Harmonicity of the Movement as a Measure of Apraxic Behaviour in Stroke Survivors

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Abstract: Due to the brain damage caused by stroke, apraxic patients suffer from tool use impairment, and sequencing actions during daily tasks (ADL). Patients fail to use tools in a purposeful manner, often adopting an inappropriate speed of the movement and a disrupted movement path (Laimgruber et al., 2005). The core of this symptom lies in the compromised ability to access the appropriate motor program relevant to the task goal (Hermsdörfer et al., 2006). Although many studies have explored kinematic and spatial features of apraxia both in object and non-object related motor tasks, there is a niche in the research to provide a spatiotemporal biomarker for this behaviour. We propose a novel approach based on dynamical systems framework (Bootsma et al., 2004), looking into the temporal and spatial components of movements. Preliminary data shows that this measure has a potential to encapsulate the disrupted motor behaviour in those patients. We put forward a circular-fit based model to quantify deviations from the regular movement pattern. The application of this study is to create a measure of motor behaviour to be implemented in the autonomous assistance system (CogWatch) that could facilitate performance of ADL both in the clinical and home-based setting.

1 INTRODUCTION

The cerebrovascular accident (CVA), whether it is caused by bleeding or ischemia, causes a permanent damage of brain tissue. Stroke survivors suffer from a range of disruptions in motor circuitry such as spasticity or loss of control over limb (paresis/plegia). In addition, stroke can cause sensory deficits as well as language comprehension and production problems. The main focus of this paper is apraxia disorder, which describes a compromised ability of CVA patients to use objects in an accurate, goal directed manner and in turn, carry out ADL (Goldenberg et al., 1996). In this study, we propose a novel quantitative approach for capturing subtle differences in motor control on the spatiotemporal dimension between patient group and healthy elderly.

2 BACKGROUND

The CogWatch (www.cogwatch.eu) project is designed to create an autonomous assistance system to aid ADL independence in stroke cohort. The primary scope of the project is addressing patients who suffer from impaired ability to use everyday tools, due to left brain damage (Bieńkiewicz et al., 2013; Hermsdörfer et al., 2013). That means inability to access previously mastered knowledge about action execution, despite a preserved ability to integrate sensory information from the environment and execute smooth movement in a goal directed manner (De Renzi et al., 1982).

The incidence of persistent signs of apraxia in the population of CVA patients is estimated to be approximately 24% of all stroke survivors (Bickerton et al., 2012). The difficulty with the use of tools is a source of frustration for patients, as it directly increases the need for the help from caregivers during ADL. This loss of independence compounds the problems associated with CVA and makes the consequences of apraxia more debilitating (Hanna-Plady et al., 2003). One of the on-going strands of the project is to identify spatiotemporal patterns emerging during the production of ADL in

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this group of patients for the purpose of monitoring online task performance, progress of recovery and feed in automatized action recognition algorithms (Hughes et al., 2013).

2.1 Apraxia Non-kinematic Features

The most widely accepted definition of apraxia describes it as neurological sign of brain damage, behaviourally observed as the inability to perform skilled, well-learned motor acts (rothi et al., 1997). As previously mentioned, this deficit cannot be however explained by shortfall of motor or sensory brain functions caused by stroke (figure 1). For example, features of apraxia are independent from the loss of motor function of the limb (paresis or spasticity) or partial loss of visual field (hemianopia) or compromised visual attention (visual neglect) (petreska et al. 2007; goldenberg et al., 2007).

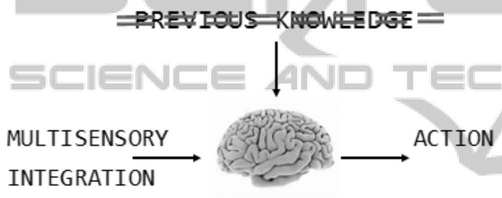

Figure 1: Illustration of the conceptual underpinnings of the apraxic behaviour. Despite preserved ability to execute movement and sensory system being functional, patients have difficulty accessing the motor concepts relevant to the action goal.

For example, problems with the object use are present when the task is performed with the non-affected limb (in the case of right handed participants with left brain damage, problems with motor features are present when the task is performed with the left hand). However, the problems with daily activities can be enhanced by these deficits, but are regarded as separate symptoms from the compromised functionality of motor schemas. Detailed descriptions of apraxia refer to three subcategories of symptoms affecting both object related and non-object related performance (Petreska et al., 2007; De Renzi et al., 1982, Jason et al., 1983). This classification refers to the transitive (object manipulation actions, e.g. using a hammer to put a nail into wooden board) or non-transitive (such as gestures, imitation and pantomime) (Goldenberg & Hagmann, 1997). The non-transitive movements involve gesture production and recognition for the meaningful gestures (such as waving goodbye) and non-meaningful ones (such as copying finger or hand postures) (Goldenberg et al., 1996). These two different subtypes of apraxia are usually described in the body of research as separate – conceptual apraxia and ideomotor apraxia respectively (Goldenberg, 2003). The problems with smooth performance of the task are referred in the literature as a third category, which is limb apraxia. Limb apraxia is defined as disruption of kinematic pattern of the movement, with preserved gesture and tool knowledge (Petreska et al., 2007). Those subtypes however, although differentiated as separate symptoms of apraxic behaviour, often coincide. In addition to apraxia Action Disorganisation Syndrome is distinguished in many other neurological disorders apart from stroke and regarded as difficulty with sequencing of the motor acts (Cooper et al., 2005). That means performing the action in an efficient and organised manner, despite preserved tool knowledge. The distinction between ADS and apraxia is however still widely discussed in the body of literature.

Due to apraxia and ADS, patients are prone to conceptual, spatial and temporal errors during daily activities that can lead to potential health and safety issues (e.g., grasping the knife by the sharp end, pouring boiling water onto the kitchen desktop). Common errors include problems with sequencing in multistep actions (e.g., action or ingredient addition, omission, anticipation and perseveration errors) along with conceptual errors (e.g., misuse of objects, object substitution, hesitation, toying and mislocation) (Petreska et al., 2007). The cognitive aspect of apraxia (i.e., the loss of knowledge how the action is performed) is often accompanied by changes in the kinematic pattern of the movement in the unimpaired hand. During the pantomime and gesture production, patients show irregularities usually in the direction of the movement, amplitude, speed and spatial position. Therefore, pantomime performance is one of the hallmarks in the neuropsychological examination of patients, due to its high sensitivity. Some patients might not exhibit a difficulty with the tool use, but fail to pantomime the performance. The plausible explanation for this phenomenon is that the priopioceptive information from grasping the tool provides additional sensorimotor input, which reinforces the selection of the appropriate motor schema (Hermsdörfer et al., 2006). The kinematic characteristics of apraxia syndrome will be further discussed in the following section.

2.2 Apraxia Spatio-temporal Features

There are several studies looking into the kinematic hallmarks of apraxic tool use. Unlike the studies using video-based approach in assessment of apraxia (Schwartz et al., 1995), or neuropsychological batteries in assessment of ADL in CVA patients (Vanbellingen et al., 2011; Graessel et al., 2009), research using motion capture recordings allows one to measure the subtle differences in the motor control. In the seminal study by Laimgruber et al. (2005), several variables were distinguished as sensitive measures of the differences between spatiotemporal features of task performance between the CVA patients and elderly controls in a pantomime task of taking a sip of water from a glass. Those variables were: movement time, peak velocity, deceleration phase and grip aperture. Deficits in the speed of the movement were also shown in other tasks such as the pantomime of sawing (Hermsdörfer et al., 2006) and pantomime and use of a hammer (Hermsdörfer et al., 2012). In a scooping motion task involving CVA patients with left brain damage, another study has reported deficits in the amplitude of the movement and reduced hand roll (Hermsdörfer et al., 2012). In addition Clark et al. (1994) have demonstrated imprecise plane of motion and trajectory shape in the pantomime and tool use of a knife when slicing a piece of bread, along with the impaired coupling in the hand velocity and trajectory shape. This was also shown by Poizner et al. (1995) in the same task scenario, which highlights the impaired joint coordination in a slicing movement. The disruptions in the kinematic features of the movement are linked to its more observable features such as perplexity, indicating a difficulty with accessing the appropriate motor plan (Hermsdörfer et al., 2006).

Other studies looking at goal-directed movement without tool use, such as pointing task, have reported impaired reaction times, acceleration deficits and prolonged movement times in the task performance by apraxic individuals (Fisk & Goodale, 1988; Hermsdörfer et al., 1999; Hermsdörfer et al., 2003; Haaland & Harrington, 1994). In grasping movements, impaired prehension and awkward hand rotation were noted as spatial features of kinematic impairments in patients (Hermsdörfer et al., 1999; Tretriluxana et al,. 2009).

2.3 Smoothness of Movement

Differences in the movement organisation in terms of spatiotemporal characteristics are usually limited to the presented above approaches, taking into consideration velocity and acceleration profiles, movement times and movement path. In this study, we focus on the movements that are naturally cyclical in both spatial and temporal dimensions (sawing, hammering and circular toothbrushing). We have chosen this particular task, due to the plethora of research investigating the oscillatory arm movements in healthy adults. Bootsma, Fernandez and Mottet (2004) have demonstrated that self-paced cyclical arm movements performed back and forth between two targets are normally represented by velocity curves that resemble a repetitive sinusoid oscillation over time. This natural harmonicity of the movement can be represented by circular shaped phase planes, when the velocity of the movement is plotted against position. This can be plotted as a semi-circle on either side of the x/y/z axis, representing one pointing movement. The assumption is that the more phase plane deviates from a regular circular shape, the less harmonic the movement. Lower harmonicity of the movement can implies a less natural the pace of the movement or a lesser degree of control (Bootsma et al., 2004).

2.4 Research Aims

The purpose of this research is to explore the feasibility of new biomarkers based on the harmonicity measure to capture the apraxic features in the movement.

3 METHODS

3.1 Experimental Design

In the study 20 healthy elderly, age-matched with patients will be tested. All of the healthy participants are to be right handed, 10 will be tested with right hand, 10 with the left hand. In the clinical group, 10 patients will be tested that suffered from first CVA, affecting primarily areas in the left brain hemisphere.

Control and patient groups will be tested under two modes of execution:

A. Actual action execution

B. Pantomime with action object visible

Three daily tasks will be tested:

i) Sawing a piece of wood

ii) Hammering

iii) Toothbrushing

Each of those conditions will have two trials of repetition and the experimental design will be counterbalanced using Latin Squares. The practice trial will include a task of pouring a glass of water from a jug (pantomime versus tool use). Motor performance will be recorded using passive marker setup and Qualisys Motion Capture system. Pantomime and tool use in addition will be assessed using the Goldenberg & Hagmann (1998) 2 point scale. The following kinematic variables will be analysed alongside: movement time, peak velocity, movement path, frequency of the movement, number of acceleration zerocrossings (jerks), deceleration phase, grip aperture and orientation. Number of errors committed and kinematic features of the movement will be compared across conditions for each patient and groups between patients and age-matched controls.

3.2 Phase Portraits and Circular Fit

Matlab script (Mathworks, 2012) was developed to provide the derivates of spatiotemporal positional data and create phase plot data. The algorithm was based on the Bootsma et al. (2004) study looking into the harmonicity of aiming movement. We have adopted the approach proposed by the authors and normalised for Aω – peak velocity of an 'idealised' harmonic movement at given amplitude and movement time and for the amplitude of the movement. This can be mathematically expressed as:

$$A\omega=(A*\pi)/(MT*2) \qquad (1)$$

where A denotes distance travelled and MT movement time.

To create a mathematical fit for the phase plot data we applied the 'Taubin' method of curve and surface fitting (1991) and incorporated it into Matlab script. This method is based on a geometric-fitting approach and minimization of the approximate mean square distance:

$$F_T = \frac{\sum[(x_i-a)^2 + (y_i-b)^2 - R^2]^2}{\sum[(x_i-a)^2 + (y_i-b)^2]} \qquad (2)$$

Where x_i and y_i refer to consecutive points from the phase plot data for each trial.

3.3 Squared Error as Candidate Measure of Harmonicity

For the purpose of calculating the deviations from the harmonic movement pattern, we have adopted squared error approach as a preliminary outcome measure. Each stroke of the movement and reversal in a trial will be normalised according to the procedure listed in the 3.2 and further centralised with respect to the origin of the fit. Subsequently a squared error will be calculated between each data point of the velocity/position data and the closest point demarked by radius from the fitted circle. The median value will be extracted for each trial and condition for each participant.

Those values will be compared across patients and healthy elderly controls.

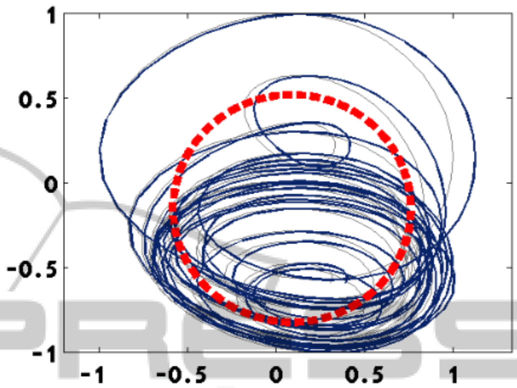

Figure 2: Illustration of how squared error measure is calculated based on the normalised phase plot data and fitted circle based on Taubin method. Black arrow depicts the 2-D distance between the fitted circle radius point and velocity/position data (red point). For each stroke of the movement and reversal, velocity/position data is centralised with respect to the origin of the fitted circular shape. The dashed red line represents a circular fit modelled to the positional data.

4 PRELIMINARY RESULTS

Preliminary data analysis provides an optimistic outlook for the method. So far 9 patient data were analysed along with the data from 16 healthy elderly subjects (10 tested on the right hand and 6 on the left hand). Graphical representation of the sample data are visualised in Figure 3. We have observed increased variability in terms of velocity/positional data in the group of apraxic patients in comparison to healthy elderly.

As illustrated on the Figure 3, preliminary data shows that in patients showing features of apraxia, we observe a disrupted pattern of harmonicity of the movement, when represented as phase plots. In addition, a difference in the surface fitting will be taken as a mean difference between the centralised movement cycle and fitted circle. In the preliminary data inspection other measures also revealed differences between patients and age matched controls, such as movement frequency, amplitude and movement path ratio (x/y/z to xyz).

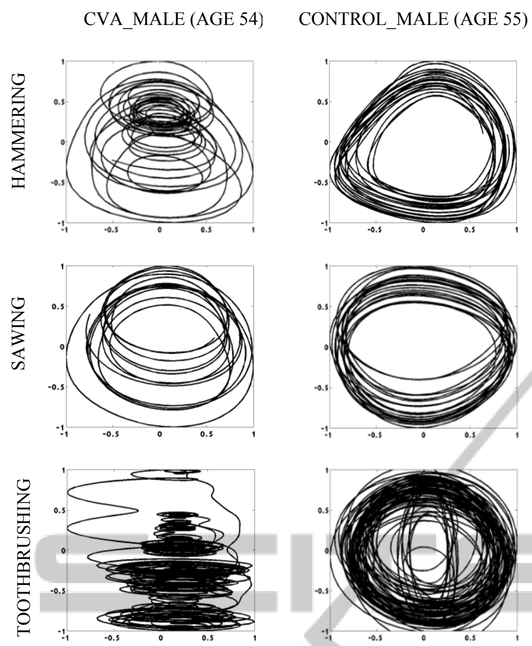

Figure 3: An example of normalised phase planes showing relation between the velocity of the movement against the position on the main movement axis (respectively z, y, x) from preliminary data analysis. Each row illustrates performance in the pantomime mode on the tasks: hammering, sawing and tooth brushing. Left panel depicts movement organisation of the apraxic individual (CVA in August 2012, 12 months prior to data collection). In the right side panel, control data for age and sex matched volunteer.

5 CONCLUSIONS

The work on this line of CogWatch project is in progress and requires detailed analysis to identify differences between selected CVA patients that show apraxic behaviour and healthy elderly performance. On the basis of the data collected in this study, a new measure might emerge that will feed into the development of the rehabilitation approach for those patients. This parsimonious approach to kinematic analysis might provide a novel insight into understanding the kinematic consequences of apraxia. The long term goal is to use harmonicity of movement as the biomarker for non-motor execution related disruptions in the performance of ADL that require cyclical movements. Authors are not aware of any kinematic biomarkers specific to apraxia being identified in a body of research. In this paper, we have argued that using the harmonicity measure might allow one to encapsulate many features of apraxic behaviour on the spatiotemporal dimension such as: movement amplitude, movement path, frequency of the movement, speed and acceleration profiles. The purpose of application of harmonicity measure in CogWatch is to compare how different interventions, based on supplementary sensory information, influence motor behaviour in patients with apraxia and monitor the progress of recovery.

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