pairs t-test was performed for each outcome measure to evaluate the differences between two time points (before and after rehabilitation). The correlation between the Drawing Test and the WMFT was assessed using Pearson’s linear correlation coefficient (r) and the corresponding p-value between T_{DT} and $\log(T_{WMFT})$, and between R_{DT} and S_{WMFT}. The threshold for the statistical significance was set at $p < 0.05$.

III. Results

The outcome measures of the Drawing Test for four directions, before and after the rehabilitation program, are presented in Fig. 2 (movement duration) and Fig. 3 (distance). The results are first averaged across three trials of the DT for each subject, and subsequently across 14 subjects. The WMFT outcome measures are presented in Fig. 4 (left – WMFT score, right – log (T_{WMFT})). Statistically significant differences in mean outcome measures before and after the rehabilitation are denoted using asterisks.

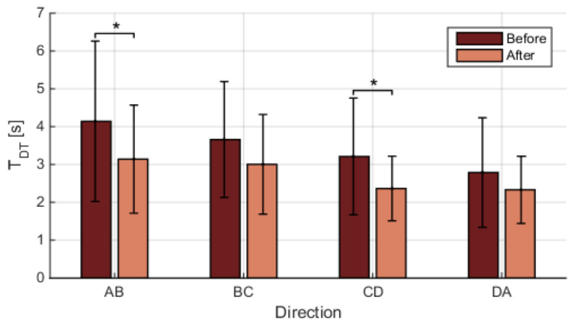

Fig. 2. The Drawing Test movement duration across 4 directions for 14 subjects. The results are represented as mean ± standard deviation. Horizontal bar with asterisks indicates the statistically significant difference in the mean T_{DT} between two conditions (*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$).

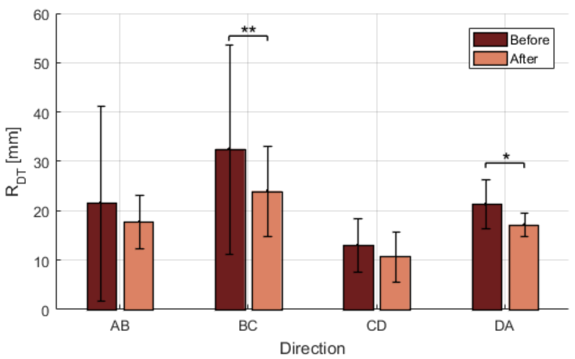

Fig. 3. The distance of the movement end points from the target corners of the Drawing Test across 4 directions for 14 subjects. The results are represented as mean ± standard deviation. Horizontal bar with asterisks indicates the statistically significant difference in the mean R_{DT} between two conditions (*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$).

The correlations between the Drawing Test and the WMFT outcome measures are shown in Table 1 for the separated DT directions (square sides – AB, BC, CD, and DA). The correlation between S_{WMFT} and R_{DT} is negative and significantly different from zero in BC direction, both before and after the rehabilitation treatment (in bold in Table 1). The positive correlation between T_{DT} and $\log(T_{WMFT})$ is statistically significant in AB direction (in bold in Table 1).

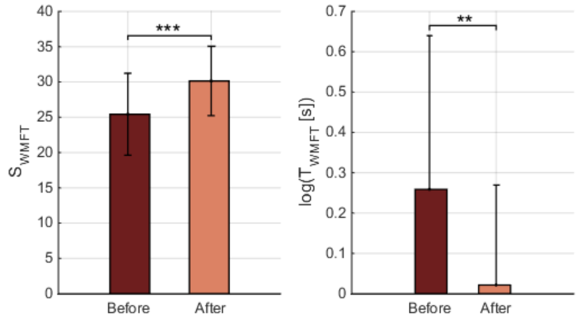

Fig. 4. WMFT score (left) and log-transformed average WMFT time (right). The results are represented as mean ± standard deviation for 14 subjects. Horizontal bar with asterisks indicates the statistically significant difference in the mean outcome measure between two conditions (*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$).

TABLE 1

Pearson's correlation coefficients between the clinical and Drawing Test-based (individually for each direction) outcome measures, and the corresponding p-values. Statistically significant results ($p < 0.05$) are bolded.

Direction	Correlation between R_{DT} and S_{WMFT}		Correlation between T_{DT} and $\log(T_{WMFT})$	
	Before	After	Before	After
AB	r = -0.42 p = 0.132	r = -0.54 p = 0.068	**r = 0.61** **p = 0.019**	**r = 0.57** **p = 0.034**
BC	**r = -0.69** **p = 0.006**	**r = -0.58** **p = 0.031**	r = 0.24 p = 0.404	r = 0.49 p = 0.071
CD	r = -0.37 p = 0.192	r = 0.22 p = 0.459	r = -0.03 p = 0.912	r = 0.19 p = 0.519
DA	r = -0.32 p = 0.264	r = -0.28 p = 0.335	r = -0.11 p = 0.707	r = 0.11 p = 0.683

Values for each subject and the Least-Squares approximation are presented in scatter plot (left – before therapy, right – after therapy) for the (BC direction R_{DT}, S_{WMFT}) in Fig. 5, and for the (AB direction T_{DT}, $\log(T_{WMFT})$) in Fig. 6.

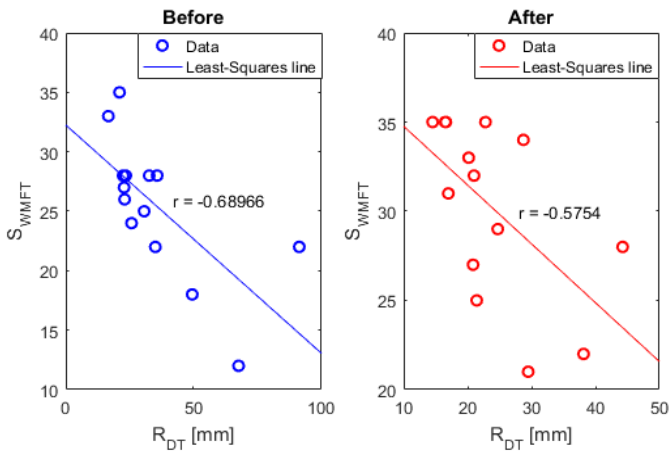

Fig. 5. The scatter plot of the distance from target vertex in BC direction and WMFT score for 14 subjects, before (left) and after (right) the rehabilitation program (statistically significant – second row left column in Table 1).

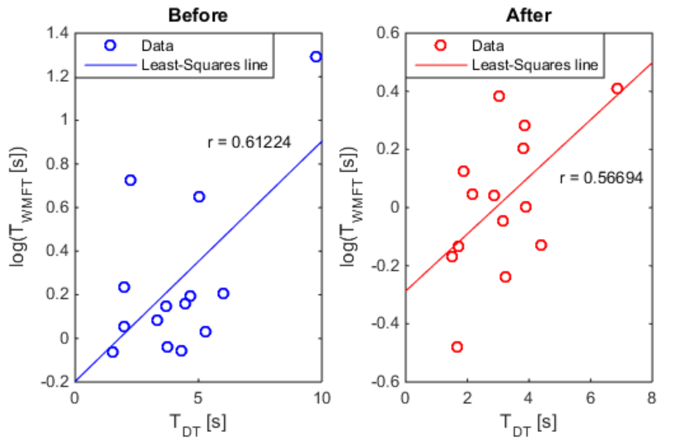

Fig. 6. The scatter plot of the movement duration in AB direction and log-transformed WMFT time for 14 subjects, before (left) and after (right) the rehabilitation program (statistically significant – first row right column in Table 1).

IV. Discussion and Conclusions

The clinical results showed improvement of motor function after the therapy, reflected both in significant increase of WMFT score and decrease of WMFT time (Fig. 4). The two measures evaluated from the Drawing Test (movement duration and distance from target), applied separately for four square sides showed the same trend of all the results as WMFT, although significant only for some. Analysis of movement duration showed significant decrease of T_{DT} after the therapy in two vertical directions, AB and CD (Fig. 2). The distance R_{DT} significantly decreased after the therapy in two horizontal directions, BC and DA, i.e. when reaching the vertices C and A (Fig. 3).

Statistically significant correlation between the R_{DT} and S_{WMFT} was found only in BC direction, while for the time-based measures – T_{DT} and $\log(T_{WMFT})$ significant correlation was only in AB direction.

Stroke survivors find especially challenging, due to spasticity and disturbed muscle synergies, movements which include shoulder and elbow extension [16]. The DT evaluates shoulder-elbow movements in horizontal plain in four directions, each of them requiring specific muscle coactivations:

- AB – elbow extension and shoulder flexion (with shoulder slightly adducted in horizontal plane during the whole movement);
- BC – horizontal shoulder abduction with fully extended elbow;
- CD – elbow flexion and shoulder extension;
- DA – shoulder adduction.

Task execution in BC direction (distal contra lateral to ipsilateral) requires maintaining maximal elbow extension and shoulder flexion and rising shoulder (increasing abduction) while reaching the vertex C. Therefore, the movement in this direction is associated with subject's ability to reach and maintain high range of motion in horizontal plane. Since the WMFT score represents overall quality of movements and is highly dependent on the range of shoulder/elbow motion, the correlation with R_{DT} is the highest in BC direction, as expected.

The highest correlation between WMFT and DT times was observed in AB direction (contra lateral proximal to distal). This might be due the fact that the elbow extension (dominant movement in AB direction of the DT) is performed in the same manner throughout DT task in AB direction and the majority of WMFT tasks assess the elbow function. Contrarily, the shoulder movements, which are more prominent in other directions of the DT task, differ more between the tasks of the two tests. In many of the WMFT tasks that evaluate shoulder function are performed outside the horizontal plane and employ other movements, such as abduction and rotation. So the similarity of the elbow related tasks within the WMFT and AB direction of the DT might have enhanced the observed correlation between the outcome measures.

Although the measures extracted from the DT in all directions follow the same trend as WMFT-based measures, our results suggest that AB and BC directions correlate significantly with the WMFT measures for the subset of shoulder-elbow tasks. This implies that the shorter/simplified version of the Drawing Test, comprising only these two directions, can be introduced.

Future work on this topic will involve exploring the relationship between DT measures and other clinical scores (e.g. FMA, ARAT, BI). Moreover, the DT kinematic data offer the possibility of analyzing and quantifying other measures of movement quality, such as smoothness, tracking error, velocity profiles, etc.

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