

# Kinematic Analysis of Upper Extremity Movement in Stroke Patients as a Rehabilitation Supporting Tool

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## Research

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# Abstract

## Background

Ischemic stroke often results in reduced mobility of the upper extremity and subsequent long-term disability. Evaluation of the effects of rehabilitation monitoring is often insufficient, while technological progress in 3D analysis application is more objective in the assessment of motor deficits. The aim of the study was to examine the use of kinematic analysis indicators for diagnosing the rehabilitation process in post-stroke patients.

## Methods

20 ischemic stroke patients in the early post-stroke phase (up to three months after the stroke) took part in the study. The study tests were conducted at the beginning of the rehabilitation process and after its completion. The procedure comprised moving the index finger and reaching for four target points (closer, farther, contralaterally, ipsilaterally) placed on a table in front of the patient. The analysis of movement time and movement trajectory was carried out using the OptiTrack system. Movement time and movement smoothness (trajectory smoothness) were calculated with the use of normalized jerk score (JERK).

## Results

The JERK parameter changed significantly in three movement trajectory directions: closer ( $p \leq 0.01$ ;  $d = 1.82$ ), further ( $p \leq 0.05$ ;  $d = 1.02$ ), and contralaterally ( $p \leq 0.05$ ;  $d = 0.91$ ).

## Conclusions

The results confirm the usefulness of the applied measurements in diagnosing the effects of rehabilitation of patients in the early post-stroke phase.

Trial registration: (not applicable)

# Background

Stroke is a dangerous medical condition with serious clinical, social and economic consequences. It is the third leading cause of death and the leading cause of severe disability among people over the age of 45 [1, 2]. Early and comprehensive post-stroke rehabilitation aims to reduce patients' mortality in the first month after the stroke as well as degree of disability and life helplessness [3]. One of stroke rehabilitation goals is to minimize the risk of pathological movement patterns, excessive spasticity, or prolonged muscular hypotonia [4]. Serious post-stroke issues include limited upper limb mobility and inaccurate diagnosis of therapy effects due to lack of precise methods of therapy effectiveness evaluation [5].

There is no system for the monitoring of rehabilitation by means of various forms of electronic recording of stroke patients' progress. The assessment of motor functions in stroke patients is usually performed with standardized clinical scales. Some of the most frequently used clinical instruments for assessing upper extremity impairment and activity capacity in stroke are the Fugl-Meyer Assessment of Upper Extremity (FMA-UE) and Action Research Arm Test (ARAT) [6]. However, observer-based ordinal instruments lack the sensitivity to assess subtle, yet, potentially significant changes in movement performance. These clinical scales tend to have a ceiling effect since they rely on scoring criteria rather than on a continuous measurement construct [7].

There have been studies of rehabilitation progress with the assistance of kinematic analysis [6, 8], in particular, with robotic exoskeletons [9]. The applied devices support the motion of the shoulder girdle and the whole upper extremity. They significantly facilitate patients' movement and allow registering the rehabilitation progress. The study of problems related to human motor skills can contribute to the implementation of better rehabilitation at the immediate and chronic stages after stroke. The current technology offers a number of kinematic indicators, which can be efficient parameters for objective functional assessment of the upper limb in people with movement disorders [10, 11]. The majority of kinematic studies on stroke patients focused on such parameters of accuracy of location in motion as close or far, low or high, or with or without clearance in front of the person. There were also studies involving different grasping tasks [12, 13]. The task used in our research is similar to routine tasks of daily living, such as interacting with touchscreens or pressing buttons on different devices. Advantages of the analysis of trajectories of movement systems as a measurement tool include standardized instructions, adaptation of tasks according to patients' functioning level, and availability of quick feedback.

The aim of our study was to use kinematic analysis indicators to diagnose the rehabilitation process of stroke patients. Realizing the difficulties related to the availability of equipment and analysis of results, we hope that in a few years' time kinematic analysis will become a common method of diagnosing treatment progress in stroke patients.

## Material And Methods

Study group:

20 patients after a left-sided stroke, aged  $65 \pm 5.2$  years (body weight  $68.05 \pm 14.80$  kg; body height  $160.57 \pm 5.95$  cm) were qualified for the study. They were classified as being in the early post-stroke phase. All participants in the study were patients of the Rehabilitation Department of St. Roch Hospital in Ozimek.

Inclusion criteria:

- first-time stroke,

- preserved manipulative hand ability, with slight restrictions on movement and spasticity below or equal to 2 scores on the Modified Ashworth Scale,
- ability to understand instruction and perform tasks, determined by a score below 23 on the Mini-Mental State Examination (MMSE) scale.

#### Exclusion criteria:

- cognitive impairment,
- sensory aphasia,
- visual impairment,
- behavioral disorders,
- joint stiffness.

Assessment of clinical status was made on the day of admission to the neurological rehabilitation department. All patients after ischemic stroke confirmed by CT scanner. Participants were assessed using functional scales National Institute of Health Stroke Scale (NIHSS), Functional Indicator "Repty" (WFR) is a Polish (Functional Independence Measure FIM) modification, and Fugl-Meyer Motor Assessment (FMA - upper limb).. All the patients were right-handed, and were fully informed about the experimental procedures. All participants received information about the experimental procedures to be carried out and they gave their written consent to participate in the study. All patients' personal data and research results are stored at the Rehabilitation Department at St Roch Hospital in Ozimek. The research project was approved by the Bioethics Committee of the Opole Medical Chamber (No. 215, March 25, 2015).

#### Equipment:

The study used the OptiTrack - Motion Capture System (NaturalPoint, Inc., Corvallis, USA) for optoelectronic motion analysis, allowing evaluating kinematic parameters of any movement. OptiTrack operates on the basis of passive markers, which during motion recording reflect the emitted IR light from seven 250e cameras. The cameras record the image of markers placed on the patient's upper body, with a maximum resolution of 832 × 832 pixels, and a frame rate of 100 frames per second. Additionally, one camera recorded video footage at 100 frames per second. This number of cameras allowed for accurate imaging of the marker's movement in space, without any loss of signal during the measurement. The data was recorded with Motive ver. 1.7.4 exported to C3D file format for processing. Markers with a diameter of 14 mm were placed symmetrically on both upper limbs. Figure 1 presents the complete set of markers in the study protocol.

#### Procedure:

The first test was conducted within two days of admission to the hospital rehabilitation department. The second test was carried out after six weeks of rehabilitation in the hospital rehabilitation department. The researchers did not interfere in the rehabilitation process and did not give any guidelines for intervention.

During the test, a patient was sitting on a chair in front of a table on which four markers were placed (Fig. 2). The task performance was recorded during one test session for all participants. One trial consisted of a continuous movement toward four target points, performed at the patient's own pace. Each participant made three series, and each series was recorded separately. During the test each participant was sitting upright with the right arm abducted at a 45° angle, elbow bent at a 45° angle, and pronated forearm with the hand on the table. The left hand rested on the table outside the tracking area. The test procedure consisted of reaching with the finger of the right hand (touching with the fingertip) target points on the table surface. After touching a target point, the participant was supposed to return the hand to the starting point and continue the movement to the next target point. The starting point was located 15 cm from the participant's chest on the sagittal axis of the body. The first target point (Closer) was placed 20 cm from the starting point on the sagittal axis of the body. The second target point (Farther) was placed 20 cm from the first target point on the sagittal axis of the body. The third target point (Contralaterally) was 20 cm from the first point on the left side of the transverse axis of the body. The hand movement took place to the left of the sagittal axis of the body. The fourth target point (Ipsilaterally) was 20 cm from the first point on the right side of the transverse axis of the body. The hand movement was to the right side of the transverse axis of the body. The target points were specially placed in different parts of the tracking area so that reaching them required different combinations of joint movements [14]. To record movement precision, a marker reflecting IR light from the cameras was placed on the participant's fingernail of the middle finger.

Data analysis:

1. 1. Movement time (TIME). The beginning and the end of movement was determined adequately to the analysis of the trajectory of JERK parameter.
2. 2. Movement smoothness (trajectory smoothness) (JERK) was quantified using a normalized jerk score (JERK) [15].

$$\text{jerk} = \sqrt{\frac{1}{2a^2} \int (\text{jrk})^2 dt}$$

jerk – normalized JERK score

jrk – third-order derivative of position with respect to time

t – movement time

a – movement amplitude

“t” and “a” are the movement time and movement amplitude, respectively, applied to normalize the jerk and eliminate the influence of movement time and distance.

# Statistical Analysis

The collected data were subsequently subjected to statistical analysis using the Jamovi 1.1.9 software package. Due to the lack of normality of distributions and homogeneity of variances of the analyzed variables, nonparametric analysis tools were applied. To determine the level of significance of differences, the non-parametric Wilcoxon test was used to determine the dependencies between the samples. The research also used the size of Cohen's d effect. The sample size was calculated to be at least 20 participants on the assumption to detect a medium Cohen's d effect size 0.5 or larger, power of 80%, and a 5% (two-sided) significance level.

## Results

The study results presented in Table 1, indicate that the movement smoothness (JERK) changed significantly in the three analyzed directions of movement (Closer:  $p \leq 0.01$ ,  $d = 1.82$ ; Farther:  $p \leq 0.05$ ,  $d = 1.02$ ; Contralaterally:  $p \leq 0.05$ ,  $d = 0.91$ ). Movement time (TIME) changed significantly only Contralaterally:  $p \leq 0.05$ ,  $d = 0.89$ . The results also show that the significance of the differences in p and Cohen's d effect size was the highest in the Closer movement direction, followed by Farther, and Contralaterally. This ranking was closely related to the degree of difficulty in performing the movement in a particular direction.

Table 1  
Descriptive statistics and significance of differences and effect size of the TIME and JERK parameters.

Side	Factor	Proces	X ± SD	p	Cohen's d
Closer	Time	Before	1,02 ± 0,27	0,08	0,79
		After	0,80 ± 0,14		
	Jerk	Before	0,29 ± 0,15	<b>0,01</b>	<b>1,82</b>
		After	0,10 ± 0,10		
Farther	Time	Before	1,36 ± 0,59	0,08	0,73
		After	0,98 ± 0,17		
	Jerk	Before	0,69 ± 0,48	<b>0,02</b>	<b>1,02</b>
		After	0,24 ± 0,10		
Contralaterally	Time	Before	1,14 ± 0,15	<b>0,04</b>	<b>0,89</b>
		After	0,85 ± 0,15		
	Jerk	Before	0,40 ± 0,26	<b>0,04</b>	<b>0,91</b>
		After	0,17 ± 0,05		
Ipsilaterally	Time	Before	1,03 ± 0,37	0,21	0,49
		After	0,84 ± 0,23		
	Jerk	Before	0,45 ± 0,37	0,11	0,78
		After	0,18 ± 0,09		

## Discussion

The analysis of movement trajectory (closer, farther, contralaterally, ipsilaterally) is becoming more and more relevant to the rehabilitation of post-stroke patients. This is supported by one of the hypotheses based on the theory of reorganization of cortical brain structures, which indicates the need for rehabilitation in the form of bilateral task performance involving both paretic and non-paretic cerebral hemispheres [16, 17]. Quantitative motion analysis provides information on the motor compensation strategies used by stroke patients, and is therefore of considerable clinical relevance [18], as it reveals the patient's current condition and allows comparisons with healthy controls [6].

The used kinematic parameters, i.e. JERK and TIME, facilitate clinical studies of patients in terms of motion analysis, and can be useful not only for better rehabilitation planning but also for enhancing the effective application of technology-based devices [19]. One of the main advantages of this method is also the detection of individual deficits, which may remain invisible in the traditional patient assessment

process. Hussain et al. [6] argue that kinematic analysis can provide valuable and specific information about sensorimotor impairment of the upper limb following stroke that might not be captured using traditional clinical scales. Our research confirms this argument since the analysis of the trajectory of movement ipsilaterally showed no differences, which is not revealed in traditional assessment. Such information can make the patients realize the need for further rehabilitation in this area.

Trajectory analysis also makes it possible to develop a reliable reference scale for healthy people [20, 21]. Otaka et al. [22] noted that arm movements in hemiparetic stroke patients were slower, less accurate, less smooth, and more segmented than in healthy controls. In the present study the imaging of movement demonstrated that toward the end of the movement its trajectory was often found to be clustered in post-stroke patients, resembling a spider's web. Similar conclusions were reached by Hussain et al. [6]. Movement time and trajectory are frequently tested in fast pointing movements using motion capture systems, and are considered key variables for kinematic movement analysis of upper limb tasks in stroke [12, 13]. The present study confirms their significance by way of performing a task of indicating a determined point by a group of post-stroke patients.

The authors of this paper also stress the possibility of using the above methodology to determine patients' individual deficits and pathological compensatory movements. The validity of determination of compensation levels and diagnosis of deficits were also discussed by other authors [8, 23]. They showed that during the reaching for an object the patients displayed a reduced arm elongation and trunk axial rotation due to motor deficit. It was related to their use of compensatory strategies which included trunk forward displacement and extra head movements. The generated specific movement compensation is closely related to the movement trajectory and the placement of objects reached for by a patient [24].

The study of movement trajectory appears to be a promising stroke assessment tool. Further research is still necessary to assess the relationship between its outcome variables and clinical measures of upper extremity impairment. This type of research proves the need to use the tools we use to support the diagnostic process of rehabilitation, however, the researchers are aware that there is still a long way to go, due to the cost and process of processing the collected information. We are also aware that the development of modern information technology will significantly simplify this system.

## Conclusions

Movement trajectory analysis can provide more relevant information for diagnosing the rehabilitation process than procedures using traditional clinical scales.

## Abbreviations

FMA-UE

Fugl-Meyer Assessment of Upper Extremity

ARAT

Action Research Arm Test  
NIHSS  
National Institute of Health Stroke Scale  
WFR  
Functional Indicator "Repty"  
FIM  
Functional Independence Measure  
FMA  
Fugl-Meyer Motor Assessment  
MMSE  
Mini-Mental State Examination  
CLAVR/L  
clavicular heads  
ACRR/L  
acromion process  
MPHR/L  
middle part of the humeri  
LEPR/L  
lateral epicondyle  
RSR/L  
radial styloid  
USR/L  
ulnar styloid  
FNR/L  
index finger nails.

## **Declarations**

### **Ethics approval**

All patients gave written informed consent. The trial and the amendments were approved by the local ethics committee - Bioethics Committee of the Opole Medical Chamber (No. 215, March 25, 2015).

### **Consent to participate**

Not applicable

### **Consent for publication**

Not applicable

### **Availability of data and material**

Data used in this study are available upon reasoned request after the submission of a reasoned research proposal, which will be evaluated by the Steering Committee of the Neurological Rehabilitation Unit of St Roch Hospital

### **Competing interests**

The authors declare that they have no competing interests.

### **Funding**

Not applicable

### **Authors' contributions**

KM, PP, BM, conceived, organized and supervised the study and conducted the research. KM and PP performed the statistical analysis, prepared and revised the manuscript. All authors approved the final version to be published.

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## Figures

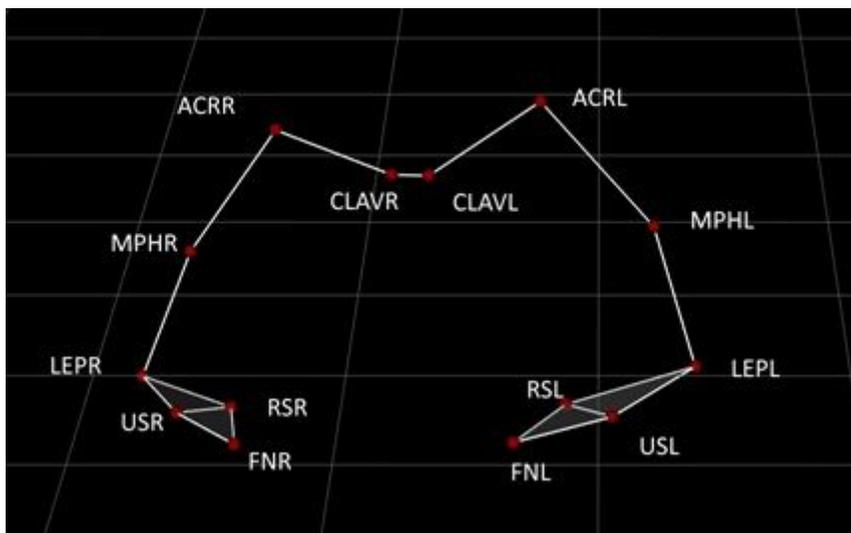
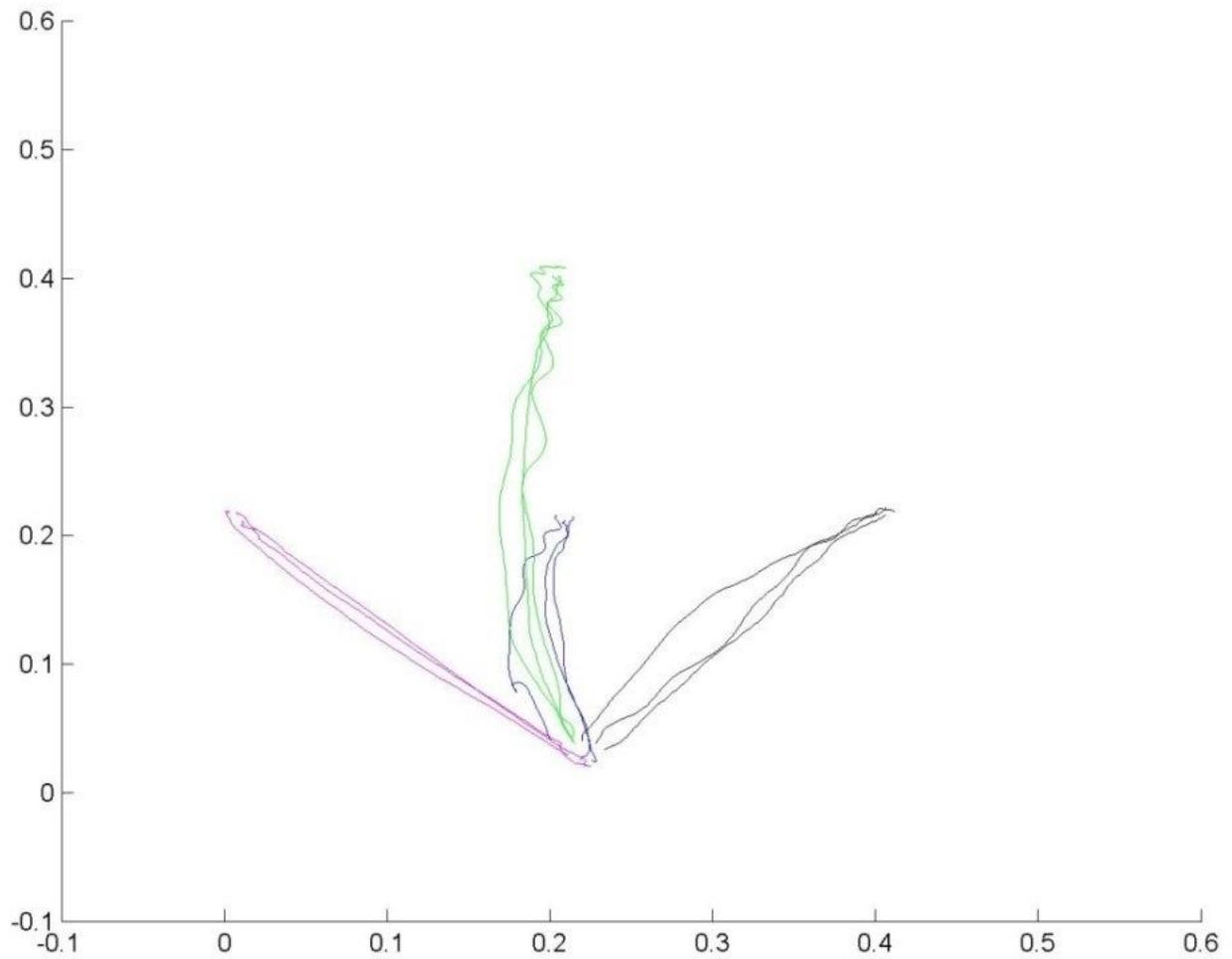


Figure 1

Upper body marker placement diagram. Markers were located on both upper limbs (right R/L left), CLAVR/L – clavicular heads, ACRR/L – acromion process, MPHR/L – middle part of the humeri, LEPR/L – lateral epicondyle, RSR/L – radial styloid, USR/L – ulnar styloid, FNR/L – index finger nails.



**Figure 2**

An exemplary diagram of the trajectory of movement to particular target points during a test series.