Evaluation of New Parameters for Assessment of Stroke Impairment

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ABSTRACT

This paper presents new parameters for the evaluation of stroke impairment using data collected with KINARM robot (Kinesiological Instrument for Normal and Altered Reaching Movements). The new parameters evaluated in this study were cross-correlation, low frequency, and high frequency. The data were collected from control (people with no neurological disorders) and stroke subjects performing a center outreach task. In this task the subjects were instructed to move the examined arm quickly and accurately from the central target position to a randomly illuminated target, and to maintain the hand at this target for the remainder of the trial. The collected data for each of eight individual reaching movements to eight different targets can be viewed as a time series. For each subject a cross-correlation between the reaching movement to each of eight targets and a straight line fitted between these targets was computed. In addition, high and low frequencies were calculated from the time series data using a Fourier transform. The results showed that the new parameters identified the same or a higher percentage of stroke participants as abnormal, compared to previously reported parameters [1], especially in the experiments performed with the non-affected arm. Therefore, the new parameters can facilitate the detection of abnormalities in the movements of stroke patients and may be used as features for the classification of stroke patients.

Keywords: stroke rehabilitation, cross-correlation, time series analysis, classification

1 INTRODUCTION

A stroke is an acute injury of the brain that can affect many body functions, often causing motor, speech, memory, vision and other sensory impairments. Rehabilitation is an important part of stroke recovery and the key to successful rehabilitation is an accurate assessment of stroke-caused impairment [2, 3]. Current clinical assessments generally involve physical assessment and visual observation by physicians. Therefore, assessment results are inherently subjective and potentially inconsistent among physicians. Moreover, current assessment tools are not adequate to reliably discriminate between different levels of performance. Thus, in practice the majority of stroke patients follow the same general rehabilitation program, which may not necessarily be optimal for each individual case.

Robotics technology can objectively monitor a subject's performance in a given task and even modify the physics of limb motion. The technology can be used in building computational systems that analyze, visualize and aid in the interpretation of sensory-motor dysfunction in stroke patients.

KINARM (Kinesiological Instrument for Normal and Altered Reaching Movements) is a robotic device developed to study fundamental issues in motor control and learning in upper limbs of primates [4] and is currently used in clinical research for assessing sensor-motor function of stroke patients prior to and during recovery. KINARM allows for the collection of quantitative measurements of upper limb movements of a subject performing a particular task. The collected kinematic and kinetic data are then assessed and stored in a database. The stored data includes measurements such as hand trajectory, elbow position and shoulder angles. From these measurements various additional quantities are derived, among which the initial direction error (IDE)[1] was identified as the best parameter to identify the largest number of stroke participants as abnormal [1]. In this paper, time series analysis was applied on data collected with KINARM. The new parameters evaluated in this study

[1] IDE (in degrees) is an angular deviation between *(a)* a straight line from the hand position at movement onset to the peripheral target and *(b)* a vector from the hand position at movement onset to the hand position after the initial phase of movement [1].

were cross-correlation, low frequency, and high frequency. The purpose was to investigate whether the new derived quantities enable better separation of stroke from control subjects. High cross-correlation would indicate that the reaching movements were very close to a straight line. Similarly, a reaching movement with very quick changes and variations would result in a high level of high frequency activity.

2 METHODS

2.1 Data Collection

The data were collected from 39 stroke subjects (22 of which had left arm impairment and 17 had right arm impairment) and 45 age-matched control subjects (people with no neurological disorders). Each subject underwent a typical stroke assessment and one "KINARM session", where several tasks were performed for each arm. The task of interest for this paper is the center outreach task.

In the center outreach task the subject starts each trial by maintaining the hand at a central target (Fig. 1a). After 1–1.5 seconds, one of eight peripheral targets is illuminated and, as earlier instructed, the subject moves the examined arm as quickly and accurately as possible to the illuminated target. The subject has three seconds to complete the movement and, when at the peripheral target, must maintain the hand at the target for the remainder of the trial. Eight trials were recorded for each target in a pseudo-random blocked design (n=64).

While the subject performed this task with each arm, the robot collected quantitative measurements of the movements of each upper limb. The collected data for each of eight individual reaching movements to eight different targets can be viewed as a time series where the X and Y coordinates of the subject's hand are displayed as a function of the duration of the center outreach task (Fig. 1b).

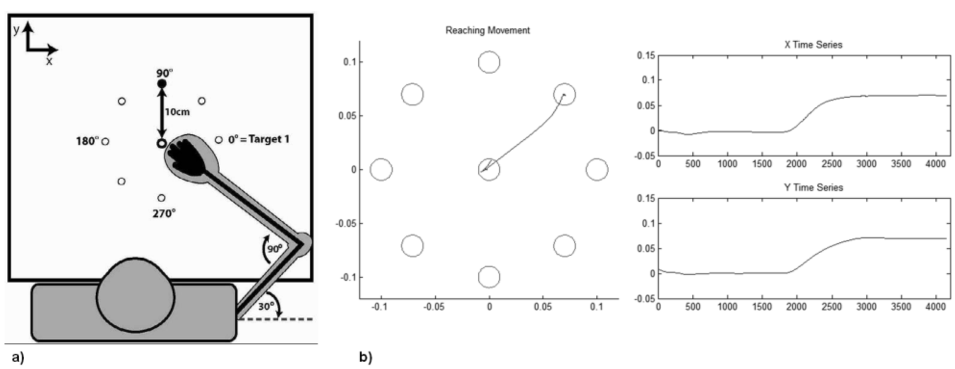

Figure 1. a) The center outreach task. In this task the subject is asked to move one hand from the center position to one of eight targets at which a light is turned on. b) The collected data for each of eight individual reaching movements to eight different targets was interpreted as a time series.

2.3 Data Preprocessing

The time series data were transformed to a reference coordinate system and all eight reaching movements for all eight targets were rotated to match the reaching movement from the central target (T0) to the second target (T2). For the cross-correlation, a set of points representing a straight line from T0 to T2 was created. For the calculation of the high and low frequencies, each reaching movement data set was padded with zeros to ensure that there are power of two data points.

2.4 Parameters Extraction

The zero-lag cross-correlation between a straight line and each reaching movement was computed for all eight trials. The high and low frequencies were derived by summarizing the high and low components of the power spectrum computed for each reaching movement. Similarly to cross-correlation, the high and low frequencies of each reaching movement were computed for all eight trials.

The resulting data contained 80 values for each X and Y coordinate for each subject. The X and Y coordinates were combined using the geometric mean. From the resulting values, the following parameters were computed: (1) mean of eight reaching movements of the mean eight trials (meanOfMeans), (2) median of eight reaching movements of the mean eight trials (medianOfMeans), (3) mean of eight reaching movements of the median of eight trials (meanOfMedians), (4) median of eight reaching movements of the median of eight trials (medianOfMedians), (5) maximum of eight reaching movements of the maximum of eight trials (maxOfMax), (6) minimum of eight reaching movements of the minimum of eight trials (minOfMin), (7) mean of eight reaching movements of the minimum of eight trials (meanOfMin), (8) median of eight reaching movements of the minimum of eight trials (medianOfMin), (9) mean of eight reaching movements of the maximum of eight trials (meanOfMax), (10) median of eight reaching movements of the maximum of eight trials (medianOfMax), and (11) maximum standard deviation of eight reaching movements for all eight trials (maxOfstd).

3 RESULTS

Fig. 2 compares typical reaching trajectories of the right (dominant) hand of a control subject (on the left) with reaching trajectories of a non-stroke-affected hand of a stroke subject (on the right). The figure clearly shows that some stroke patients do experience difficulties in motor performance not only on their stroke-affected side, but also on their non-stroke-affected side.

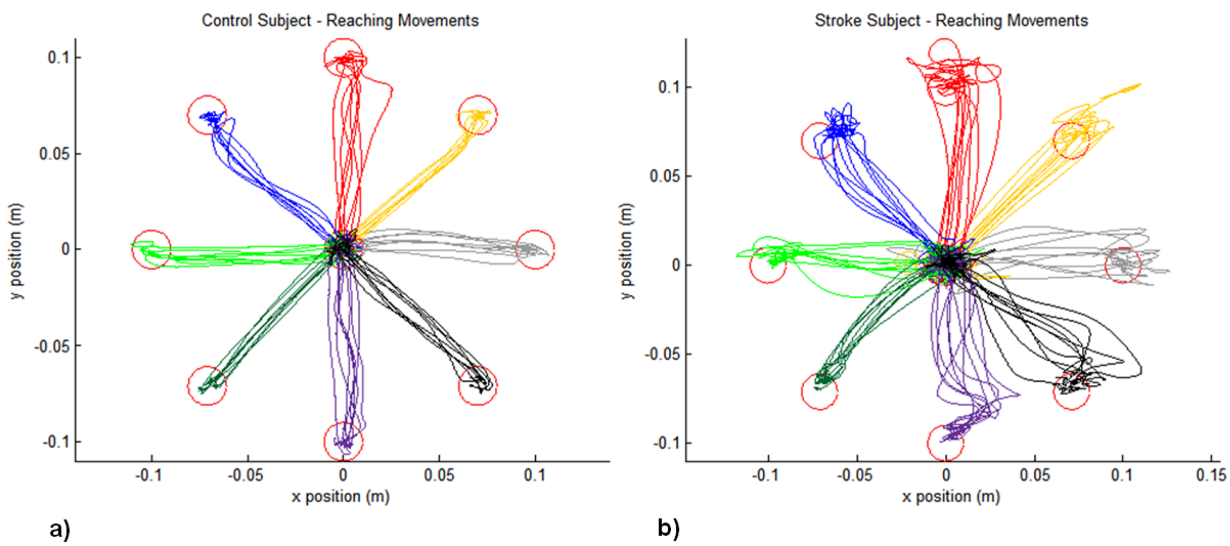

Figure 2. Reaching trajectories: a) control subject (right, dominant limb). b) stroke subject (right, dominant, non-stroke-affected limb).

To compare the performance of stroke subjects with respect to controls using the newly proposed features, the 5% – 95% inter-quartile range of the control subjects was computed for all parameters. Tables 1 and 2 show the percentage of stroke subjects who differed from normal behavior and fell outside the 5% – 95% inter-quartile range of the control group for the center outreach task performed with right and left hand respectively. The results are divided into right affected (RA) and left affected (LA) categories. For comparison, results of the IDE parameter are also shown. Among the new parameters, values that have a higher percentage than the IDE parameter are highlighted in red.

The best results were combined into one feature vector of length 11 that included: meanOfMedians, meanOfMin and maxOfstd of cross-correlation results; and minOfMin, maxOfMax, medianOfMax and maxOfstd of high and low frequency results. A support vector machine classifier was used to separate the resulting data into stroke and control groups. Table 3 shows the ten-fold cross validation classification results with close to 80% accuracy for both the right and left hand experiments.

Finally, the classification results were also compared to the arm and hand Chedoke McMaster clinical scores obtained for both hands on the same day as the center outreach task was performed. The Chedoke-McMaster Stroke Assessment is a questionnaire based, widely used clinical assessment of stroke impairment that maps the physical impairments and disabilities that impact the daily activities of individuals with stroke on a seven-point scale [5]. The results show that a large number of stroke subjects with a perfect Chedoke McMaster score have motor deficits and were successfully classified as 'stroke' using the proposed parameters.

Table 1. Percentage of stroke subjects who differed from normal behavior and fell outside the 5% – 95% inter-quartile range of the control group for the center outreach task performed with *right hand*. Results are divided into right affected (RA) and left affected (LA) categories.

		High Frequency		Low Frequency		Cross-correlation	
		RA%	LA%	RA%	LA%	RA%	LA%
1	meanOfMeans	47.06	27.27	41.18	22.73	41.18	**36.36**
2	medianOfMeans	29.41	27.27	35.29	27.27	41.18	31.82
3	meanOfMedians	23.53	13.64	17.65	22.73	47.06	31.82
4	medianOfMedians	29.41	27.27	29.41	31.82	47.06	**36.36**
5	maxOfMax	29.41	**45.45**	35.29	**59.09**	52.94	**45.45**
6	minOfMin	**64.71**	31.82	58.82	**45.45**	47.06	**36.36**
7	meanOfMin	35.29	**40.91**	35.29	27.27	52.94	**50**
8	medianOfMin	5.88	31.82	17.65	**40.91**	35.29	31.82
9	meanOfMax	47.06	**50.00**	35.29	**50.00**	52.94	**40.91**
10	medianOfMax	35.29	**36.36**	41.18	**50.00**	29.41	31.82
11	maxOfstd	47.06	**45.45**	47.06	**40.91**	29.41	22.73
	mean IDE	64.71	36.36				

Table 2. Percentage of stroke subjects who differed from normal behavior and fell outside the 5% – 95% inter-quartile range of the control group for the center outreach task performed with *left hand*. Results are divided into right affected (RA) and left affected (LA) categories.

		High Frequency		Low Frequency		Cross-correlation	
		RA%	LA%	RA%	LA%	RA%	LA%
1	meanOfMeans	11.76	31.82	17.65	40.91	**41.18**	68.18
2	medianOfMeans	23.53	13.64	23.53	36.36	11.77	50
3	meanOfMedians	17.65	4.55	17.65	31.82	**41.18**	72.73
4	medianOfMedians	11.76	4.55	**29.41**	18.18	17.65	63.64
5	maxOfMax	**35.29**	**95.45**	**35.29**	**90.91**	29.41	68.18
6	minOfMin	17.65	18.18	**29.41**	45.45	17.65	59.09
7	meanOfMin	11.76	27.27	23.53	31.82	**41.18**	**81.82**
8	medianOfMin	11.76	50.00	17.65	45.45	29.41	**81.82**
9	meanOfMax	**41.18**	**72.73**	**29.41**	68.18	**41.18**	68.18
10	medianOfMax	**41.18**	**77.27**	**35.29**	68.18	0	36.36
11	maxOfstd	29.41	59.09	**35.29**	63.64	11.77	40.91
	mean IDE	23.53	72.73				

Table 3. Classification results using a support vector machine classifier and comparison of the results to clinical scores.

Classification				Proposed method vs. Chedoke-McMaster			
	RH (%)	LH (%)		Stroke subjects with perfect arm and hand Chedoke-McMaster score that were correctly classified as "Stroke"			
Correct Rate	80	81		affected limb (n = 13)		non-affected limb (n=33)	
Sensitivity	82	85		RH	LH	RH	LH
Specificity	80	74		10	8	25	22

4 DISCUSSION AND CONCLUSIONS

The results showed that the new parameters identified the same or a higher percentage of stroke participants as abnormal, compared to the IDE parameter, especially in the experiments performed with the non-affected arm.

The main advantage of the new parameters over the existing parameters is that they capture the entire nature of the movement as opposed to the IDE parameter which only characterizes the initial phase of the movement of a subject. It only captures the period from movement onset to the first minimum hand speed, which is the first local minimum after the first maximum hand speed. The first minimum hand speed is generally reached within the first second of the total movement duration. The cross-correlation is a measure of how straight the movement was. A higher value for the cross-correlation indicates that the movement was more accurately directed towards the illuminated target. High standard deviation between trials indicates inconsistent movements. Reaching movement with very quick changes and variations would result in a high level of high frequency activity.

The percentage of left-affected performing with their non-affected and affected limbs is higher than the right-affected subjects performing with their non-affected and affected limbs respectively. This indicates that left-affected subjects tend to show greater deficits in performance with both their affected limbs as compared with right-affected subjects. This pattern was previously detected through other parameters [1].

Some of the new parameters were able to detect more abnormalities in left-affected stroke subjects performing with their non-affected limp (see table 1). A support vector machine was able to separate stroke and control subjects with high accuracy. In addition, classification using the new parameters has a better ability to detect movement abnormalities than the Chedoke-McMaster assessment. Many stroke patients with perfect Chedoke-McMaster scores nonetheless showed abnormal reaching movements and were thus classified as stroke patient. Without the newly proposed parameters, these patients most probably would not receive any rehabilitation for their non-stroke-affected arm and hand. Regardless of the progress achieved with this study, it is important to note that more work needs to be done to more successfully detect motor deficits in stroke patients.

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