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Stroke-affected upper extremity movement assessment via continuous relative phase analysis

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ABSTRACT

Paper presents the quantified assessment of stroke-affected upper extremity (UE) coordination via continuous relative phase (CRP) analysis. 14 post-stroke patients were divided into 3 groups based on the severity of impairment according to Wolf Motor Function Test (WMFT). CRP was determined based on UE kinematics parameters measured using inertial measurement units fixed on arm, forearm and hand while subjects performed designated movement. UE movement cycles were analysed based on the metrics derived from phase planes, the phase angle and CRP plots, as well as the calculated range of motions and CRP variability rates. It was found that CRP variability is associated with impairment level, i.e. it is decreasing with a higher level of dysfunction. Therefore, the CRP might serve as measurable quantity and could be valuable for supporting clinical assessment and quantifying impairment severity of UE motor functions.

1. Introduction

Various motor dysfunctions caused by stroke or other neurodegenerative diseases negatively affect the quality of life. Sufferers of stroke demonstrate slower, less smooth, less efficient and less precise upper limb movements compared to non-affected persons [1–2]. In addition, stroke sufferers may have decreased coordination between shoulder flexion and elbow extension, and may use compensatory movements such as excessive trunk and shoulder movements [16]. It has been shown, that various stroke rehabilitation strategies like constraint-induced movement therapy [23] or robot-assisted rehabilitation [15] facilitate better recovery. It is common for rehabilitation specialists to evaluate the progress and effect of a rehabilitation strategy on motor function recovery. General examination of motor dysfunction includes assessment of strength, muscle tone, muscle bulk, coordination, abnormal movements and various reflexes. Many of these are better detected through simple observations. Wolf Motor Function Test (WMFT) is one of the tools regularly used in clinical practice for post-stroke upper extremity (UE) motor assessment and it provides clinician with the score on the ability of the patient to perform the motion (ranging from 0 – no motion to 5 – normal) [18,23–26]. Depending on the WMFT task, the time elapsed from the start to end is most frequently determined. However, there are several other kinematic characteristics of upper limb movements after a stroke that can be measured [1,5]. Kinematic analysis of upper and lower limb motion, as well as coordination, is usually performed while post-stroke individuals walk [4,20]. When evaluating WMFT, UE coordination is often only assessed visually, i.e. without instrumentation to measure kinematics. However, additional instrumentation and a quantitative assessment might facilitate improved diagnostics or more detailed assessment of the rehabilitation progress [14]. Due to its vast amount of muscles and joints the human body has multiple degrees of freedom that must be controlled in order to achieve goal-oriented movements. Such redundancy of actuators results in increased motor variability. Taking into account that human movement is a variable, kinematic

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data from isolated joints (e.g. angle, displacement, velocity, etc.) are analysed as functions of time. Early studies regarded variability as error or "noise" in the performance of movement [25]. Others explained variability not as good or bad phenomena, but simply stated that it reflects the variety of coordination patterns used to complete the task [9,17]. Within the context of human body movement, the definition of the coordination varied from selective activation of degrees of freedom resulting in organized motor activity, or mastering redundant degrees of freedom in order to create coordinated locomotion patterns [31], to the most recent understanding by introducing the concept of abundancy, which means that all degrees of freedom contribute to the stability and flexibility of the task [32]. It has been suggested that the coordination or coupling between segments may be an important line of investigation [6]. Quantifying the coordination between two body segments depends not only on the technique used for the assessment but also on the researcher's particular approach. The most popular methods for quantifying coordination appear to be vector coding and continuous relative phase (CRP) [1,3,6,10,17,21,28] or principal component analysis [33]. The CRP quantifies the coupling (coordination) relation between the kinematics of two body segments that are linked in this case both anatomically and mechanically. When analyzing CRP graph, the one can evaluate whether the segments are moving in-phase (CRP is closer to 0°) or antiphase (CRP is closer to 180°). In gait analysis, most common measures derived from CRP data are averages over a functional unit of the movement cycle [28]. CRP measures have been used to quantify the coordination between different body segments and joints during various activities [13]. Advances in the field of non-linear dynamics have shown that collective variables, such as relative phase, are able to capture the underlying spatial-temporal dynamics of coordination [7–9,27]. CRP is usually applied when analyzing cyclic movements [13,28]. However, studies show that it has the potential to provide quantitative information on multi-joint coordination of discrete movements [3,19], which is the case when performing simple WMFT motions. Unfortunately, there is lack of studies where CRP was used for separately quantifying coordination and motor function states in the movement assessment of damaged UE. Coordination plays a significant role in important daily activities, which are also the focus of advanced UE stroke rehabilitation. Quantitative information gained from CRP analysis may further facilitate clinical assessment and guide personalized stroke rehabilitation.

This study is focused on the assessment of stroke-affected UE movement based on intra-limb coupling strength and coordination analysis. The main purpose is to quantitatively represent UE coordination while performing non-cyclic movements during clinical motor function assessment.

2. Methods

2.1. Subjects

Kinematic data from UE were collected at Vilnius University Hospital "Santariskių Klinikos" Center of Rehabilitation, Physical and Sports Medicine. Fourteen stroke patients (age 60.8 ± 12.5 (mean ± SD)) were recruited for the study. The inclusion criteria were: all participants suffered their first ischemic stroke, paresis of the most affected upper extremity – 2 points of elbow and shoulder flexor and extensors muscles force according the Lovett scale, had no previous orthopaedic surgery or rehabilitation treatment, had the ability to sit in the wheelchair or on the chair and move the affected UE, and had the ability to understand and follow verbal instructions. The exclusion criteria were as follows: haemorrhagic stroke, repetitive rehabilitation, affected limb plegia, muscle tone of affected limb more than 1 point according to Modified Ashworth Scale, Mini-Mental State Examination less than 24 points and other diseases or states influencing motor control of upper extremities. Since the aim of this study is to investigate whether CRP is correlated to WMFT scores as provided by clinicians, no healthy subjects were included as a control group.

All procedures performed in studies involving human participants were in accordance with ethical standards of the national bioethics committee (protocol No. 65-11-95) and with the 1964 Helsinki declaration.

2.2. Experimental setup

A total of ten motor tasks based on WMFT and disability and health ICF guidelines were included in a clinical test series [26]. The motor tasks were selected regardless of the patients' level of UE function. Three wireless inertial measurement units (IMU) (Shimmer Research, Dublin, Ireland) were fixed on the segments of the most stroke affected upper extremity (Fig. 1) and were used for measuring the kinematics of the upper extremity during the movement. Each motor task was evaluated by WMFT score based on the performance and all scores were summed up. However, not all subjects were able to complete all ten tasks, i.e. if they failed to perform a task the corresponding score was 0 and the kinematic data from IMUs were not collected. The item task 3 of part A of WMFT was one of the easiest tasks which all 14 subjects were able to perform. Therefore in this study only this one task will be analysed in detail. This motor task focusses on the extension of the elbow on a table. The patient is sitting on a chair in front of a table and places his/her hand on the table. Then he/she attempts to reach across the table by pushing the forearm forward. The movement should be initiated by the shoulder and upper arm leaning

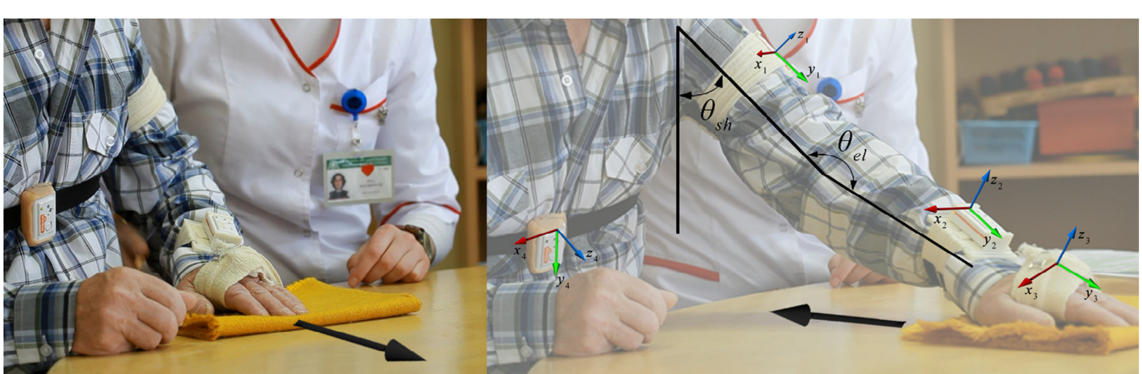

Fig. 1. Placement of the IMU sensors on the upper extremity. Left: UE at initial position. Right: the elbow in extended position before moving the hand back. Black arrows indicate direction of movement.