Analysis of eye movements, kinematics and dynamic aspects of performance during activities of daily living in stroke patients

P. Gulde, C. Hughes, M. Parekh, M. Bieńkiewicz, & J. Hermsdörfer

***Abstract* — Apraxia is a neuropsychological symptom occurring as a consequence of cerebrovascular accidents (CVA). Apraxic individuals suffer from compromised access to motor concepts relevant for execution of activities of daily living (ADL). The CogWatch project aims to develop an automatized rehabilitation system that would facilitate performance of ADL. This study investigates signals which the CogWatch system can use to recognize human actions and intentions as well as apraxic errors during the performance of ADL tasks. Eye movements, hand kinematics and the dynamics of manipulated objects are recorded during the task of tea-making as an example of ADL. Data analysis is demonstrated using a performance example and first analysis results are shown for movement paths and times for the whole task and its sub-segments. CVA patients showed similar path lengths but prolonged movement times and less executed sub-segments in comparison with age-matched control subjects.**

***Keywords* -** Apraxia; CVA; Eye-movements; Kinematic analysis; ADL;

I. INTRODUCTION

Apraxia describes a symptomatic of loss of performance in using tools for goal achievements, which can be caused by stroke [1]. In this study we try to identify characteristics in apraxic patients' eye movements as well as hand kinematics in the everyday activity of tea making. In stroke patients, kinematics of upper limp performance in ADL have been intensively tested in the context of paresis, effects of apraxia and action disorganization syndrome on movement kinematics have however only rarely been analyzed [7]. In particular, deficits in the different segments of a multi-sequential ADL have not been evaluated so far. The study is part of the CogWatch (www.cogwatch.eu) project that is to develop a technical solution to promote independency in execution of ADL. The goal of the analysis of eye movements, hand kinematic and dynamics of manipulated objects is to provide an insight into apraxia in complex sequential tasks and support the development of action recognition algorithms. Recent studies report 24% incidence of persistent features of apraxia in CVA patients [2] and the project aims to deliver new technological solutions that would promote devices that restore function or assist task execution. Thus, offering a new approach to rehabilitation after dismissal from the hospital unit.

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II. METHODS

A. Experimental design

Task protocol is based on a tea-making scenario. Participants are instructed to prepare a cup of tea using water, a kettle, teabags, milk and sugar (see Fig. 1). Additional a distractor item (instant coffee jar) is placed on the working surface. The task is performed six times, twice bimanual, twice with the ipsilesional hand (dominant hand in control subjects) and twice with the contralesional hand (non-dominant hand in control subjects), if possible.

B. Subjects

Until now 7 CVA patients (3 with left and 4 with right brain damage) were tested. Patients were recruited from the Clinic for Neuropsychology at the Hospital München-Bogenhausen in Munich. In addition, 9 age-matched controls were tested in the same task scenario. Ethical approval was obtained by a local ethics committee.

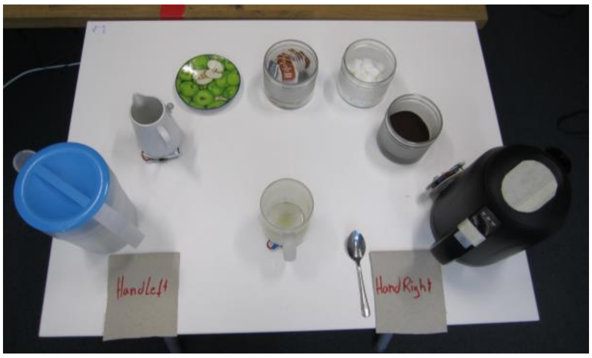

Figure 1: Experimental setting

C. Apparatus

Subjects are asked to wear a SMI-ETG eye tracking device during the task performance. The eye-tracking glasses incorporate a HD scene camera (sampling rate 30Hz). Fixations are identified and assigned to fixated objects off-line. In addition, positional data of both hands are recorded with the use of 5 Oqus Motion Capture cameras (Qualysis) at a sampling frequency of 120Hz (three passive markers are attached to each hand, mid-palm section). The mug, milk jug and kettle (base and body) have force and acceleration sensors attached (custom made by CogWatch technological partners, sampling rate 200Hz). Therefore additional dynamic data are recorded from 4 object sensors and synchronized with the spatio-temporal data from eye-tracking and motion capture. Figure 3 shows the synchronized data streams of the fixations, coasters and motion capturing devices for the tea making task in a healthy control subject during the bimanual task condition.

D. *Analysis*

Data are segmented into discrete actions and analysed using three different approaches:

- Analysis of fixations
- Analysis of kinematic and dynamic features
- Qualitative scoring of the performance

1) *Segmentation*

The whole task is segmented into the following action segments [4]:

1. Pour water in the kettle
2. Switch the kettle on
3. Place a teabag in the mug
4. Pour the heated water into the mug
5. Remove the teabag
6. Add milk
7. Add one sugar cube
8. Stir the tea

In a first step, boundaries of action segments are identified via the force and acceleration signal of the object sensors (coasters) according to defined thresholds of sensor signals [4]. The fine adjustment of action-segments is then performed with the use of hand kinematics [5]. An example of all recorded signals and of the resulting segments is shown in Figure 2 with numbers referring to the action segmentation above.

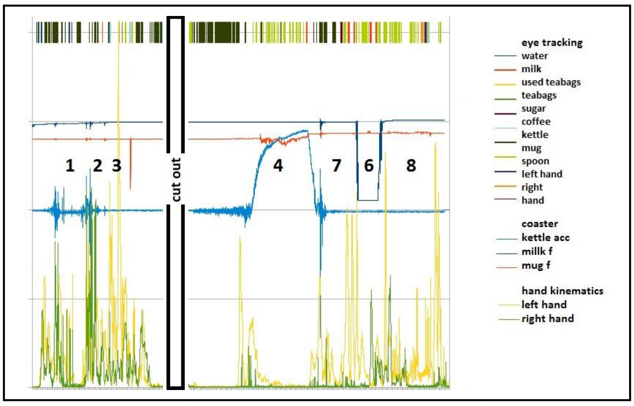

Figure 2: Example of segmentation via coaster data of the data streams for the task of making a cup of tea (bimanual). In the upper row the fixated objects are indicated using a color code (see legend on the right side). The lower two lines (yellow and green, baseline at '0') show the tangential velocities of right and left hand movements. In the blue and orange lines of the graph the most relevant signals of the coasters are depicted (see legend on the right side). The waiting time until the water in the kettle was boiling was cut from the data stream as indicated by the thick vertical lines. The resulting duration of the task was 132s. The numbers above the coaster signals refer to the action segments defined.

2) *Analysis of fixations*

The number and duration of fixations is assessed for the complete task and for the action segments The type of fixations can be determined using the categorization of Land and Hayhoe (2001) (directing, guiding, checking, locating, see [3]). Further, data are screened for irregularities in look-aheads and look-backs as well as other disruptions in the task execution i.e. hand fixations.

3) *Analysis of kinematics*

Positions and velocities of the hands are determined from the motion recordings and smoothed using a 1s LOESS filter ('local regression'). Following measures are determined for the complete action and action segments (see Fig. 2):

- Velocity
  - Maximum Peaks
  - Mean peaks
  - Number of peaks
- Movement times
- Path lengths

4) *Scoring*

Videos of the subjects' performance are coded to define apraxic behavior. Analysis assesses four error characteristics:

- Presence of errors
- Error patterns
- Eye movements in the context of timing of errors
- Sub-segment transitions analysis

The apraxic error classification will be based on the proposal by Hughes et al. [6] with 12 categories of apraxic errors previously reported in the tea-making task. The analysis of eye movements in error context will be focused on the exploration eye fixation pattern before, during and after the occurrence of errors. The sub-segment transition analysis will use Markov process-matrices to simulate tea-making and will offer insight into error emergence.

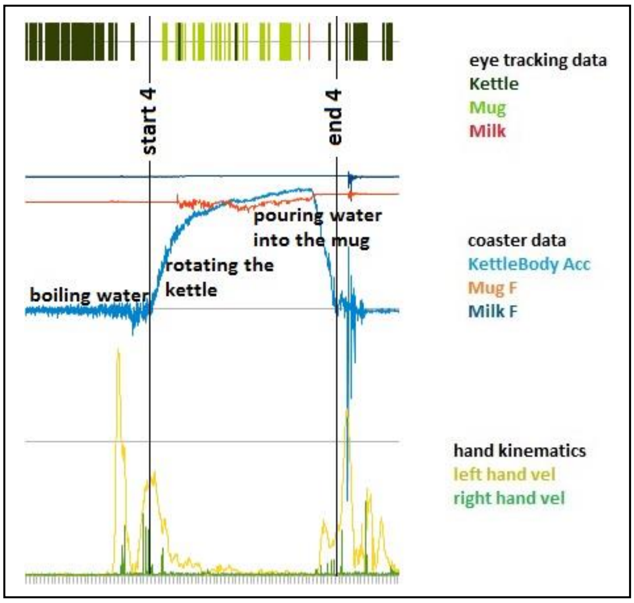

Figure 3: Example for the sub-segment 4 ('Pour heated water into the mug') extracted from the synchronized data streams for the task of making a cup of tea (see Fig. 2). Eye tracking data refers to fixations over time, coaster data to force and acceleration courses and hand kinematics to velocities. The sub-action lasted 14s.

III. ANALYSIS EXAMPLE

Figure 3 shows an extract of Figure 2. The sub-segment 4 ('pour the heated water into the mug') is shown for a control subject (bimanual performance). Note that the kettle body's acceleration sensor is giving distinct signals when the water starts boiling and the kettle is lifted with the left hand. When the kettle is put back on its base the irregular signals' peaks are visible in the coaster data of the mug and the milk's carafe. While pouring the water into the mug, the mug's force sensor amplitude is raising due to the added water. Before lifting, the kettle is fixated and while pouring, the subject is looking at the mug until putting back the kettle. The segmentation is done via a threshold for the kettle base force sensors (not displayed) and the kettle body acceleration sensors for segment 4 [4].

IV. PROGRESS

Action-segmentation and kinematic analyses have been done for path lengths and movement times. Figures 4 to 6 show the normalized values (basis control) for the control group (blue bars) compared with the CVA patients (orange bars) in unimanual trials, where controls used their non-dominant hand and CVA patients their ipsilesional hand. Analysis for segment 2 ('switch the kettle on') is missing since it could not always be differentiated from segment 1 ('pour water in the kettle').

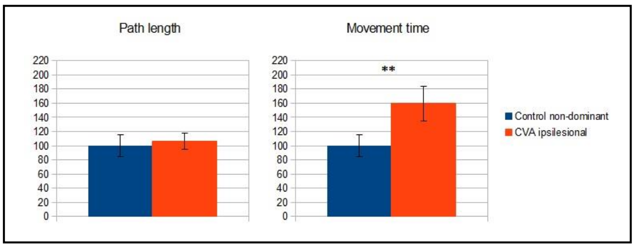

Figure 4: Path length and movement time for the complete task of tea-making before segmentation. The values were normalized. T-test revealed asignificant difference for the movement time with a p-value of .0004 and an effect size of .37.

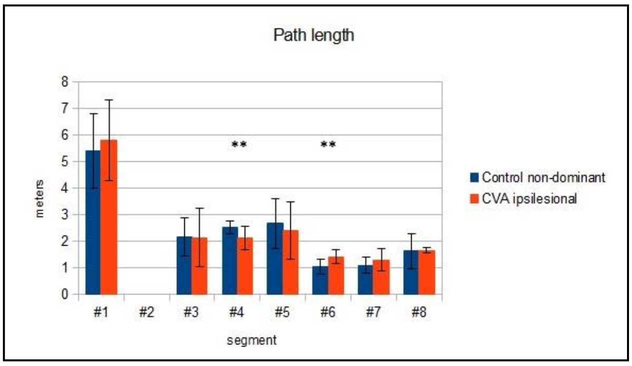

Figure 5: Comparison of path lengths for 7of 8 sub-segments in the tea-making task. T-test revealed significant differences for segments 4 and 6 with p-values of .002 /.001 and effect sizes of -.3 / .33.

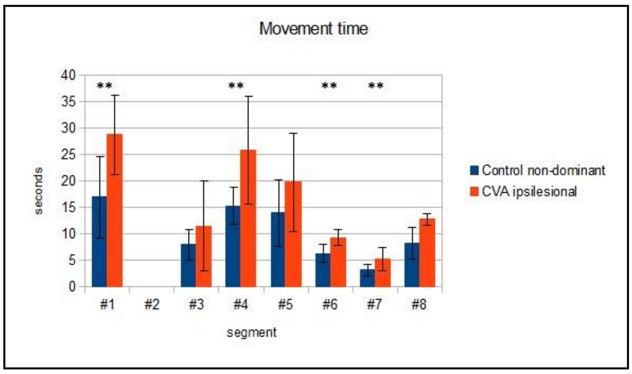

Figure 6: Comparison of movement time for 7of 8 sub-segments in the tea-making task. T-test revealed significant differences for segments 1, 4, 6, 7 and 8 with p-values of .0003 /.001 / .00002 / .003 / .001 and effect sizes of .39 / .39 / .47 / .32 / .53.

Figure 4 shows that patients needed longer to complete the whole task than the control group. This prolongation could not be attributed to paresis since the performance of the ipsilesional non-paretic hand is shown. Longer movement times did not correspond with longer path lengths as obvious from figure 4. The behavior of CVA patients therefore was characterized by slower but not by more or longer hand movements. In the segmental analysis only two segments showed significant differences in path lengths and five in movement times. Not every segment was affected in the same manner. Interestingly, the sub-task of pouring liquids into the mug revealed opposing effects for segment 4 (water) and 6 (milk). While path length was significantly reduced in segment 4, it was significantly prolonged in segment 6. It has to be considered that the validity of comparisons is still suffering from data losses due to missing sub-actions in their action-patterns in the CVA group (i.e. missing stirring of the tea or not removing the teabag, see Fig. 7) and the difficulty of isolating segment 2 ('switch the kettle on') from segment 1 ('pour water in the kettle') in both groups.

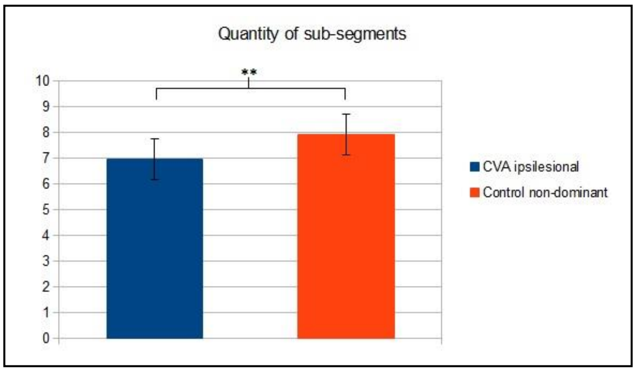

Figure 7: Comparison of executed sub-segments for the whole tea-making task. T-test revealed a significant difference with a p-value of .005 and an effect size of .28.

Figure 7 displays the average number of executed sub-segments for the whole tea-making task. CVA patients showed omissions and repetitions, but also the control group showed deviations from the number from the optimal number of 8 sub-segments, sometimes adding or omitting one sub-segment. In both groups mainly omissions of removing the teabag or stirring the tea occurred. However, in total controls performed less mistakes. The difference between the groups in the number of sub-segments executed in the tea-making task is significant with a p-value of .005, but of small effect (effect size of .28). A possible factor in committing mistakes in the preparation of tea with milk and sugar could be lack of familiarity of this type of tea in Germany. Nonetheless, clear instructions were given by the investigator and the experimental setting offered well-defined affordances.

V. FUTURE DIRECTIONS AND TECHNOLOGICAL CHALLENGES

Data collection for the paradigm is still in progress. The goal is to extend the number of subjects with CVA to 20. Current development is focused on resolving problems like synchronisation of the data streams (from coasters, motion capture and eye tracking – see Fig.2). It is expected that findings will provide valuable input into the further development of the CogWatch system. Kinematic data may be used to indicate skill and security of task execution. Gaze fixations data may emerge as an early indicator of upcoming apraxic errors that can be used in future versions of the system to prevent errors before they occure.

ACKNOWLEDGMENT

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REFERENCES

[1] Goldenberg, G., Hermsdörfer, J. & Spatt, J. (1996). *Ideomotor apraxia and cerebral dominance for motor control.* Cognitive Brain Research, 3, 95-100.

[2] Bickerton, W., Riddoch, J., Samson, D., Balani, A., Mistry, B. & Humphreys, G. (2012). *Systematic assessment of apraxia and functional predictions from the Birmingham Cognitive Screen.* Journal of neurology, neurosurgery & psychiatry with practical neurology, 83(5), 512-52.

[3] Land, M. & Hayhoe, M. (2001*). In what ways do eye movements contribute to everyday activities?* Vision Research, 41, 3559-3565.

[4] Hughes, C., Parekh, M. & Hermsdörfer, J. (2013). *Segmenting instrumented activities of daily living (IADL) using kinematic and sensor technology for the assessment of limb apraxia.* Communications in Computer and Information Science, 374, 158-162.

[5] Forde, E. M. E., Rusted, J., Mennie, N., Land, M. & Humphreys, G. W. (2010). *The eyes have it: An exploration of eye movements in action disorganization syndrome.* Neuropsychologia, 48 (2010), 1895-1900.

[6] Hughes, C., Baber, M., Bienkiewicz, M. & Hermsdörfer, J. (2013). *Application of Human Error Identification (HEI) Techniques to Cognitive Rehabilitation in Stroke Patients with Limb Apraxia.* HCI, 8 (2013), 463-471.

[7] Hermsdörfer, J., Li, Y., Randerath, J., Roby-Brami, A., Goldenberg, G. (2013). *Tool use kinematics across different modes of execution. Implications for action representation and apraxia.* Cortex, 49, 184-199.