CogWatch – Cognitive Rehabilitation of Apraxia and Action Disorganisation Syndrome

D1.3.2 Report on patient requirements II

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EXECUTIVE SUMMARY

WP1 has two main aims: to increase understanding of the AADS syndrome and evaluate user needs through experimental work. Both aims feed into designing the CogWatch prototypes and developing effective strategies in using CogWatch for providing rehabilitation or assistive feedback.

In section 1 we report progress on patient recruitment using the screening procedure we have developed (as defined in T1.3). We note that UOB as well as TUM have achieved the target patient recruitment goals. Contrasting error patterns in ADL and neuropsychological tests in patients with left and right brain damage indicate directions for individualising CogWatch performance to patient needs.

Section 2 describes the procedure and development of the task scenario that was chosen by the consortium for prototype 2, tooth brushing. This work is part of T1.1. Initial patient testing reveals errors to be expected include sequencing and omissions as well as poor movement quality.

Section 3 describes experimental work that aimed to systematically test efficacy of different cueing and feedback strategies. We divided the section into work that primarily contributes to the development of P1-tea making and to P2-toothbrushing. This work is part of T1.3.

Section 4 describes experimental work that aim to increase the understanding of AADS syndrome from a more basic scientific level, specifically focusing on understanding the neural correlates of activity of daily living. We report functional imaging, and lesion-symptom mapping experiments with healthy and patient participants. This work contributes to T1.3, providing a better understanding of the neural architecture of processes involved in activities of daily living and the effects of neural impairment associated with AADS. This work is expected to lead to new insights in developing more efficient rehabilitation procedures.

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REVISION HISTORY

Revision no.	Date of Issue	Author(s)	Brief Description of Change
v1	17/07/2014	TUM	Wrote TUM contribution
v2	21/07/2014	UOB	Added UOB contribution
v3	29/07/2014	UOB	Final draft version for Peer Review
v4	30/07/2014	UPM-LST	Quality Control and format review.
V5	13/08/2014	UOB_PR	Corrected draft based on peer review comments
V6	25/09/14	UOB_AW	Formatting, references, updating conclusions

LIST OF ABBREVIATIONS AND DEFINITIONS

Abbreviation	Abbreviation
UOB	University of Birmingham
TUM	Technical University of Munich
P1	Prototype 1: tea making
P2	Prototype 2: tooth brushing
AADS	Apraxia and action disorganization syndrome
BCoS	Birmingham Cognitive Screen
SD	Standard deviation
L(R)BD	Left (right) brain damage
AAT	Aachen Aphasia Test

1. REPORT OF PATIENTS RECRUITMENT AND TESTING

This section is concerned with recruitment and assessing stroke and brain damaged patients to improve the identification and classification of AADS syndrome (T1.3.1) which is relevant to setting up relevant conditions of P2 (toothbrushing) and to the evaluation of P1.2 (tea making) and P2.

1.1 UOB

UOB works primarily with patients who are no longer in hospital, or taking part in any formal rehabilitation training. Therefore the patients' time is relatively free and we invite them to participate in multiple testing sessions. Because UOB was originally delayed in achieving the required number of patients to be recruited to the project, we continued recruiting to achieve our original targets. To date UOB has recruited 70 patients, 72% of those were identified to suffer from AADS symptoms based on the screening procedure. The screening procedure (specified in deliverable WP 1.1 & 1.3) includes five tests from a standardised test the BCoS (Humphreys et al., 2012): Gesture production, Gesture recognition, Gesture imitation, Figure copy and multiple object step use (Figure 1 shows the number of patients who failed each of these tests). In addition it includes 2 specifically designed daily living activity tasks: a document filing task and tea making. So far we only tested 40 patients on these additional screen tasks. 7 (17%) and 9 patients (22%) scored 2 SDs below age match controls, and hence failed the tea making and filing tasks respectively. In line with the literature, patients have more difficulty completing gesture and pantomime tasks than task involving interaction with real objects.

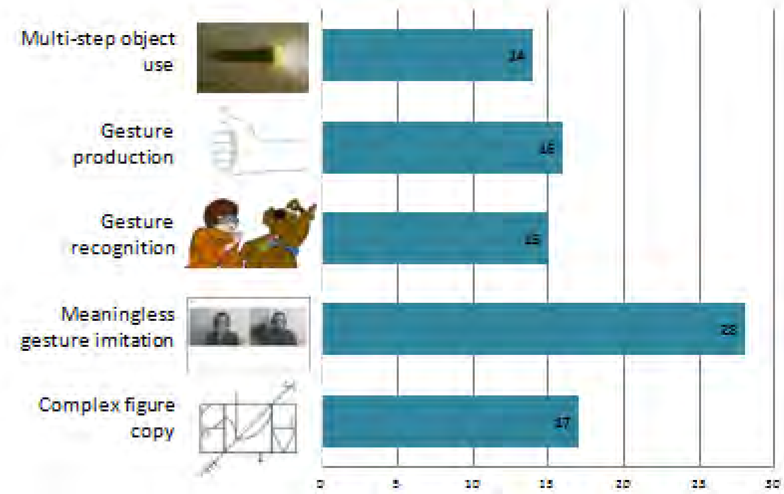


Figure 1: BCoS Screen data

Fig 1: Number of patients out of 70 tested, who failed each of the five CogWatch AADS screening tasks.

1.2 TUM

The summary of patients' recruitment and their characteristic was finalized and the report will be submitted as a manuscript to a scientific journal. This report is based on the clinical screening conducted in the Bogenhausen hospital in Munich, Germany. The study design was approved by the ethical committee of the Medical Faculty of TUM. Informed consent was obtained from all subjects, and the study was conducted in accordance with the Declaration of Helsinki. Thirty eight left brain damaged patients (LBD) were included along with seventeen right brain damaged patients (RBD). Four patients were excluded because of incomplete data and two because of bilateral damage. Participation in the screening was voluntary.

The aim of this report was to investigate the relationship between aphasia and other neuropsychological symptoms occurring as consequence of CVA. In particular we aimed to investigate whether difficulties with AADS can be linked to other sensory and cognitive deficit apart from the impaired access to the conceptual knowledge about tool use or compromised ability to sequence multi-step actions or execute fine motor movement.

1.2.1 <u>Demographic data</u>

The mean age for the LBD patients was 58 (SD=12 years), for the RBD patients 61 years (SD=12 years). The LBD group comprised 20 males and 18 females, the RBD group, 9 males and 8 females. All participants suffered from 1st CVA and were tested within the range of 2 weeks post-stroke up to 4 months. All participants were patients of Bogenhausen hospitals or attended outpatients clinic.

The clinical screening comprised of a Birmingham Cognitive Screen (BCoS): praxis and, spatial and controlled attention sections (Humphreys et al., 2012) along with Complex Tea Making Task and Document Filing (please see Deliverable 1.3.1 for detailed description of the procedure). The screening took an hour to administer, but in some patients had to be completed within two sessions. In addition, in the LBD group Aachen Aphasia Test was administered to assess their level of language comprehension in a separate session by a neurology consultant of the Bogenhausen hospital (Huber et al., 1984). The results are summarized in Figure 2.

1.2.2 <u>Overall task performance – Complex Tea Making Task</u>

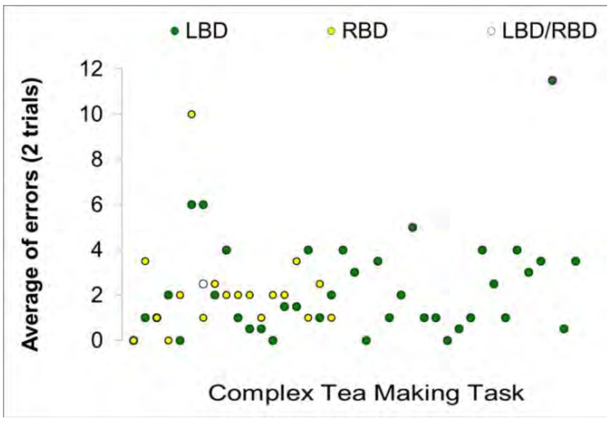


Figure 2: Errors for complex tea

Error Type	Definitions	Example
Addition (AD)	Adding an extra component action that is not required in the action sequence	Adding instant coffee to cup2
Anticipation (AN)	Performing an action earlier than usual	Turning the kettle on before pouring water into the kettle
Execution (EX)	An error in the execution of the task	Dropping the sweetener dispenser onto the table
Ingredient Omission (IO)	Failing to add an ingredient required to complete the task goal	Failing to put sugar into cup1
Misestimation (ME)	Using grossly too much or too little of some substance	Pouring half of the milk jug contents into cup2
Mislocation (ML)	An action that is appropriate to the object in hand but is performed in completely the wrong place	Pouring some liquid from the bottle onto the table rather than into the glass
Ingredient Substitution (IS)	An intended action carried out with an unintended ingredient	Pouring coffee grounds instead of sugar into cup2
Perplexity (PLX)	A delay or hesitation in performing an action	Picking up a tea bag and then pausing for an extended time before placing it into a cup
Perseveration (PER)	The unintentional repetition of a step or subtask	Adding more than one tea bag to a cup
Object Substitution (OS)	An intended action carried out with an unintended object	Pour heated water into non-cup1 object
Quality (Q)	The action was carried out, but not in an appropriate way	Putting the tea bag and the paper label into a cup
Sequence (S)	Performing an action much later than usual	Switch kettle on after preparing both cups of tea
Sequence Omission (SO)	An action sequence in which one step or subtask is not performed, despite the lack of any intention to omit the step or subtask	Turning on the kettle on without having added water

Table 1: Error definition - TUM

In the Complex Tea Making Task participants with LBD and RBD showed some impairment in the task performance. Figure 2 depicts average number of all errors committed during the trial by each participant. On average LBD participants committed 2.35 errors (SD=2.26) and RBD=2.29 (SD=2.18). The error taxonomy was developed throughout the project and is summarized in Table 1.

Patients' performances during the task were recorded by video. Each video recording was assessed by two researchers at TUM. Their scoring was averaged for each participant. Consistency of assessment reached 95% across individual ratings. Figure 3 illustrates the frequency of errors according to Table 1 taxonomy. Independent t-tests for each error categories revealed no differences between the RBD and LBD group ($p>0.05$). Only in the frequency of sequencing and misestimation errors there was a trend in the data showing prevalence of those errors in the RBD sample ($p=0.07$).

In a further analysis we regrouped the errors according to the classification of errors proposed in the paper by Bienkiewicz et al. (2014) into three categories; sequencing errors, conceptual errors and spatio-temporal errors. *Sequencing errors* included action: addition, anticipation, omission, perplexity and perseveration. *Conceptual errors* included ingredient omission, ingredient substitution, misestimation and quality errors. *Spatio-temporal* error category incorporated execution errors, toying and mislocation. We used this novel approach to examine further the correlations between the neuropsychological syndromes and the difficulties exhibited by patients.

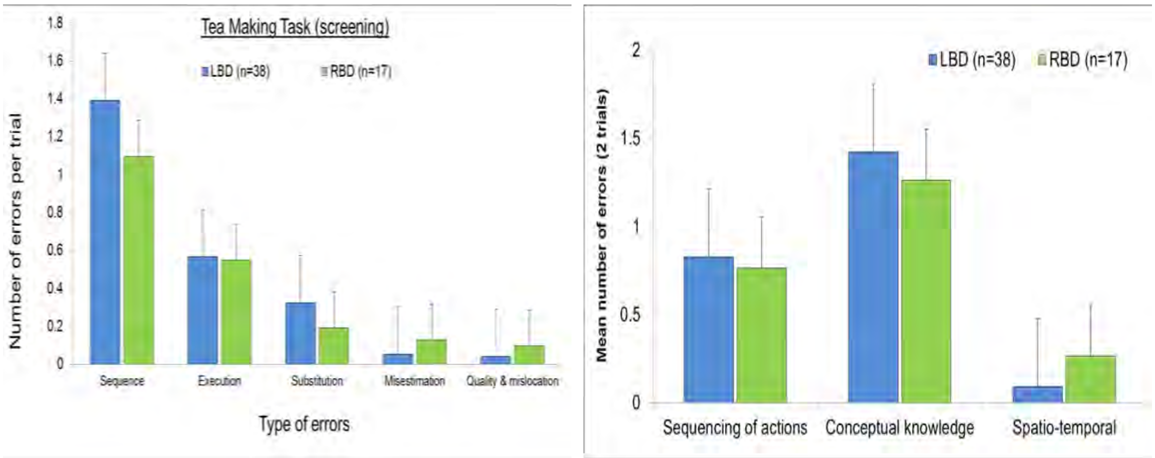


Figure 3: Error classifications

Fig 3: On the left, the charts present average number of errors per trial for the left (blue) and right (green; LBD, RDB) patients. On the right, the data organized based on three error types.

The error Independent t-test revealed differences between LBD and RBD group on only in the spatio-temporal dimension of errors $F(53)=8.846$, $t=1.760$ $p<0.02$. RBD patients on average committed more spatio-temporal errors in the Complex Tea making task than the LBD group. The differences between the number of error committed in the grouped sequencing errors and conceptual errors was not statistically significant ($p>0.05$). In summary, both groups of patients showed impaired performance in the multi-step action of preparation of Complex Tea Task. Patients with RBD more often show problems with spatio-temporal aspects of movement performance. These deficits can manifest as inadequate spatial positioning and handling of the objects, inefficient grasp or problems with fine motor control. These findings are consistent with the previous body of research e.g. Hartmann et al. 2005 (see Bienkiewicz et al., 2014a for review). In addition we have observed a trend in the data towards higher frequency of errors in the misestimation and sequencing category.

1.2.3 Overall task performance – Document filing

In the Simple Document Filing Task participants with LBD and RBD showed impaired task performance. Figure 4 depicts average number of all errors committed during the trial by each participant. On average LBD participants committed 1.94 errors (SD=2.24) and RBD=2.29 (SD=2.59). Figure 5 depicts the spread of number of errors committed in the task. Both groups demonstrated difficulty in this task.

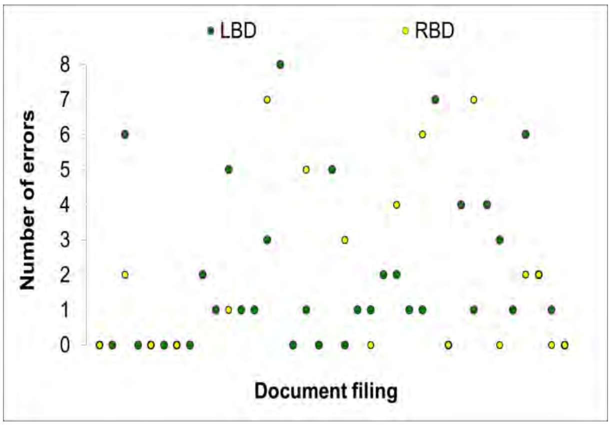


Figure 4: Number of error in filing task

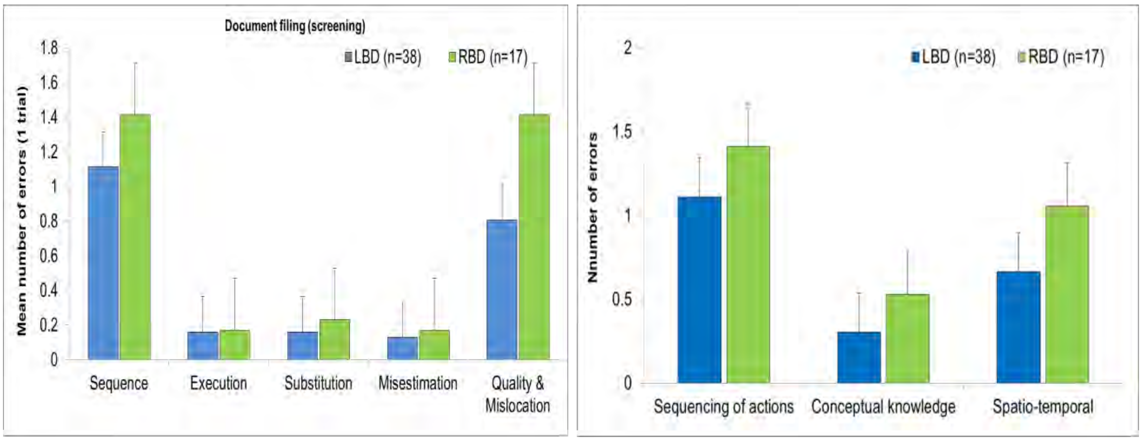


Figure 5: Error classification

Fig 5: On the left, the chart presents average number of errors per trial for the left (blue) and right (green; LBD, RDB) patients. On the right, the data organized based on three error categories.

In a comparison to the Complex Tea Making Task the profile of committed errors was different. There was increased frequency of quality and mislocation errors. In each error category RBD patients on average had higher error frequency than LBD group, however the difference was not statistically significant. Similarly to the Complex Tea Making task the majority of the errors were committed in the Sequence category (error taxonomy consistent with *Table 1: Error definition - TUM*).

In addition we applied a new taxonomy of errors, as proposed by Bienkiewicz et al. (2014) and divided all errors in the new categories. Independent t-test revealed differences between LBD and RBD group in the conceptual and spatio-temporal dimension of errors $F(51)=4.5$, $t=1.285$ $p<0.05$; $F(51)=6.67$, $t=1.24$, $p<0.02$. RBD patients committed more conceptual and spatio-temporal errors in the document filing task. The differences between the number of error committed between LBD and RBD in reference to the sequencing of the actions was not statistically significant.

1.2.4 <u>Clinical screening BCoS</u>

All the patients included were screened with the BCoS praxis and spatial attention battery. Figure 6 presents results for the LBD and RBD group in comparison to the control and patients data published by Bickerton et al. (2012).

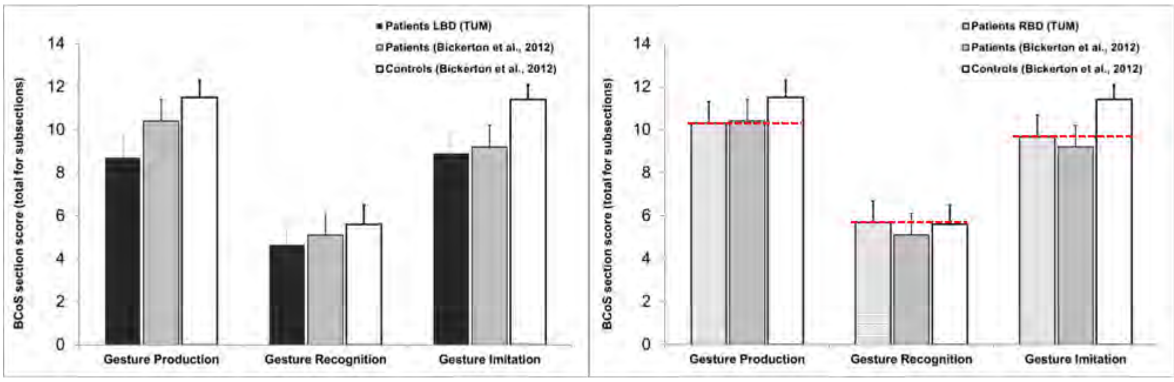


Figure 6: BCoS - gesture tasks

Fig 6: Illustration of the summary of scores on the praxis pantomime scales. Left panel: Scores of the LBD patients depicted were lower than the ones reported by seminal report of Bickerton et al. (2012). Right panel: In contrast, RBD patients had similar or higher scores than patients included in the Bickerton et al. (2012).

As summarised in Table 2 both patient groups demonstrated mild to moderate neuropsychological deficits. The LBD group was on average more impaired on the pantomime praxis scales than the Bickerton et al. (2012) patients and RBD sample. On the other hand RBD patients had on average more pronounced difficulties in spatial attention as visible in the scores in the Apple and Extinction tests. This was partially due to hemineglect/hemianopia as a co-morbid syndrome in those patients and hemi-paresis.

The next section presents findings from the correlation analysis between the Complex Tea Making and Simple Document Filing performance and the BCoS scores along with AAT (Aachen Aphasia Test).

BCoS subtest	MOT		Apple Test				Extinction				Complex Figure	
			Asymmetry complete		Asymmetry incomplete		Visual Extinct		Tactile Extinct			
Group/Value	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
LBD	11.5	1.2	0.2	1.2	0.1	0.9	0.0	1.2	-0.5	2.7	37.8	11.1
RBD	10.6	1.4	2.5	4.3	3.6	4.8	0.4	6.2	4.5	5.6	29.8	15.3
Norm scores (under 64 years of age)	11		|1|		|1|		|1|		|1|		42	

Table 2: BCoS Screen tasks

Table 2: M – Average value for the group, SD – standard deviation for the group, |n|- absolute value. Norm scores taken from the Bickerton et al. (2012). In the spatial attention tests (Apple and Extinction) minus value denote left sided problems with attention, positive values indicate right-sided deficits of attention.

1.2.5 Behavioural correlates of deficits in AADS

The aim of this work was to correlate the neuropsychological deficits with the performance in the Complex Tea Making Task and Simple Document Filing Task. The correlation analysis revealed that there was no relationship across performances between the two tasks, suggesting that the tasks involved different set of cognitive resources so both are presented below. For each patient group different subtests of BCoS were taken into consideration depending on descriptive statistics presented in the previous section. For example Apple Test scores were not taken into consideration for the LBD as, apart from mild attentional deficits, patients did not suffer from compromised spatial attention (e.g. neglect).

Based on the differences in the scores in the clinical screening RBD and LBD patients were separated for the purpose of correlation analysis. For each group, the presentation of results is divided in two parts. First we considered the global categories of the action errors observed in patients during both tasks (see Tables 3 and 5). Secondly we looked into links between particular errors (see Table 4 and 6).

In the LBD group the analysis was conducted with the inclusion of AAT scores. No relationship was found between the AAT scores and the task performance ($p>0.05$) (see Table 3). However, the deficits in the visual extinction noted a negative relationship with the difficulties in sequencing the Simple Document Filing Task. The same relationship was observed with the Tactile Extinction task. Pantomime praxis subscales correlated highly with the performances in both tasks. Gesture Production and Gesture Recognition had a significant negative correlation with the deficits in sequencing the Complex Tea Making Task. In addition, Gesture Recognition and Gesture Imitation had a significant negative correlation with the number of Conceptual errors committed in the Simple Document Filing (see Table 3). In particular in this task, Gesture imitation score was negatively linked to the quality errors in this task. Another significant finding was the link between the Rey Figure performance and the substitution error in the Complex Tea Making task, suggesting a link between the complex cognitive skills and ability to retrieve necessary ingredients for the task (See Table 4). There was no relationship between the number of errors and the time needed to accomplish the task goal.

	MOT	TEA			FILING		
		Sequence	Concept-ual	Spatio-temporal	Sequence	Concept-ual	Spatio-temporal
MOT		0.01	-0.13	0.02	0.18	-0.11	0.03
Visual Ext	-0.23	0.07	-0.09	-0.23	-.376*	0.19	-0.13
Tactile Ext	-0.02	-0.03	0.16	0.10	.433**	0.06	0.24
Gesture Prod	0.22	-.424**	-0.07	0.12	-0.07	-0.25	-0.01
Gesture Recog	0.24	-.447**	-0.05	0.08	-0.10	-.424*	-0.14
Gesture Imit	.452**	-0.27	-0.06	0.08	0.02	-.368*	-0.09
Rey Figure	0.10	-0.18	-0.25	-0.20	-0.07	-0.06	-0.05
AAT No	0.25	0.19	-0.07	0.08	0.03	0.03	-0.20
AAT Pr	-0.18	-0.24	-0.06	-0.13	-0.12	-0.21	0.06

Table 3: LBD - Correlation among the screen tasks - error categories

*Table 3: Correlation table for the Complex Tea Making and Document Filing performance, divided into three subcategories with the BCoS subtests. * p<0.05, ** p<0.01*

	Tea			Filing		
	Misest -imation	Substit -ion	Misloc -ation	Misest -imation	Quality	Misloc -ation
MOT	0.01	-0.13	0.02	0.18	-0.11	0.03
Visual Ext	-.380*	0.12	0.01	0.20	-0.01	0.01
Visual Tact	0.28	0.11	0.10	-0.01	0.19	0.08
Gesture Prod	-0.06	-0.26	0.16	-.337*	-0.23	-.355*
Gesture Rec	0.04	-0.19	0.16	-.584**	-.501**	-0.18
Gesture Imit	-0.01	-0.10	0.11	-0.21	-0.28	-0.11
Rey Figure	-0.05	-.334*	0.09	0.17	-0.03	0.09
AAT No	-0.21	0.18	0.10	0.17	-0.14	0.09
AAT Pr	0.10	-0.30	-0.15	-0.12	0.01	-0.14

Table 4: LBD - Correlation among the screen tasks – particular errors

*Table 4: Correlation table for the Complex Tea Making and Document Filing performance, with the BCoS subtests and most relevant action errors listed. * p<0.05, ** p<0.01*

In RBD patients we expected that compromised spatial attention might influence the performance in the ADL type of tasks (see Tables 5 and 6). In RBD patients visual attention is often compromised by left sided neglect. Indeed, we found a relationship between the neglect indication and MOT subtest and BCoS and number or misestimation errors. There was no correlation between other errors and the score in the Apple Test. The link between the misestimation error (e.g. using too much of certain ingredient) is an important finding for understanding the complexity of AADS. Compromised visual extinction was found to negatively correlate with errors on spatiotemporal dimensions in Complex Tea Making task and errors in the sequencing of action in Simple Document Filing. In particular, visual extinction was linked to the mislocation errors across both tasks. Interestingly, no relationship was found between Tactile Extinction (linked to the loss of proprioception, due to plegia or paresis) and task performance. Another finding was that ability to accurately demonstrate pantomime of tool use and communication gestures was linked to the number of errors. The worse performance on the Gesture Production in RBD patients the more errors were observed in both tasks. In particular we found a correlation between Gesture Production score and the number of sequencing errors in Complex Tea Making task and misestimation and quality errors in Simple Document Filing task. Interestingly Gesture Recognition score was linked to the misestimation errors in Simple Document Filing task (with possible underpinning in the spatial attention test) In addition, there was a relationship between the Gesture Imitation score in RBD patients and spatiotemporal aspects of the Complex Tea Making task, in particular, mislocation errors (also in Simple Document Filing task). However, these correlations did not hold when partially controlled for the performance in the Apple Test and Visual Extinction test (p<0.05), which suggests a strong contribution of the spatial deficits to the difficulties with multi-step actions in AADS and with transitive and intransitive gestures. Importantly, also the link between the sequencing errors in the Simple Document Filing and the score on Gesture Imitation does not reach significance levels when partially controlled for the spatial attention.

	MOT	TEA			FILING		
		Sequence	Concep -tual	Spatio-temporal	Sequence	Concept -ual	Spatio-temporal
MOT		0.11	0.20	0.28	0.03	0.22	.538*
Apple Test C	.519*	-0.21	0.09	0.14	0.02	-0.06	0.29
Visual Ext	0.23	-0.38	-0.19	-.582*	-.522*	-0.36	-0.23
Visual Tact	0.34	-0.18	0.01	0.22	0.32	0.02	0.23
Gesture Prod	-0.18	-.558*	-0.36	-0.11	-0.36	-0.37	-.488*
Gesture Recog	0.29	-0.29	-0.42	-0.11	-0.46	-0.41	-0.04
Gesture Imit	0.12	-0.41	-0.29	-.659**	-.615**	-0.31	-0.22
Rey Figure	-.702**	-0.26	-0.38	-.586*	-.618**	-0.43	-.545*

Table 5: RBD - correlation among the screen tasks – action categories

*Table 5: Correlation table for the Complex Tea Making and Document Filing performance, divided into three subcategories with the BCoS subtests. * p<0.05, ** p<0.01*

These findings are seminal for understanding the neuropsychological deficits underpinning ADS in RBD patients. Finally, Rey Figure performance was linked with all the tasks involved: MOT, Complex Tea Making and Simple Document Filing. This is test involves many different cognitive functions that also contribute to the successful ADL functioning. Strong negative correlations were found - the lower the score on the Rey subtest the higher frequency of errors in the Complex Tea Making and Document Filing tasks, along with MOT. In addition, this subscale correlated strongly with the spatiotemporal errors in the Complex Tea Making task (mislocation) and sequencing difficulties and quality errors in the Simple Document Filing. In summary, the analysis of the correlates of impaired ADL performance in

RBD revealed multifaceted links primarily with spatial attention. Interestingly there was no correlation between the task performance time and the number of errors. This finding was replication of findings in the LBD group and has theoretical implications for using a time of the performance as a measure of apraxic behaviour.

	TEA			FILING		
	Misestimation	Substitution	Mislocation	Misestimation	Quality	Mislocation
Apple Test Inc	.559*	0.14	-0.20	-0.24	0.08	-0.05
Visual Ext	-0.03	0.14	-.708**	-0.22	0.11	-.541*
Tactile Ext	0.26	-0.10	0.07	-0.39	0.25	0.02
Gesture Prod	0.30	0.02	-0.40	-.506*	-.486*	-0.42
Gesture Rec	0.23	0.16	-0.40	-.509*	0.02	-0.18
Gesture limit	0.00	0.28	-.782**	-0.27	0.03	-.494*
Rey Figure	-0.26	0.07	-.533*	0.13	-.492*	-0.423

Table 6: RBD - correlation among the screen task – particular errors

*Table 6: Correlation table for the Complex Tea Making and Document Filing performance, with the BCoS subtests and most relevant action errors listed. * p<0.05, ** p<0.01*

1.2.6 Summary of findings

Analysis of the screening data served two purposes; i) to select candidates suitable for the CogWatch intervention; ii) to explore the neuropsychological correlates of AADS. Overall, 50% of patients met the inclusion criteria for CogWatch intervention and they were approached to participate in further studies. Descriptive, comparative and correlational analysis of the dataset provided new findings that will broaden the understanding of AADS in the research community. Similarly to the previous reports (e.g. Hagmann et al., 2005) we have observed mild to severe impairments of both patient groups (LBD and RBD) in the ADL tasks: Complex Tea Making task and Simple Document Filing task. Those findings reinforce the view that apraxia and action disorganisation syndrome can be difficult to disentangle (Humphreys and Forde, 1998). However, in the Complex Tea Making task we reported higher ratio of the spatio-temporal errors in the RBD sample than in LBD group. In Simple Document Filing group RBD patients had higher frequency of both conceptual and spatio-temporal errors than LBD group. This error taxonomy is a novel approach to understanding of difficulties AADS patients. Nonetheless, the results are congruent to the previous reports suggesting problems with smooth motor control in RBD group (see Bienkiewicz et al. 2014 for review). Interestingly, the performance on both tasks was not correlated to each other, suggesting that they both involved different set of higher cognitive functions. Complex Tea Making involved multi-step object use, whereas Simple Document Filing can be referred to as simple tool use action. In LBD sample we found no relationship between the AAT scores and the task performance (despite a positive correlation between AAT and pantomime praxis scales of BCoS). Praxis pantomime scales had a strong negative correlation with the action errors in both tasks (sequencing and conceptual). Rey Figure performance was negatively correlated with the number of substitution errors in Complex Tea Making task. In addition, in LBD group loss of proprioception (caused by plegia/paresis) was linked to the difficulties with sequencing the tasks. Analysis of the RBD samples revealed strong correlation between compromised spatial attention (due to hemi-neglect or hemianopia) and the spatial aspects of task performance, namely mislocation and misestimation errors in both tasks. In addition, poor score on the visual attention tests was reflected further in diminished ability to accurately recognise and imitate gestures on the pantomime praxis scales in BCoS, although the current analysis cannot confirm the direction of this relationship. All together these findings might suggest that compromised spatial attention contributes to the AADS difficulties in RBD group and project on ADL functioning of patients. Interestingly there was no link between the Tactile Extinction and task performance (unlike in the LBD group). Finally, Rey Figure performance in RBD patients correlated negatively with performance on Complex Tea Making, Simple Document Filing and MOT. Taken together with similar results in the LBD sample, use of Rey Figure in clinical assessment might be an indirect measure of deficits in ADL functioning. In sum, analysis of neuropsychological correlates of AADS in LBD and RBD patients revealed that both groups although might suffer from compromised ADL independence, manifesting behaviourally in a similar way, the underpinning factors of those deficits might be different.

2. DEFINING ACTION TREE AND TASK MODEL FOR P2

In this section we report on work under T1.1 aimed at describing the second scenario task, tooth brushing, elaborating subtasks of the activity in more detail, and defining the goals that signal completion of tasks and subtasks. These descriptions and definitions are being used in the development of the monitoring and feedback devices of CogWatch P2 and in the design of patient studies.

2.1 Tooth brushing Action Tree

The action tree and feedback table for tooth brushing was designed based on interviews with and observation of patients, carers professionals who work with patients and dental health professionals. Based on the information gathered we decided to have two versions of the action tree which differ in their level of detail. Depending on patients' severity they would start with the simplified version of the task, including all the basic sub-tasks. Following success with the simplified version they will progress to a more detailed version of the task, which breaks down the brushing act to lower level actions.

Our initial research found large heterogeneity of common practices in tooth brushing procedure. However, tooth brushing as opposed to tea making has a clear health goal and therefore has clear guidelines and recommendation from health professionals. To accommodate health professional guidelines as well as allowing the preservation of common practice, we decided that sub-tasks which are common practice but are not recommended by current dental hygiene professional will not be mandatory, hence the task model will not cue for them or consider them as omission if skipped, on the other hand they will not be considered as toying and would be identified and logged by the system. We indicate these sub-tasks below.

The simplified task model is based on the sub-task level of the action tree (like prototype P1) and included the following sub-tasks:

1. Fill glass with water
2. Clean/wet toothbrush (not mandatory)
3. Put toothpaste on toothbrush
4. Brush teeth for at least 2min
5. Brush tongue (not mandatory)
6. Clean mouth with water (not mandatory)
7. Spit
8. Clean toothbrush
9. Dry mouth
10. Empty glass

The extended version breaks down the toothbrush sub-task to its components. We divide the mouth to pairs of teeth (based on the ISO system http://en.wikipedia.org/wiki/Dental_notation), assuming the toothbrush covers 2 teeth at a time. Each pair needs to be brushed on the outer, inner and top surfaces. In addition, based on discussion with dental professionals the recommended brushing movement should focus on the gum line. With limited dexterity it is advised to use small horizontal movements oriented toward the connection between the teeth and gum, with some vertical movements away from the gum. Each tooth should be brushed about 5 times, again with limited dexterity it is better to focus on number of brushing strokes than brushing time.

2.2 Error definitions

2.2.1 Detecting and classification of action errors while tooth brushing in stroke patients

There is a scarce body of research investigating tooth brushing behaviour in patients with AADS (Bienkiewicz et al., 2014a; Schwartz et al., 1991). Currently P2 is being developed targeting facilitation of the oral hygiene in those patients. The aim of this study is to investigate the occurrence of AADS errors during the tooth brushing task in CVA patients with LBD and RBD in a naturalistic setting. Findings from this study will feed into the development of P2 and presented results are preliminary (two case studies).

2.2.1.1 Methods

Participants. 2 patients tested, 1 Female, out of 10 patients planned (1st CVA event). All participants were recruited from Bogenhausen hospital in Munich, Germany. During the recruitment phase potential participants were screened according to the usual preference to use electric of manual toothbrush and prosthetic teeth. The participation in this study was voluntary. The study design was approved by the ethical committee of the TUM Medical. Informed consent was obtained from all subjects, and the study was conducted in accordance with the Declaration of Helsinki.

Apparatus. Participants were tested in the CogWatch lab in the KMB hospital in Munich. The experimental setting comprised of wash bowl with tap, mounted on the wall, mirror, chair and set of tools and distractor items (see Figure 7). The set of objects included toothbrush and toothpaste (displayed vertically in a cup), 3 paper towels and two cups. The distractor items used in the experiment were two dispensers mounted on the wall (with disinfectant and soap), Nivea cream, cotton bud container and a comb. Two digital cameras (Panasonic HDC-SD909) were mounted to provide two video recordings: one of the bowl setup, the second on the mouth area of the patient.

Figure 7: Experimental set up

Top image presents the experimental set up in the KMB, hospital Munich lab. Two video cameras, one directed toward the sink and the object and a second one toward the patient face record the events. The target and distracter objects were arrange on the sink edge. See text for details.

Procedure. Each of the participants was comfortably seated in front of the washing basin. They were asked to familiarize themselves with the setup and ask questions. All participants obtained the same oral instruction: ‘Please brush your teeth as usual’. The same procedure was repeated three times and analyzed as three trials.

Data analysis. Each trial was assessed separately according to the error classification used previously in CogWatch project (Hughes et al., 2013). Table below illustrates the errors relevant for the tooth brushing task (see Table 7). The sequence of sub-task goals for the task was defined as: add water to glass, add toothpaste to toothbrush, brush teeth, spitting, clean/dry around mouth area, clean brush and empty water glass.

Error Type	*Definitions*	*Example*
Addition (AD)	Adding an extra component action that is not required in the action sequence.	Comb hair. Cream face.
Anticipation (AN)	Performing an action earlier than usual.	Dry face even it`s not wet.
Execution (EX)	An error in the execution of the task.	Drop toothbrush.
Ingredient omission (IO)	Failing to add an ingredient required to complete the task goal.	No toothpaste on toothbrush. No water in cup for cleaning mouth.
Misestimation (ME)	Using grossly too much or too little of some substance.	Too much or less water in cup. Too much or less toothpaste on toothbrush.
Mislocation (ML)	An action that is appropriate to the object in hand, but is performed in completely the wrong place.	Toothpaste on comb. Brush face with toothbrush.
Ingredient substitution (IS)	An intended action carried out with an unintended ingredient.	Putting cream instead of toothpaste on toothbrush.
Perseveration (PER)	The unintentional repetition of a step or subtask.	Brush teeth again.
Object substitution (OS)	An intended action carried out with an unintended object.	Brushing teeth with comb. Put toothpaste instead of toothbrush under water.
Quality (Q)	The action was carried out, but not in an appropriate way.	Brushing teeth too strongly. Brushing teeth too short.
Sequence (S)	Performing an action much later than usual.	Wet face after drying.
Sequence omission (SO)	An action sequence in which one step or subtask is not performed, despite the lack of any intention to omit the step or subtask.	Not dried face. Not cleaned mouth.

Table 7: Tooth brushing error definitions

2.2.1.2 Results

Preliminary results are presented in Tables 8 and 9 summarising two case studies, one male with LBD, one female with RBD.

Patient 1	**Error type**	**Frequency**		
		Trial 1	Trial 2	Trial 3
Fills cup to equal or more than 80% of its capacity	Misestimation	1	1	0
Brushes teeth too strongly →bleeding	Quality	1	1	1
Does toothpaste directly into the mouth	Mislocation	1	1	1
Floods floor, because of losing control of cup	Quality	1	0	0
Doesn´t lean enough over the sink for spitting	Quality	3	0	1

Drops water out of mouth beside the sink	Quality	0	1	2
Does toothpaste into mouth two steps too early	Anticipation	1	1	1
Doesn`t spit	Sequence omission	1	0	1
Takes subject (toothbrush) too early (but corrected by himself)	Anticipation	0	0	1
Spits over disabled hand	Quality	2	1	0
Brushes inaccurate	Quality	1	1	1

Table 8: Patient 1

Patient 1 (LBD). Characteristics: Male, 67, Time of stroke: 01.01.1998, 1st stroke, Right handed, Right sided neglect, Right arm plegia, Aetiology: Ischemic (MCA), Temporal-Occipital Lesion, Aphasia Wernicke.

Patient 2	**Error type**	**Frequency**		
		Trial 1	Trial 2	Trial 3
Drops a bit of toothpaste on toothbrush	Execution	1	0	0
Drops water out of mouth beside the sink during tooth brushing	Quality	1	0	0
Patient let the water run during tooth brushing	Sequence omission	0	0	1

Table 9: Patient 2

Patient 2 (RBD). Characteristics: Female, 63, 1st stroke, Right handed, Left sided neglect, Left arm plegia, ICB

2.2.1.3 Conclusions and future plans

Preliminary results show that the patient with LBD demonstrated more pronounced difficulty with tooth brushing task. Errors included occurred in the dimension of quality, misestimation and omission of action sequence. Overall in three trials patient 1 committed 28 mistakes. In comparison, patient 2 committed four mistakes. This lays the ground for further work in trying to understand how sensory information can aid ADL performance in CVA patients. The results of this study, although promising are not conclusive.

By the end of the summer we plan to collect and analyse the data of 8 more patients.

2.3 Common tooth brushing errors

Based on the data above and interviews and observations with clinicians, we identified the most common errors that were also likely to be detected by the action recognition model in CogWatch.

Omission errors: in the simplified version omitting any mandatory step, while in the extended version failing to visit a location in the mouth.

Sequence errors: when patients follow an illogic sequence, e.g. brushing before putting toothpaste on the brush; cleaning the brush in an empty glass, cleaning the toothpaste from the toothbrush before brushing.

Brushing errors: in the simplified version patients not spending enough time in mouth; while in the extended version we would cue for the following errors: patients biting the brush, brushing too hard and not cleaning the gum line (too few horizontal movement with the brush oriented toward the gumline).

Some AADS patients have difficulty in moving the toothbrush into the mouth. We have not explicitly defined it as an error as we would require the patient to accomplish this task before they use the CogWatch system. We would consider developing an additional tool that could help them in achieving that (see 3.2.2), but this will be separated from the task model.

3. CUEING EXPERIMENTS

The work presented in this section involved carrying out studies with healthy young and elderly controls and AADS patients (T1.3.2) in order to provide evidence of effective cueing and feedback in ADL task performance. The work in this task will contribute to developing the feedback loop of the CogWatch system and to designing patient studies in its evaluation. The first section relates to P1 tea making (and in one case snack preparation) the second to P2 tooth brushing. A summary of the studies may be found in the final Conclusions (section 5).

3.1 P1 - Tea making

3.1.1 Errorless vs. errorful approach (UOB)

Background: There is a debate within the neuropsychological community between two rehabilitation procedures error-less and 'errorful' (Middleton and Schwartz, 2012). In errorless learning, the rehabilitation procedure aims to prevent the patients from committing an error. This is done by providing the information on the required response at every step. Errorless procedure eliminates the need of the patient to rely on retrieval processes to guide behaviour and responses. The rationale is that enough repetitions and exposures to the correct responses will serve as implicit memory traces that guide future actions. In contrast 'errorful' learning is based on the well-established phenomenon in psychological research that difficult acts of retrieval are an important factor in learning and memory, as it enables participants to practice retrieval of information (Roediger and Karpicke 2006). It further enables explicit correction of errors, based on the idea that learning occur through errors.

Figure 8: Example of cues

Cue example, still extracted from the video clip used. The still show a coherent contextual cues for pour milk before adding water to the cup

Current study: UOB conducted an experiment to directly compare between the two approaches when applied to rehabilitation of daily activity, i.e. tea making. We used a pre-training-post paradigm. The pre and post testing trials were identical across both conditions, the training trials differed depending on the condition. In the errorless training, participants received a predictive cue which directed them through all the steps of the task. In the errorful condition participants received feedback only when they committed an error.

3.1.1.1 Methods

Participants. 10 patients who were identified by the screen to have potential problems in tea making were recruited.

Materials. The CogWatch making tea table set-up was used, including water jar, kettle, milk jag, cup, teaspoon, teabags, sugar cubes, bowl for re-used teabags and a jar of instant coffee.

The items were arranged as in the CogWatch prototype 1. For the cues we used video cues (from prototype 1, Figure 8) depicting first person right handed perspective sub-action. The cues were congruent with relevant environmental context (e.g. different video for sugar cube added to white tea as opposed to black tea). The video cues were presented with speech instruction in the background. The cues were initiated manually by an experimenter.

Design & Procedure. The experiment had a 2(time: pre, post) x 2(training: errorless, errorful) within subject design. Training type was manipulated across sessions. The sessions were separated at least by a week. Each session included: 2 pre-training trails; 6 training trails and 2 post-training trials.

Patients were trained on one type of tea from prototype1 (black tea, white tea, black tea with sugar, and white tea with sugar). Prior to testing, participants described their preferred cup of tea (e.g. tea with milk and no sugar) and the sequence they use. Based on this individual description, we chose a tea type that differed from their preferred tea in one component (e.g. adding or subtracting a sub-action; for the example above they may ask to do a tea with milk and sugar). The action sequence remains similar to what the patient described. Throughout the testing they were trained and tested only on the non-preferred tea.

Auditory-visual, speech and video cues were initiated by the experimenter. In the errorless condition these were provided continuously, such that once the patient has completed a sub-task (add water to kettle) they received the cue for the next sub-task (boil kettle). In the errorful condition the cues were provided when an error was detected. If the error was fatal the trial was aborted and a feedback was given describing the error. All trials were recorded using video taken from a first person perspective. The errorful session was run only with patients who made errors during the pre-trials, since in the absence of errors the patients will not requires any cueing. All patients were tested in the errorless condition, as this did not depend on whether they made an error or not.

Data Analyses. For each trial we coded whether it was completed successfully, the number of correctly completed sub-tasks, number and types of errors and average time for completing a sub-action.

3.1.1.2 Results

Three out of the 10 patients made consistent errors during the pre-trials. Here we present initial data from two of these patients.

UBP033 – This patient was overall very confused. He made specific sequence errors and perseveration errors around the use of water and stirring. For example he boiled the kettle before he added the water. He added the water to the kettle and then without boiling poured them to the cup. He stirred before he added water to the cup. The patient was tested first in the errorless condition. See Figure 9.

Errorless condition: the patient did not complete any **pre-trials** successfully – making primarily sequence and omission errors. During the **training trials**, he only partially followed the cues, he completed all required sub-actions, but due to sequence failing (boil water before adding to kettle) he failed to successfully complete 3 out of the six trials; though his number of errors was reduced. During the **post-trials**, the patient retained his performances only for the first trial, dropping in the second post-trial test.

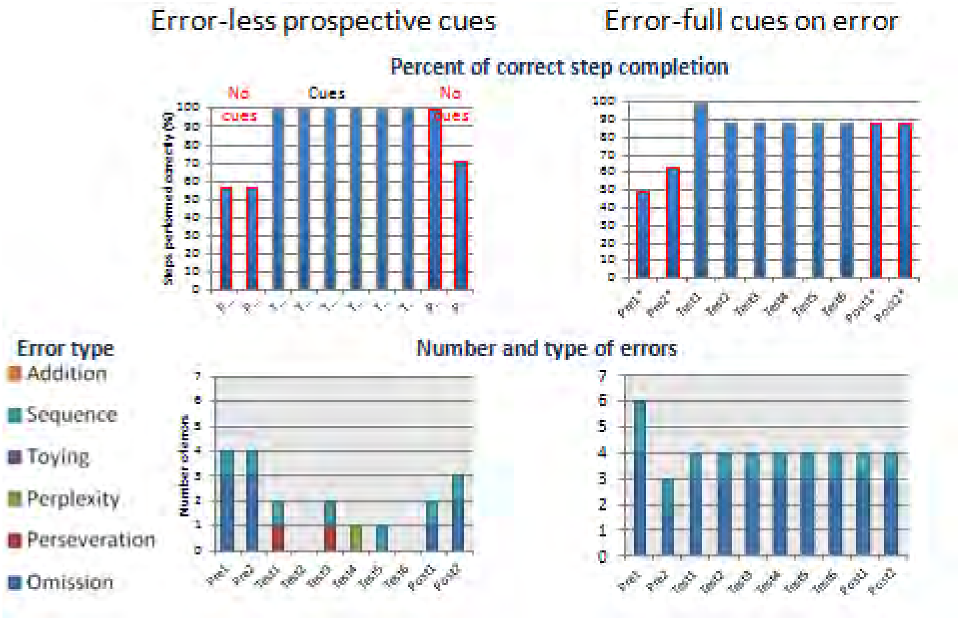


Figure 9: UBP033 results

Fig 9: For each condition and each trial, the top charts show the number of correctly completed steps (sub-tasks); bottom charts shows the number and type of errors made. Within each chart, the bars represented the trials within a session. The two bars on the left are the pre-trials; then 6 training trials and the two on the right are the post trials

Errorful condition: both **pre-trials** were not completed successfully. The patient performances dropped to his initial level at the beginning of the second session. During **training** and **post** trials he maintained a consistent level of performances, with 80% or more of sub-task steps completed correctly, but he also had high level of errors (sequence and omission) which meant he did not complete any trial successfully.

UBP035 -This patient was more confident in his actions and had a very specific and replicated error. He was consistently distracted by the coffee jar, adding coffee and tea to his mug. We note that he does not drink coffee and tea as a drink usually (as accustomed in Malaysia), but he appeared to be distracted by the coffee. See Figure 10.

Errorless condition: the patient did not complete any **pre-trials** successfully – making primarily an addition error, but completing most steps correctly. During the **training trials**, he completed all required sub-actions and successfully completed all trails though he showed perplexity and toying errors on all trials. During the **post-trials**, the patient made a fatal addition error only for the first trial and completed successfully the second trial but show uncertainty evident by his perplexity, tying and perseveration errors.

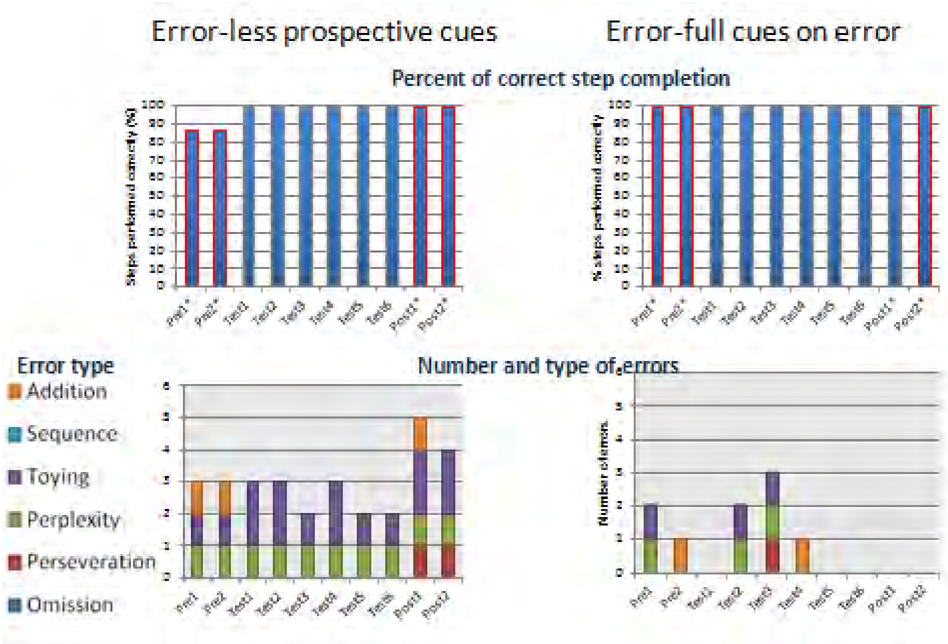


Figure 10: UBP035 results

Fig 10: For each condition and each trial, the top charts show the number of correctly completed steps (sub-tasks); bottom charts shows the number and type of errors made. Within each chart, the bars represented the trials within a session. The two bars on the left are the pre-trials; then 6 training trials and the two on the right are the post trials

Errorful condition: The patient appeared to maintain some learning from the previous session – showing overall better performances. He completed the first **pre-trial** successfully, but then failed on the second trial (adding both tea and coffee to the mug). During **training** he made fewer perplexity and toying errors and was cue for next step, completing first 3 trails successfully. In trial 4 he made a fatal addition error and the trial was aborted given him the appropriate feedback. Following this, in the remaining training trials and the **post** trials he maintained a consistent level of successful performances with no errors.

3.1.1.3 Conclusion and future planning

These initial results suggest that the impact of errorful and errorless procedures on rehabilitation vary with patient severity. UBP033, who showed relatively severe impairments, benefitted more from the errorless approach, though the impact appear short lasting. On the other hand, UBP035 who had a specific and reproducible error benefited more from the errorful procedure and the explicit feedback on his error; while the implicit feedback given in the errorless condition only confused him.

In the future, we plan to collect data from 2-3 additional patients who make errors during pre-trials. These patients will start with the errorful condition training.

3.1.2 Prospective cueing effects on ADL performance after stroke (TUM)

The aim of this study was to compare behaviour of patients with AADS under error feedback and prospective guidance in a naturalistic task setting (breakfast making scenarios). There is a lack of conclusive research in the literature what type of guidance helps patients with AADS to accomplish task goal in ADL related scenarios (Bienkiewicz et al., 2014a). This study aims to investigate whether there is a benefit of using pictorial instruction in the feedback mode (when error is committed) and/or in prospective mode (to prevent error occurrence) versus no guidance. This research was conducted in the Bogenhausen hospital in Munich, Germany. The study design was approved by the ethical committee of the TUM Medical Faculty. Informed consent was obtained from all subjects, and the study was conducted in accordance with the Declaration of Helsinki.

3.1.2.1 Methods

Participants. Six patients were enrolled in the study: 3 Females, 5 with LBD, 1 with RBD damage. Age 42 to 82 years (Ø 65 years). In addition 5 healthy adults (Ø 24 years) were tested on the same task.

Materials and apparatus. Participants were tested in the CogWatch lab in the KMB hospital in Munich. The experimental design comprised of three tasks: making a bowl of cereal, making a sandwich with jam and making a sandwich with ham or cheese. List of ingredients is depicted on the Figure 11. In addition patients had access to knife, spoon, fork, and custom made nail board (to facilitate one-hand spreading performance). In addition, in each task apart from the ingredient list, participants had one distractor item (cereal- water, jam- mustard, cheese – jam).

Figure 11: Breakfast ingredients

Ingredients used in the experiment: bread, jam, butter, cheese, ham, milk, linen seeds, raisins, banana chips, and oats.

Figure 12: Experimental setup

The pictorial instruction was displayed on the 19 inches LCD Dell Monitor (see Figure 12). In the feedback condition if participant committed a mistake an auditory alert (500Hz) was displayed followed by a picture of the next step of sub-action specified by action tree (see Figures 13-15). The interface was controlled via tailored software operated on a separate Lenovo laptop. In the prospective information condition participants were asked to watch a pictorial instruction showing action performance step by step and then commence the trial after an auditory tone is displayed (500Hz).

Procedure. Participants were asked to sit comfortably in front of the workspace. After short oral instruction participants were invited to ask questions. Each task included 3 trials that were randomized across participants: no feedback condition, prospective feedback and error correction. The block of trials was preceded with practice trial so that participants could familiarize with the task. In the no feedback condition participants were asked to perform the task without any instructions or feedback. In the prospective cueing condition participants were prompted about the next step in the action sequence on the screen (with the use of pictorial instructions). In the error correction condition participants obtained an auditory warning signal if they committed action error followed by pictorial instruction showing the next 'correct' step.

Data analysis. Each trial performance was recorded using Panasonic camera (HDC-SD909) and SMI eye tracking glasses. The performance was assessed with the use of error taxonomy proposed by Buxbaum, Schwartz and Montgomery (1998) and measurement of overall time of task performance. Error classification included: omission errors, sequence errors, object substitution, misorientation of the grasp, spatial misorientation and tool omission. The eye tracking data will be analyzed further on in the project.

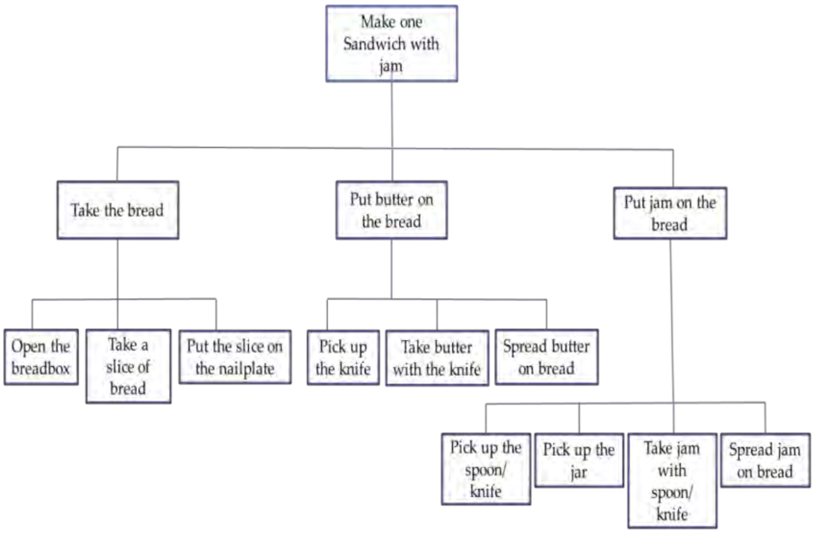


Figure 13: Example #1 for the breakfast task

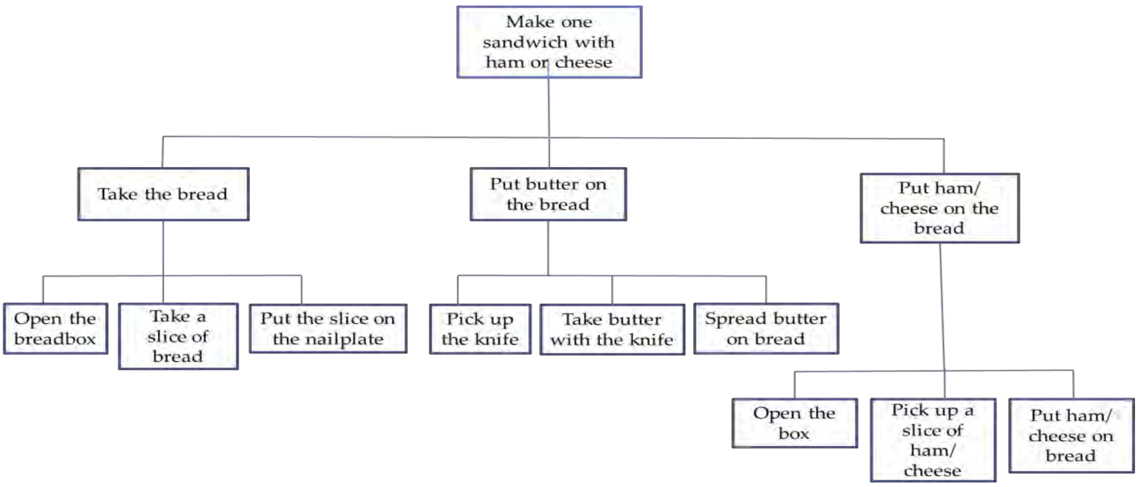


Figure 14: Example #2 for the breakfast task

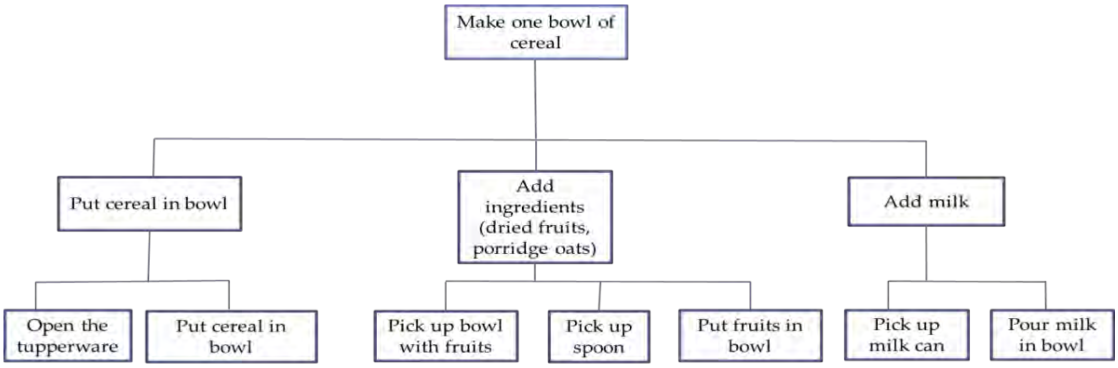


Figure 15: Example #3 for the breakfast task

Illustration of the task sequence tree. Each of the boxes represents action sub goal necessary to complete the task. Boxes placed at the same level denote sub goals organized by different ingredients.

3.1.2.2 Results

There was a statistically significant difference between the patients and young controls with regards to the time they took to complete the task and the number of errors across all conditions and all tasks (MANOVA, time x error x group, $p<0.001$) depicted in Figure 16. There was no statistical difference between the scenario condition (no guidance, feedback, prospective) and number of errors committed (see Figure 17) but a trend for fewest errors with prospective cueing.

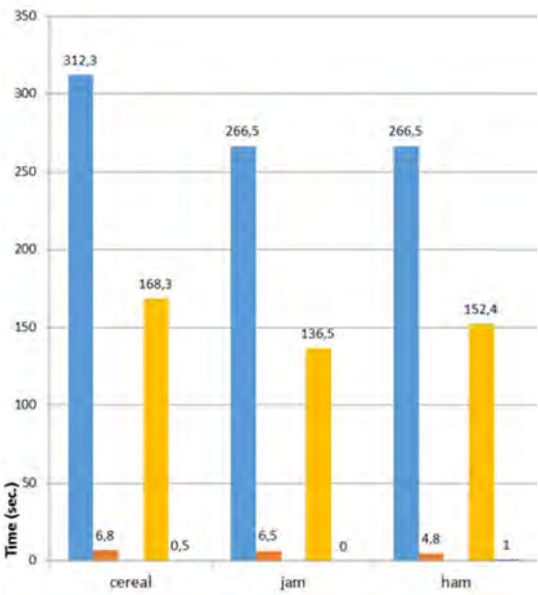


Figure 16: Results breakfast tasks

Fig 16: The chart presents timing and error data in three different breakfast tasks. Blue, average time for the patients (Pt) to complete the task; orange, average number of errors of the patients; yellow, average time for the controls (Cnt) to complete the task; blue, average number of errors of the controls.

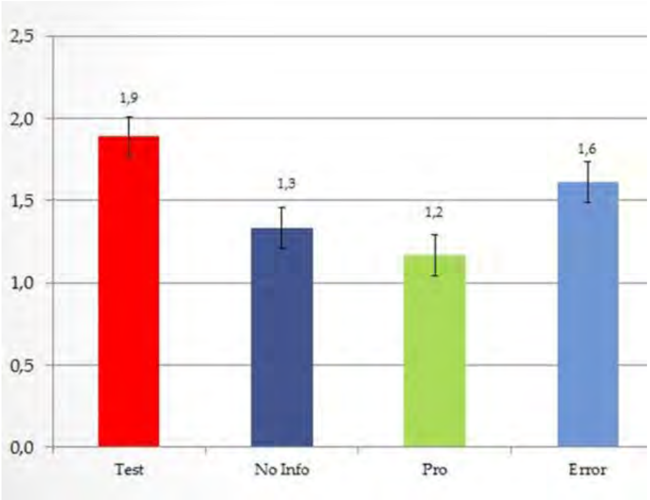


Figure 17: Error in cueing experiment

Fig 17: Number of errors committed by the patients across all task scenarios. Test – initial practice trials; No info – trials with feedback or guidance of any type (simple repetition of the task); Pro – prospective cues; Error – feedback only on errors.

3.1.2.3 Conclusion and future planning

We note that similar to results reported in section 3.1.1.2; less errors were made during trials where a prospective cue guided the patients throughout the completion of the trial. The data suggests that using prospective cues achieves lower error rates during training which may be seen as an advantage of assistive technologies, when support is constantly available. However, we note that here the rehabilitation effects of removing the cues later on were not tested and it may be that error correction results in better long term retention. Furthermore, like the results reported in section 3.1.3.2, with healthy participants' repetition of the task, even where no feedback provided, improves performance.

Further work is necessary to test more patients and identify differences between conditions. Descriptive statistics show a potential benefit in terms of using prospective guidance to facilitate ADL in patients with AADS. The tested sample was characterized by high variability therefore no conclusive statements can be drawn. No statistical significance was found for the differences between three guidance conditions. There was a significant difference between the controls and patients in the time taken to accomplish the task goal. In addition, it was noted during the experimental protocol that the patients had at times failed to direct their attention to the screen. Therefore a possible solution would be to implement a tactile feedback (such as a vibrating wrist device) to provide them an alert to attend to the screen or use auditory commands. During testing participants had to be often prompted by the researcher to attend to the monitor.

3.1.3 Alert cues vs. goal reminder vs. repetition (UOB)

Background. There is a paucity of research that test directly and systematically effects of different cuing procedures and modalities on performances of daily activity.

Current study. In this study, which is still ongoing, we compare three cuing procedures: 1) task repetitions with no cues; 2) auditory alert cues on errors; 3) goal reminder cue which is left on the screen throughout the trial. This experiment is conducted with young and elderly neurologically healthy participant. We used a dual task approach as a model for AADS deficits. We have reported part of this data in previous deliverables.

3.1.3.1 Methods

Participants: Neurologically healthy young (N=36; f=25; mean age = 23) and elderly (N=4; f=3; mean age = 61).

Materials: We use a similar setup of the complex tea procedure designed as the CogWatch screening test. Participants were seated next to a table. The layout of the table included various ingredients and objects needed for making different types of hot beverages including two mugs, kettle and a teaspoon (see *Figure* 19: Objects arrangement on the table). Goal instruction (*Figure 18: Cue instructing the goal of a trial*) and cues were presented on a computer screen located in front of the participants. As a distraction task, participants were given paper and pencil tests to be completed at pre-defined intervals during each trial.

Figure 18: Cue instructing the goal of a trial

The cue provide a pictorial and verbal description of the two types of hot drinks that needed to be made

Design and procedure: The experiment had an initial assessment → pre → training → post design. In each trial participant made two cups of hot drinks based on given specification. There was one pre and one post trial. The procedure of pre and post trials was identical and did not involve any cueing. There were 5 training trials in between. The procedure for the training trials varied between participants: 1) training with no cue or feedback; 2) training with an auditory alert cues when error is committed; 3) training in which a visual picture plus verbal description of the hot drinks required was presented on the screen throughout the trial.

Figure 19: Objects arrangement on the table

Each trial started by presenting the trial goal instruction, specifying the two hot drinks needed to be made for 30sec (Figure 18). In the initial assessment participants were asked to make the two type of teas used in the CogWatch screen (i.e. tea with milk and two sweeteners; tea with lemon and sugar). Then each trial involved different types of hot drinks. After the initial assessment, all trials were completed with distracting procedures: 1) participants were put under time pressure (e.g. required to complete the task 50% faster than time taken during the initial assessment); 2) participants used their non-dominant hand (e.g. left hand); 3) two times during each trial, a 30 sec of paper and pencil distracting tasks was introduced: after the presentation of the instruction cue and after a minute into the trial.

Data analyses. The trials were video recorded. Each trial was scored based on the CogWatch scoring system (see deliverable 1.3), maximum 20 points. In brief each correct step was awarded a point while an error leads to point reductions. In addition we collected the time to complete the whole task, number and type of errors. We focus the analysis on the pre and post trials. In addition, to avoid ceiling effects, we only include participants who did not score 20 points in the pre-trial.

3.1.3.2 Results

We present the data only for the young participants (*Figure 20: Results of cueing experiment with healthy*). Despite the extensive distraction procedure relatively few participants made errors during the pre-trial. Out of 12 in each group, 10 made an error in the no cue condition and five in each of the two cued conditions. The results for these participants show that across all three conditions and three procedures there was an improvement in performance from the pre to the post trial. Specifically, relative to the pre-trial in the post-trial, participants' scores were higher; trials were completed faster and less error were made. There were no reliable differences between the three procedures. When exploring the type of errors made, the most common errors were omission errors which were reduced in all three cueing procedure. Interestingly, both cueing conditions led to increase in addition errors, though this appeared stronger during alert that the reminder cue condition.

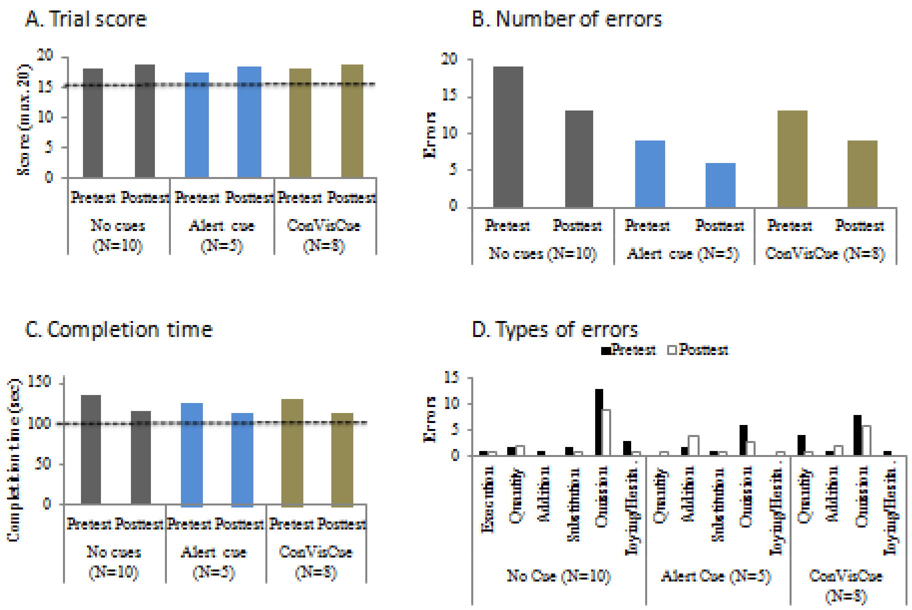


Figure 20: Results of cueing experiment with healthy

For each condition data is presented for the pre and the post trials. **A)** charts presenting the trial score (max 20). The dotted line indicates the cut-off scores for impaired performance, based on the CogWatch normative data. **B)** Number of errors **C)** Time for completing a trial; And **D)** Number of errors divided by error type.

3.1.3.3 Conclusion and future planning

Cuing had no added benefits for young and healthy adults beyond simply practicing the task. More so cueing was associated with increase in addition errors. Thus for high functioning participants cueing can hinder performances. In the future we plan to complete data collection for the elderly, to achieve 12 participants in each condition.

3.1.4 Simulated environment I – click & drag

Background. Although infrequent, action errors are often the sole dependent variable in experimental work. We propose that the strength of the link between any two actions is reflected both by errors and in the time taken to select that action. Inter-action intervals (IAIs) therefore offer a means of investigating the conditions under which difficulties in selecting individual actions may occur – even in the absence of errors.

The current study explores the effects of task-structure and visual feedback on errors and IAIs in a computer-simulated drink making task.

3.1.4.1 Methods

Participants. Neurologically healthy young (N=21; f=16; mean age = 22.52) and elderly (N=9; f=4; mean age = 68.89)

Materials. A 2-d cartoon of a kitchen was used as a background on a computer screen (*Figure 21: Simulated environment I*). In this virtual kitchen all objects and materials needed for making a tea or coffee were displayed. Objects were manipulated through click-and-drag actions with a computer mouse. A second display was used as baseline. Here only the location of three objects with no background or environmental contextual information was presented.

Design and procedure. The experiment included three conditions. Two experimental conditions: high ecological validity: with visual feedback in which manipulation was evident on the objects (e.g. poured milk was visible in the cup), low ecological validity: no visual feedback objects did not change their properties based on the way they were manipulated. In the remaining trials visual feedback was not given. This was manipulated across blocks. In the experimental trials participants made one hot drink for specification. They simulated the execution of the sub-task steps by clicking and dragging the objects (e.g. pour water from kettle to cup was done by clicking on the kettle and drugging it to the mug. A third baseline condition was included to measure movement speed. In this condition, the actions in the kitchen trials were replicated in an *isolated condition* to enable estimation of movement times as a function of the distance between objects. Participant had to start on 1 move to 2, click on 2 and drag it to 3.

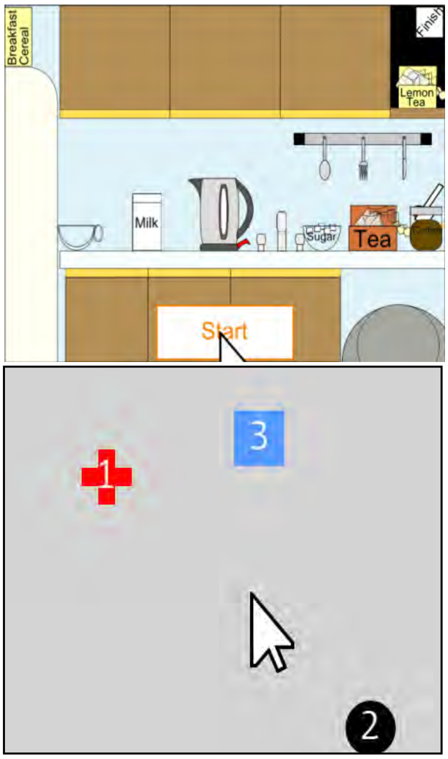


Figure 21: Simulated environment I

Top image show the display of the kitchen background. Bottom image show the display of the control condition of click & drug movement speed.

Data Analyses. We collected number and type of errors. For correctly completed trials, we collected the timing between sub-action (Inter action interval, IAI). IAI for a given sub-action was computed as the time an object was 'dropped' to the time this sub-action began.

3.1.4.2 Results

Errors: 149 errors were made over 1056 trials. The error rate per trial was 11% (young) and 21(elderly). More errors were made in the no feedback condition (see Figure 22). The most frequently occurring errors were omissions (see Figure 23). The highest number of errors occurred at the *add sugar* subtask (see Figure 24).

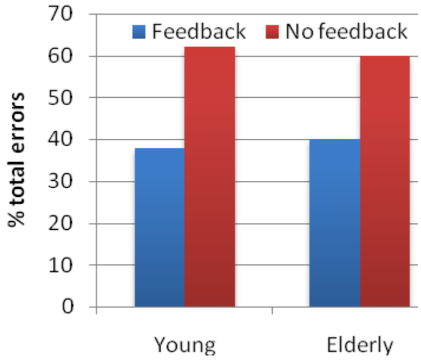


Figure 22: Error results Simulated Task I

The charts present proportions of errors for each group in each condition.

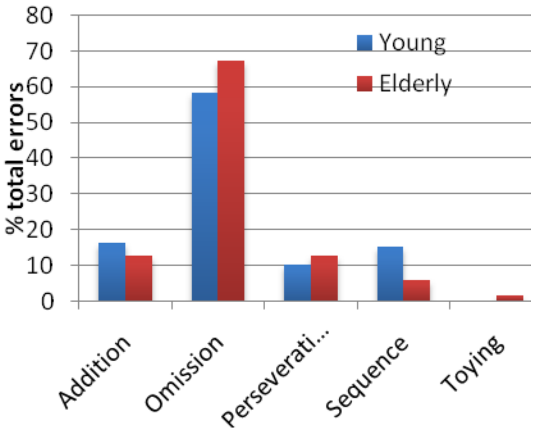


Figure 23: Error types

The charts present the proportion of error types by group.

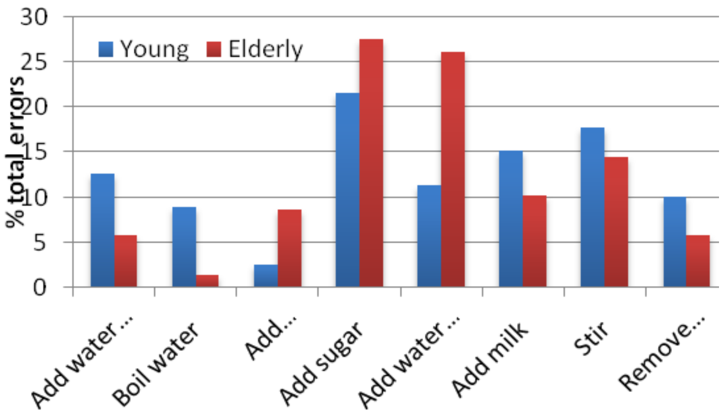


Figure 24: Errors by sub-tasks

The charts shows proportions of errors made for each sub-step by group.

Timing - Inter action interval: IAIs (young participants only) were collected from correctly executed trials only. Mean IAIs were longest when *selecting* actions in the experimental compared to the baseline condition (see *Figure 25: Timing results*). Action selection was slowed at higher-level points (*select action*), relative to lower-level, between-decision point actions (*carry out action*) $p < 0.0001$. This effect was compounded at decision points *(Is sugar needed?)* and reduced for high-frequency actions where no decision was needed *(add water to cup)*. There was no effect of feedback on IAIs.

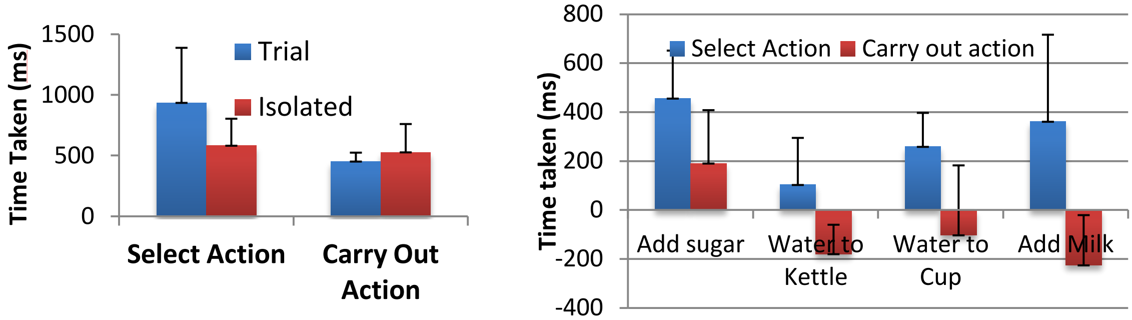


Figure 25: Timing results

The chart on the left shows the average time to select (IAI) and execute (i.e. carry out action) a sub-task in the experimental (trial) and baseline (isolated) conditions. The chart on the right shows the average selection time (IAI) and execution times for each sub-action across participants, after the subtraction of the baseline condition.

3.1.4.3 Conclusion and future plans

The initial results suggest that similar pattern of errors (pre-dominantly omissions) occurred in simulated as well as real environment. This suggest that simulated environment serve as a good proxy for testing effects of different factors on executing activity of daily living.

The results further suggest that elderly do not show a reduction in their ability to execute activity of daily living. This is consistent with our previous findings, that age does not affect processes related to activity of daily living, and interaction with objects. Contextual visual feedback, presenting an environment with higher ecological validity reduced the number of errors made, relative to no feedback with lower ecological validity. Not surprisingly, inter action interval (IAI) as an index of time for action selection was longer during experimental than baseline trial and there was no effect on the time to execute an action (click and drag). When examining the sub-task independently, selection time (IAI) was longer for the sub-task that was not consistent across trials: add sugar and add milk. These trials were associated with most errors as well. Interestingly, for some sub-task execution time was faster during the experimental compare to the baseline conditions (e.g. add milk, water to kettle).

Future plans are to complete the collection and analysis of elderly data to have a group of 20 participants by the end of the summer.

3.1.5 Simulated environments II – testing the task model

Background. Testing the impact of different factors on activity of daily living using real objects presents many methodological challenges. It further limits the ability to control for interfering factors, restricts the amount of trials that can be tested that often results in 'noisy' measurements of behaviour. Therefore simulating activity of daily living within a computer environment is advantageous. As mentioned in previous studies there is a paucity of studies that systematically test the effects of cues on the ability to execute activity of daily living.

Current study. We designed a second 2-d simulated environment to test effects of learning, context and feedback received. In addition, we implemented the task model in the background to be able to identify errors and provide end of trial feedback. Participants were asked to make one of 8 types of hot drinks, 4 simple tea (prototype 1) and 4 coffee version of the same drinks. Sub tasks were completed by clicking on the task associated object (e.g. clicking on the water tap to fill up water in the kettle, clicking on a teabag to add it to the cup). Object manipulation did not affect the display. To test the effects of visual context, objects were either presented on a kitchen background, or without the kitchen background. The no background presented the object at the same spatial location on a grey background. We tested effects of history-feedback by providing half of the participant a list of the actions they completed; finally learning was tested by comparing performances at different trial repetition times.

3.1.5.1 Methods

Participants. We tested young (n=15) and elderly (n=12) healthy participants and 3 neurological patients.

Materials. We used a modified version of the CogWatch task model to design the experiment. The task model was modified to include the additional coffee drinks, and to provide only a feedback at the end of the trial of whether the hot drink was completed successfully or not, with no informative feedback. A picture of a kitchen was used as a background for the objects in one condition (see Figure 26), in the second only the relevant objects were presented with a grey background. Clicking on relevant object was noted by an auditory beep. Relevant objects included: water tap (=Add water to kettle), switch for the kettle (=boil water); kettle (=add water to mug); box of teabags (=add teabag); jar with instant coffee (=add coffee to mug); sugar bowl (=add sugar to mug), teaspoon (=stir); milk (=add milk), bin (=remove teabag). The other objects on the screen were not associated with any action.

Figure 26: Tea simulator display

Design and procedure. The experiment had a mixed design with feedback type (sub-task history, no history) as a between subject factor and type of background (kitchen, grey), and trial number as within subject factors. At the beginning of the experiment, the set up was explained to the participants, and they were given 8 trials to practice each type of hot drink. The background was manipulated across blocks counterbalancing the order of the blocks. In each trial the participant were presented with a verbal description of the type of hot drink they need to make (e.g. black coffee with sugar). This was presented for 2sec; once ready the participant click the start button and clicked the relevant sub-action needed (represented by the objects involved), the finish button was clicked to indicate that the participant had finished. At the end of each trial the participant received feedback on accuracy. On average participants completed 160 trials; half with a kitchen background and a grey background.

Data analyses. We collected accuracy, response time and action sequence data. Using the task model we identified the type and number of errors participants made in each trial. We computed an average time to select a sub-action. We computed average of the correlation between correct action sequences to measure how consistent these were across the test.

3.1.5.2 Result

Error analysis. We first examined the type of error controls and patients made in the 2D simulated environment. The errors were defined based on the CogWatch task model, and were classed to omissions, hesitation +toying, perseveration, sequence, addition and other. We describe the distribution of these error for each condition (recall a 2 (kitchen BG: yes, no) x 2 (Feedback: yes, no), see Figure 27.

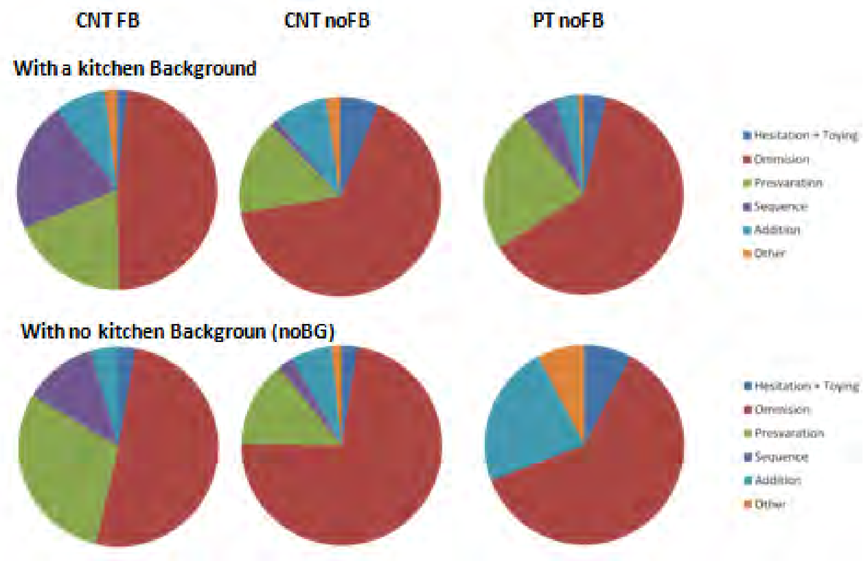


Figure 27: Error type analysis

Proportion of errors as a function of (left-centre-right) control (CNT) or patient (PT) with feedback (FB) or without feedback (noFB) and (above-below) kitchen background present or absent (noBG)..

As commonly reported for activity of daily living task, the most common error across all condition and participants were omissions errors (red-brown). These errors were more common in participants who received no feedback (i.e. noFB = reminder list of completed sub-tasks) compare to those who received (FB). Omission errors also increased when objects were presented without the kitchen background (compare bottom to top row). The next most common error was perseverations (green) than sequence. A different error pattern was observed for the patients who performed the task with no kitchen background, in this context there was an increase of addition errors and no preservation or sequence errors.

Effects of training. We next analysed the effects of training on the number errors (independent of type) and the response time for selecting a sub-task. The later analysis was carried out only for trials in which no error was committed. Each participant completed 40 trials making each of the 8 hot drinks 5 times. We binned the trials to 5 time points, each including 8 trials.

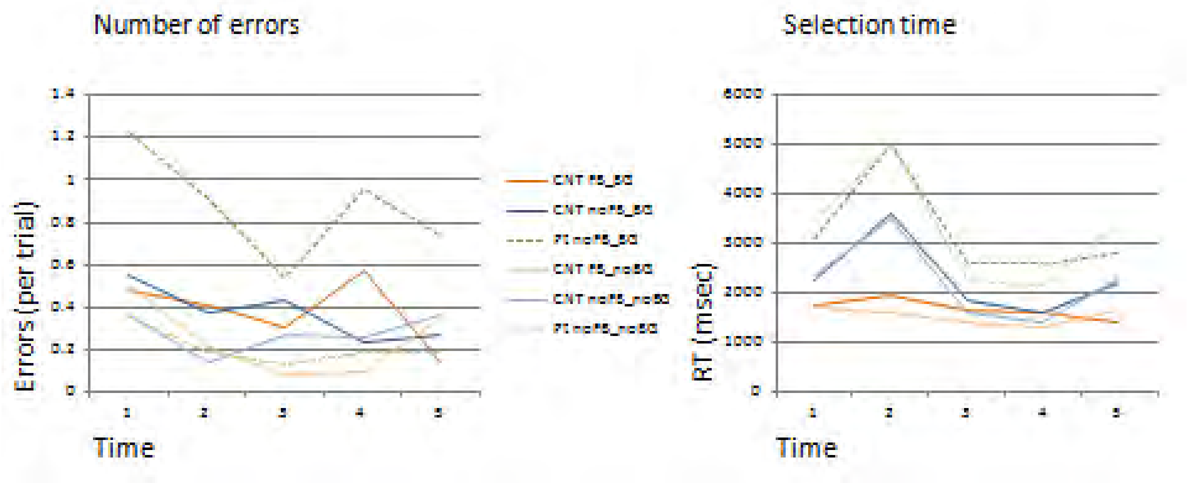


Figure 28: Effect of learning

Controls who received feedback shown in orange (CNT FB), controls who received no feedback are blue (CNT noFB), patients are dotted green line (Pt noFB). Bright colours represent results during trials where the kitchen was presented as a background (BG); dimmer colours represents results of trials without the background picture (noBG).

As can be seen in Figure 28, overall improvements were observed for all participants and across all conditions (compare time 1 to 5). Training reduced the number of errors and also reduced the time to select a correct sub-task. Participants overall find it easier to complete a drink with no kitchen background than when the background was displayed (compared bright to dimmed colour for each group). Patients were overall slower, and made more errors when the trials were performed with a kitchen background. Finally participants who received no feedback (blue) were slower at the first 16 trials but later manage to match the speed of the participants who received a feedback.

3.1.5.3 Conclusion and future plans

The data suggest that similar type of error distribution is observed when completing a hot drink in a simulated environment as when using real objects. This suggests that a simulated environment could be a useful platform to test and assess effects of training and cueing strategies.

Surprisingly we found that removing the kitchen background made the task easier (participants were faster and made less errors); it reduces the overall number of omissions errors, and completely changed the error pattern of the patients. We suggest that the kitchen background increased the overall perceptual load making it more difficult to select the target and filter out distracting information. Based on these results we suggest that keeping the kitchen environment as minimal as possible will potentially prove very beneficial for patients.

Future plans are to finalize data collection, aiming for 15 elderly and at least 10 patients with AADS. We also plan to test patients with a condition in which the P1.2 CogWatch cueing strategy would be used.

3.1.6 Impact of research on the designing of P1

Based on the above five experiments we conclude that the most common error is omission errors. Our data suggest that omissions are results of cognitive load rather than lack of knowledge. All experimental manipulations tested reduced the overall cognitive load while performing the task (reminder of goal; prospective cue, alert for errors; familiarity with the task through repetition, environmental feedback; history feedback). As a consequence they all led to reduced error rates, which specifically affected omission errors. However, we also noted that a non-informative alert cue in the short run has the potential cost of increase addition errors. *Hence we suggest for CogWatch avoiding the use of non-informative alert cues alone as a form of feedback*. We note however that this conclusion is primarily based on data from healthy participants. In this set of experiment, our working assumption is that the impact of cues would be more extreme in patients with AADS.

Comparing errorless vs. errorful procedure, we note that the relative benefit of each procedure depends on symptoms severity and profile. Performance with continuous predictive cues during the errorless training procedure was associated with higher completion rate; though the impact of errorless learning was temporarily and short lived. Furthermore, patients did not always follow the cues, and some were confused by the cues when in contradict their inner schema showing increase in perplexity errors. On the other hand performance under the errorful condition was more stable and remained high even after the support of the system was removed.

Therefore for CogWatch we suggest that both errorful and errorless strategies be supported. To reduce the potential of confusion due to conflict between patient inner action schema and system schema, we implemented the option to personalize the action sequence schema. We also provide a guidance cue, only when it is clear that the patient is not sure how to progress: patient press the help button, or patient show perplexity for longer than 30sec.

3.2 P2 – tooth brushing

Tooth brushing as opposed to tea making involves interaction between hand and body. It is known that AADS patients have specific problems in performing accurate manual movement that involve the body (Goldenberg 2013, Apraxia, Oxford University Press, UK). Hence the following three studies aimed to investigate sources of impairment in hand-body interaction, the impact of different types of cues, and the role of concurrent visual feedback on reaching in the environment.

3.2.1 Cueing in manual gesture production and evaluation

Background. As observed by previous studies (Goldenberg 2013, Apraxia, Oxford University Press, UK), and by our screening procedure (see Figure 1: BCoS Screen data), the most impaired aspect in AADS patients is the ability to imitate another gesture performed on the face. While producing a gesture from a verbal command or labelling an observed gesture were less frequently impaired. The two tasks of the screen differ in the modality of the input (i.e. visual-gesture vs. verbal command) and the meaningfulness familiarity of the gesture (i.e. meaningless unfamiliar vs. meaningful and familiar). Furthermore, a dissociation of impairment in gestures has been proposed based on their type and content. Specifically it has been suggested that transitive gestures (pantomiming the use of object, e.g. drinking) are mediated by a different mechanism than intransitive gestures (communicative hand movement; e.g. waving goodbye). Intransitive gesture are often less impaired than transitive. We note that the two types of gestures differ in the reliance of communicative/language system.

The current study aimed to dissociate between various factors that affect gesture processing. Specifically, we tested the effects of input modality (visual gesture vs. verbal command), gesture type (transitive, non-communicative intransitive), target of gesture (face, imaginary face) on gesture production and gesture evaluation. Thus we run two tasks, in the first participant were required to produce a gesture following an instructive cue. In the second participants were presented with a video depicting someone else producing a gesture to the same cue. In the second task the task was to judge whether the gesture produced was accurate.

3.2.1.1 Methods

Participants. We tested 6 neurological patients (3 females). Two patients (P1 & P3) had no AADS deficits, 3 patients (P2, P4 & P6) showed impairment in at least one gesture task (*Figure 1: BCoS Screen data*), 3 failed the multistep object task (P4, P5 & P6). Hence one of the six patients failed both a gesture and the multistep object tasks.

Materials. Pilot study identified 5 transitive gestures performed on the face (e.g. tooth brushing, ear cleaning, hair combing) and 5 geometrical shapes that can be served as the non-communicative intransitive gestures (e.g. circle, triangle, square, diamond, wave). These gestures were identified to be reliably depicted by a verbal label as well as a pantomime movement. Video recording of a male performing each gesture on his face and on his imaginary face in front of him served as the visual instructive cue in the gesture production task. The verbal instructive cue in this task was printed on the screen (e.g. tooth brushing, circle). For the gesture evaluation task a second set of videos was record. Here gestures were performed by a female actor. Four types of gestures were produced: correct gesture, spatial error, orientation error and hand as a tool error.

Design and procedure. The gesture production task had the following factors: instructive cue (2: video, verbal), type of gesture (2: transitive, geometrical shapes), target of gesture (2: own face, imaginary face). Participants started with the gesture production task. For the geometrical shape gestures, participants were instructed to draw them around and on their face or on the imaginary face. Participant held their hand on the table, a beep that followed each instructive cue, indicated to participants to produce the gesture. Each gesture was produced once in each condition. The gesture production task was performed first. Cues were presented using e-prime.

The gesture evaluation task was run following the gesture production task. The task included the following factors: instructive cue (2: video, verbal), gesture type (4: correct, spatial error, orientation error, tool as a hand error). The experiment was realized using e-prime. Each gesture was presented 10 times half following a verbal cue and half following a video cue. Each correct gesture was presented twice while each error gesture once.

Data analysis. For the data production study patients' performances were recorded using videos. Two raters evaluated each gesture scoring it on accuracy and quality and if error were made the type of error were coded. In the gesture evaluation study, accuracy and RT were recorded using e-prime.

3.2.1.2 Results

Gesture production study: Overall performances were more accurate on the patients' own face relative to the imaginary face. Performances appear to be better following a verbal than video cue. Finally producing transitive gestures were better on patients' own face; while producing shapes were better on the imaginary face (see Figure 29). The most common error type was of the positioning of the hand relative to the face – this error was much more prominent in the imaginary face condition in which patients misrepresent the size of the head, or its shape when producing the gesture.

Figure 29: Gesture production

Fig 29: Top scatters present the accuracy and quality of gesture for each patient in each of the eight conditions. Left scatter present the results for gesture produced on one owns face, right scatter the results for the imaginary face. Red notated the performances of the two non AADS patients. Bottom pie-charts present the distribution of error type across the own and imaginary face conditions.

In the **gesture evaluation** study participant were more accurate at evaluating gesture following a verbal than a video cue. Identifying the hand as tool error was the most difficult gesture to recognize, especially in the video condition. This was surprising since the two gestures look very different (see Figure 30).

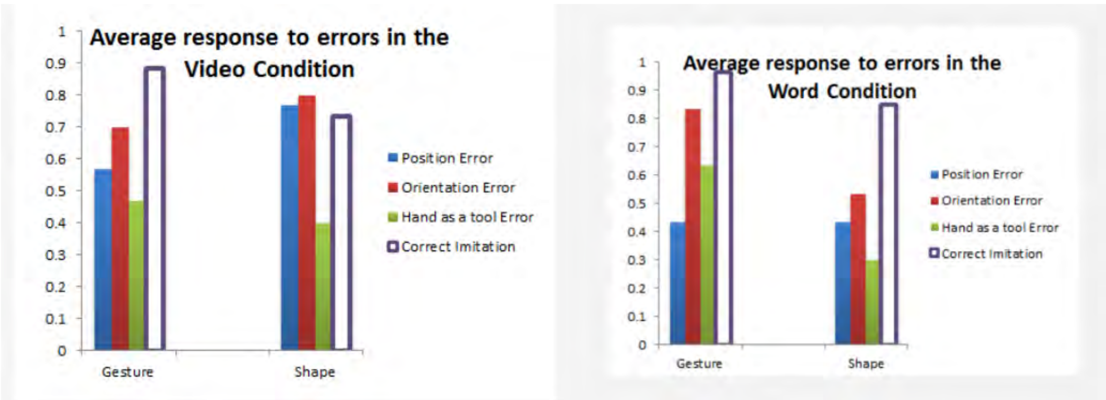


Figure 30: Gesture evaluation

Fig 30: Accuracy results for the four different gesture types averaged across patients, on the left for gesture following a video cue and on the right following a verbal cue. Correct responses are depicted by the white bars; coloured bar for the different error types.

3.2.1.3 Conclusion and future plans

Overall AADS patients showed more impaired performances than non-AADS patients. However the pattern of their behaviour was similar to those with non-AADS. Surprisingly patients were better at producing gestures from verbal cues, and were also better at evaluating gestures following a verbal cue in comparison to video cues. This suggests that patients maybe accessing their semantic knowledge when producing and evaluating gestures and that the video cues are potentially interfering with their own gesture schemas.

Future plans is to collect more data, we aim to recruit 15 elderly controls and 10 additional more patients by the end of the year.

3.2.2 The potential of ecological sounds in facilitation of tool use in AADS

The aim of this study was to investigate how external sensory information can guide the movement in the CVA patients suffering from AADS. In particular, we were interested to investigate the use of ecological sounds in facilitation of pantomime and tool use in those subjects. Ecoacoustics define environmental sound as an audible product of physical event, caused by interaction of the materials (i.e. changes in the aerodynamics of surroundings) (Gaver et al., 1993). Recent research suggests that motor networks associated with mirror neurons respond to the action-related sounds (Kohler et al., 2002; Ticini et al., 2013). Use of environmental sounds was previous demonstrated to improve mobility in movement disorders i.e. Parkinson's disease (Young et al., 2014; Bienkiewicz et al., 2014b). So far strategy training approach was found as the most promising approach to rehabilitation of AADS (Bienkiewicz et al., 2014a). There is lack of evidence whether sensory cueing can facilitate tool us in those patients in an immediate fashion if presented prospectively to a patient. The aim of the presented study was to investigate the potential of event-based sounds, compared to picture sequences and auditory instruction, in improving motor performance in CVA patients manifesting AADS.

3.2.2.1 Methods

Participants. Eleven subjects with LBD and five patients with RBD (M= 62.3 years) were recruited following their hospitalization period in the Bogenhausen hospital, Munich, Germany. The time post CVA ranged from 1 – 89 months. In addition twenty age-matched (M= 63.9 years) control subjects were tested (10 on dominant hand use, 10 on the non-dominant hand use). All subjects were tested in the CogWatch lab at the TUM site. The study design was approved by the ethical committee of the Medical Faculty of the Technical University of Munich. Informed consent was obtained from all subjects, and the study was conducted in accordance with the Declaration of Helsinki.

Experimental design: The experimental design involved pantomime and actual tool use in three tasks: hammering, sawing, and tooth brushing. The practice trial comprised of pouring a glass of water (to explain differences between different cueing conditions, two execution modes and familiarize participants with the experimental setup). The experimental design consisted of four different cueing modes (prior to task execution): no cues, auditory instruction (step by step commands for each of the subactions e.g. 'Pick up the saw'), pictorial instruction (step by step 3rd person perspective display), and ecological sounds (10s recording of action goal). Each mode of execution: actual use and pantomime involved two consecutive trials. Presentation of the experimental conditions was fully randomized using Latin-squares design.

Apparatus: The display was controlled via customized software programmed in C#. The movement data is collected with the use of 5 Qualisys Oqus cameras and analogue board interface. The sound stimuli were recorded with low-noise condenser Rode N1 microphone and Yamaha Audiogram 3 (movement of neurologically healthy 26 year old male). Derivate data from motion capture recordings was analyzed using custom developed MATLAB program.

Procedure: Participants were asked to position themselves comfortably in front of workspace table. If CVA participant was constrained to the wheelchair the table height was adjusted. Oral instruction was given prior to the task and time was given to ask questions. Different sensory conditions were introduced in the practice trial (pouring a glass of water). The setup and pictorial cues were mirrored for the left-hand users.

Data analysis: Pantomime and tool use was assessed using the Goldenberg & Hagmann (1997) 2 point scale by two trained assessors. The scores taken for analysis were averaged between researchers. In addition, errors will be categorized according to the error classification proposed by Schwartz et al. (1999). The motion capture data was filtered using 8Hz Butterworth filter prior to obtaining derivates of spatial position. Using 3% velocity threshold (of the peak velocity) the section of the movement was extracted (showing an oscillatory motion). The following kinematic variables noted in the literature as motor features of apraxia (Laimgruber et al., 2005) were further analyzed: movement time, peak velocity, acceleration; along with others like median velocity, number of velocity peaks, interruption index (zero crossings without change of strike direction), movement frequency, duration of the cycle, movement amplitude, minimal and maximal position on the main movement axis, path on x-y-z axis, path ratio, circularity of the movement and polar variation. Repeated Measures ANOVA design was used for inferential statistics (mode x sensory condition) with Between-Subject Factor side of brain damage.

3.2.2.2 Results

The results of the video scoring are summarized on Figure 31. Score 2 describes a smooth and adequate motor performance. Score 0 denotes performance that is inadequate or no performance at all.

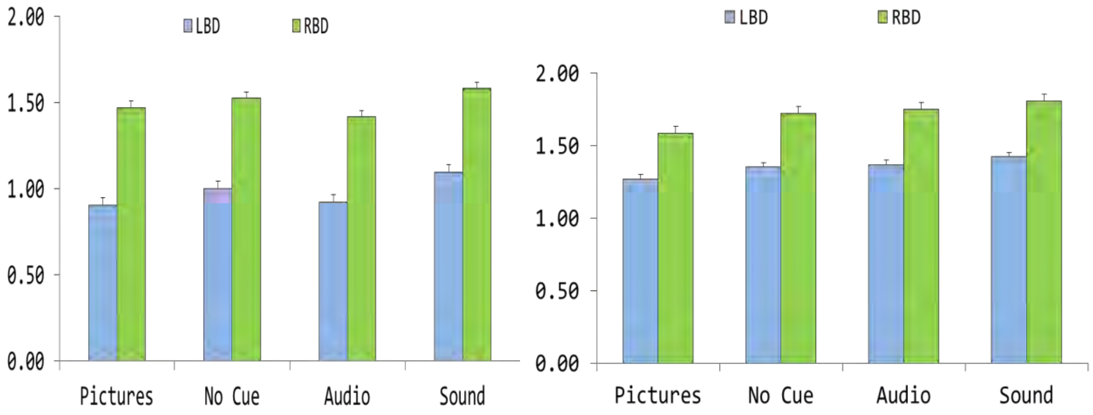


Figure 31: Ecological sounds results

Fig 31: The charts present the average movement scores across all conditions for the left and right CVA patients. The charts on the left present the results for the pantomime task; while the one on the right for the real object use.

As depicted in Figure 31, the video scoring did not provide conclusive information about the most efficient way of cueing. However, for pooled scores for both RBD and LBD patients, there was a trend in the data set towards main effect of sensory condition on the score $F(3,12)=2.9$, $p=0.07$. There was no effect of the brain damage as Between-Factor on the performance. ($p>0.05$). There was no effect of mode on the performance for LBD patients, however for RBD patients it was close to significance levels $F(1,4)=6.62$ ($p=0.06$).

The error count failed to reveal differences between mode, sensory conditions and brain damage ($p>0.05$) (see Figure 32). For pooled performance the mode execution had a significant main effect on the score $F(1,14)=21.6$, Eta=0.64 ($p=0.001$) and sensory condition $F(3,12)=3.7$, Eta=0.53 ($p=0.05$). Planned simple contrast (sound vs other conditions) did not reach significance level.

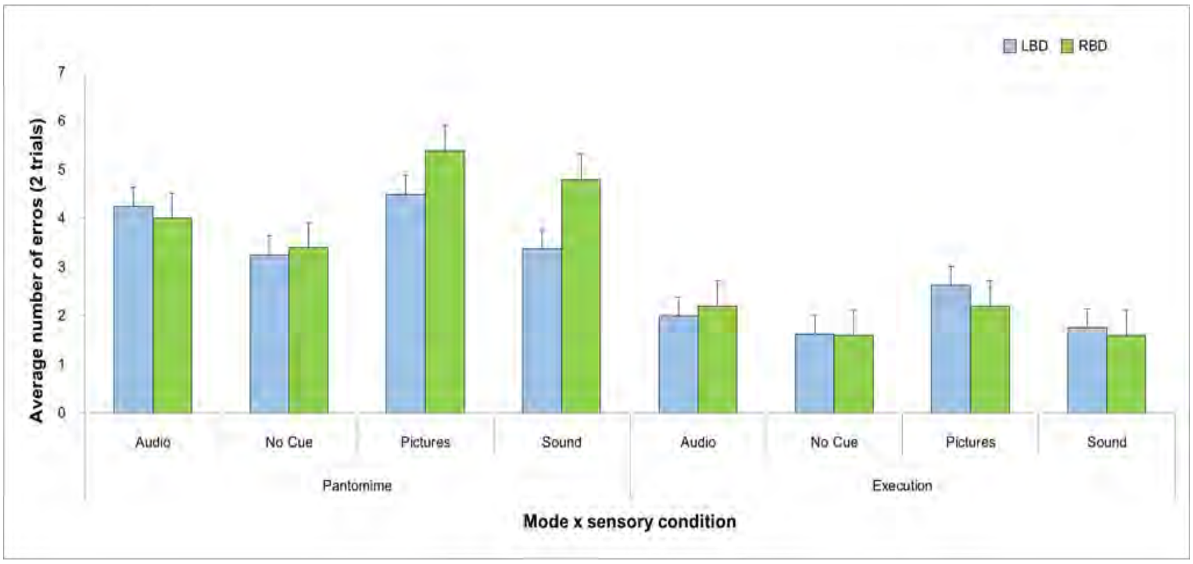
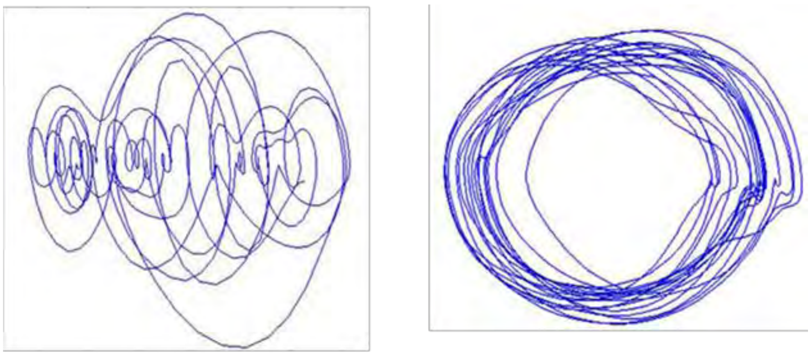


Figure 32: Error results

Fig 32: The number of errors in each condition, error bars denoted standard error. Execution = operating real objects.

From the kinematic features the most informative variable was found to be a polar variation function of the movement. Polar variation as an index value captures variability among cycles of repetitive motion. It is a novel application of this type of analysis for kinematic movements and it measures the overall harmonicity and smoothness of kinematic data. This parsimonious approach allows capturing many kinematic features at once (such as position, velocity, acceleration, zero-crossings). Previous attempts such as looking at circular pattern of relative velocity over position presented in PPR2 (2013) have proven unfruitful. For the purpose of this analysis we present the data only from sawing and hammering movement as tooth brushing data is still under analysis. Figure 33 illustrates that polar variation can represent variability of the movement as an index value.



0.35 0.004

Figure 33: Kinematic data

Fig 33: Comparison of the patient data (left panel, LBD execution) during sawing movement versus healthy age-matched control. Left panel illustrates phase plane for the velocity over position (normalized) with high polar variability - 0.35 as compared to the neurologically healthy adult performance with low index of variability 0.004.

For the neurologically health individuals there was a significant main effect of sensory condition on the polar variability in the hammering task, both in the execution and pantomime conditions F(3,16)=6.4 p<0.001, Eta=0.5, and mode F(1,18)=22.2 p=0.005, Eta=0.6, with the lowest polar variation in sound condition. The hand did not have a main effect on the polar variation, although there was a trend toward higher polar variation with the left hand (p=0.07). In the sawing task there was a main effect of mode on the polar variation F(1,18)=22.8, p>0.001, Eta=0.6, and a trend for the sensory condition p=0.07 (see Figure 34).

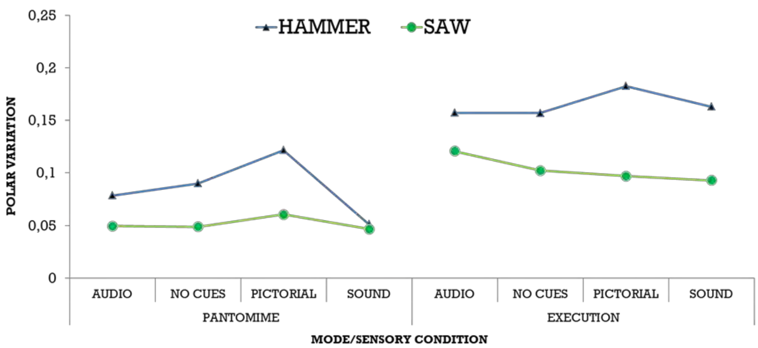


Figure 34: Polar variation data

Fig 34: Overview of the polar variation in health age-matched controls. Note the lowest values of polar variation in the sound condition in hammering task and a trend towards it for pantomime in sawing task.

For the patients there was a main effect of interaction mode with brain damage side on the polar variation in both hammer ($p<0.05$, Eta=0.21) and saw tasks ($p<0.05$, Eta=0.19). Patients with LBD had higher polar variation in the pantomime condition than RBD patients, but lower than RBD in the execution mode (see Fig x). Sensory condition in both groups had significant main effect on polar variation in hammering task ($p<0.05$, Eta=0.31) and sawing task ($p<0.05$, Eta=0.24). There was a main effect of interaction of mode and sensory condition and brain damage ($p<0.05$). Post-hoc Bonferonni comparisons revealed significant differences between the groups in the execution mode for the pictorial instruction (RBD vs controls, LBD vs RBD, $p>0.05$) in a sawing task. There was a trend for RBD and LBD for lower values of polar variation in the sound condition for pantomime ($p=0.09$) (see Figure 35). In addition, LBD patients had significantly different polar variations from controls in the pantomime sound and pictorial condition for the hammering task ($p<0.05$) and sawing task in the execution mode prompted with auditory instruction with both RBD and controls ($p<0.05$).

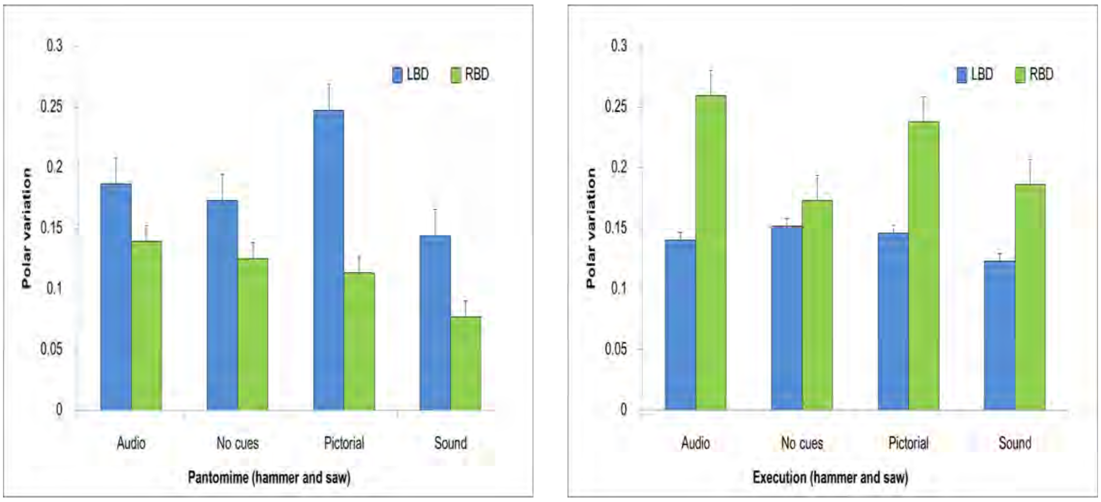


Figure 35: Polar data patients

Fig 35: Top graph illustrates pantomime performance of LBD and RBD patients across conditions. Bottom graph depicts execution performance of LBD and RBD across conditions. Red line denotes average polar variation value across all sensory conditions for healthy age-matched controls. Error bars denote standard error.

3.2.2.3 Conclusion and future plans

This study has important implications for understanding how sensory information can affect motor control both healthy adults and CVA patients. Analysis based on polar variation calculation revealed a facilitation of the performance under sound priming conditions. In other words low polar variation movements were performed in a smooth oscillatory fashion without interruptions. Both in healthy adults and patients, the most benefit of priming with sound was found in the pantomime condition, where the variability of the movement is not constrained by tool. Pantomime performance in LBD patients is a hallmark of apraxic behavior used in a clinical assessment (see section 2B). Further studies are necessary to investigate whether sound facilitation could be achieved in online fashion and used in the CogWatch interface. Importantly there seems to be a need to tailor the cues to the needs of patients and the side of their lesion. Long-term benefits of exposure to ecological sounds or enhancement of regular occupational therapy also need to be explored. For example it is not clear, mostly due to limited sample, the impact of sound on the performance in RBD patients during real tool use execution. Other limitation is that the patients enrolled in the study were often many months after CVA (up to 89). Investigating effects of exposure to sensory information in the post-acute phase (shorter than 6 months) could provide more insight into real clinical value of use of ecological sounds in this sample of patients.

3.2.3 Reaching to targets – proprioceptive vs. visual feedback

Background. AADS patients have difficulty in producing hand-body actions, where spatial errors being one common error (e.g. failure to reach the mouth with the toothbrush, or failure to follow the hair and find the location of the hair when brushing/combing it) (Goldenberg, 2013). The sources of this impairment are debated. One hypothesis suggests that AADS patients suffer from impaired proprioception, as when moving the hand toward the body, the hand is often outside the sightline and hence the movement trajectory need to be guided by feedback signal from the hand on its location.

In the **current study** we aimed to test the ability to use proprioceptive information as opposed to proprioceptive + visual cues in controlling hand movements toward spatial targets. In addition, we compared the ability to move to a target located on the table as opposed to a target located on the body.

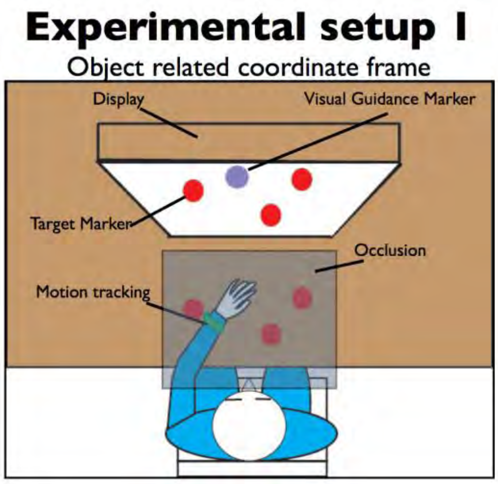


Figure 36: Experimental set-up reaching to virtual targets

3.2.3.1 Methods

Participants. 10 healthy elderly and 16 AADS patients were tested.

Materials. The experimental setup is presented in Figure 36. It included a screen presenting four virtual targets (red circles) and a starting point. Targets referred to the locations on a table, or the upper body. In both cases hand movements were occluded from view using cardboards, placed over the table or under the chin. Magnetic sensor attached to the wrist was use to record the hand movement and an eye tracking devise was used to record eye movement during the task

Design and procedure. The experiment had 2 (virtual target location: table, upper body) and 2 (cues: visual feedback on hand location, no feedback) factorial design. Conditions were manipulated across blocks in random order. The task was reaching toward the four targets as fast and accurately as possible. Once the hand was over a target the target colour turned green till the hand moved away. The hand starting and end position was marked as an 'X' and was visible for participants. Once moved the hand was occluded from view. In the visual feedback condition the position of the hand in the virtual space was marked as a blue circle, hence the task was to move the blue circle such that it overlapped the red. In the non-visual feedback no feedback was provided on the location of the hand in the virtual space, and participants had to infer that based on the proprioceptive signal.

Data analysis. We measured number of targets hit, dwell time on targets, time to reach a target, overall distance covered, maximum velocity, deviation from optimal trajectory and movement smoothness. In addition we measured correlation between hand and eye movements and over all eye scanning pattern.

3.2.3.2 Results

We report target hits and hand dwell time results of 6 healthy controls and 12 patients for the upper body condition. The scatter plots in Figure 37, show the performance of each participant in each condition, separated to healthy elderly and AADS patients. It could be seen that reaching targets in the visual feedback condition was much easier than based on proprioceptive signal alone, this was more pronounced in the patient group. Patients also tended to dwell longer on the targets than healthy, making their overall movement trajectory less smooth.

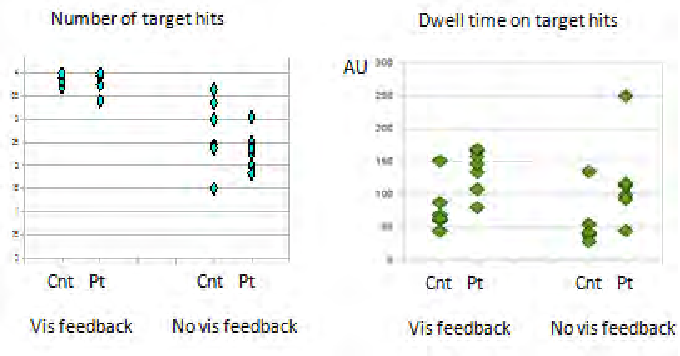


Figure 37: Reaching to upper body targets – results

Each participant is presented with a diamond, Cnt columns present the performances of the healthy elderly control while Pt columns present the performances of the Patients. Vis = visual feedback.

3.2.3.3 Conclusion and future plans

Our study supported the hypothesis that the lack of visual feedback impairs ability to control fine hand movement, thus suggesting that proprioceptive signal only is not easily used for controlling fine hand movement.

In future we plan to analyse all relevant variables by the end of the summer.

3.2.4 Impact of research on the designing of P2

Our data suggest that verbal instructive cues maybe more efficient in guiding hand-body interaction gestures. In addition, we show that online visual feedback on hand location improves patients' ability to control their hand movements and reduces spatial errors. Hence we plan to implement both these type of cues in P2.

4. UNDERSTANDING AADS

One Objective of WP1 was to extend the understanding of AADS syndrome offering novel insight into the definition and neural correlates on the symptoms. The studies in this section are aimed at this objective described in T1.3.1.

4.1 Function-lesion mapping

4.1.1 Lesion correlates of ADL deficits following left and right brain stroke (Manual VBM on ADL)

The aim of this study is to investigate the neural correlates of the ADL tasks in AADS patients using Voxel-based lesion mapping. Voxel-based lesion-symptom mapping (VLSM) is a method for analysing the relationship between the anatomical locations of brain lesions with behavioural measures. It is an approach for determining the function of brain areas and their role in different behavioural processes. It has been established and used in several studies analysing the connection between the location of lesions and deficits in the behaviour in patients, who are suffering of for example optic ataxia (Karnath and Perenin, 2005), aphasia (Baldo et al., 2006) and also apraxia (Hermsdörfer et al., 2013; Randerath et al., 2010). In this project we aim to investigate the association of tissue damage in brain lesions of patient with left (LBD) and right brain damage (RBD) with their behavioural performance in two actions of daily living. The aim is to characterize those brain areas relevant for the specific tasks in patients and also investigate possible differences due to the lesion site. Of particular interest is the separate analysis of three different error types often seen in patients with AADS. The question if these error types including conceptual, sequencing and spatial-temporal errors during action performance (Bienkiewicz et al., 2014a) are related to different lesion patterns is planned to be addressed in this study and compared between tasks.

4.1.1.1 Methods

Participants. Forty-eight patients (34 LBD and 14 RBD) have been tested with both tasks and will enter the VLSM analysis. The anatomical data is available for 23 left and 9 right brain damaged patients at this point and the given preliminary results will include the data from these patients. Table 10 lists the patients' demographics, lesion information and the number of patients with the different error types in each of the two tasks for the preliminary analysis.

Lesion	**N**	**Age**	**Filing**			**Tea**		
			Concept	**Seq**	**Sp-temp**	**Concept**	**Seq**	**Sp-temp**
LBD	**23**	**57**	**7**	**12**	**13**	**19**	**11**	**2**
RBD	**9**	**67**	**5**	**7**	**5**	**7**	**5**	**4**

Table 10 Error types (conceptual, sequential, spatio-temporal) by lesion side

Procedure: The Tasks Actions of daily living - The tasks taken for analysis were part of clinical screening presented in the section 2B. Namely the Complex Tea Making task and Simple Document Filing (described in detail in D1.3.2 2012).

Voxel-based lesion-symptom mapping. The software used to conduct a VLSM analysis is MRIcron and the non-parametric mapping software (Rorden et al., 2007b, 2007a). The lesion of each patient is manually outlined on the original brain images. Around 20 % of the images are computed tomography images (CT), the rest include magnetic resonance images (MRI) of the patients brains. All lesion masks were normalized with the clinical toolbox (Rorden et al., 2012) to a standardized brain for statistical comparisons. This toolbox includes MRI and CT brain templates based on a population of healthy adults with similar ages (mean 65 years of age) as it is commonly seen in patients suffering from stroke. Therefore this normalization routine is ideal for conducting a VLSM analysis with brain images from different modalities like CT and MRI.

The VLSM is performed separately for the document filing task and the tea making task and also for the three error types (conceptual errors, sequencing errors and spatial-temporal errors). The error scores for all tasks are transferred into a binary data set, therefore coding the information if a certain error type was present or not. This data set is entered into the non-parametric mapping software in order to perform a Liebermeister test for binary-coded behavioral data. Only voxels, which are damaged in at least 15 % of the patients, are included in the analysis. MRIcron is used to display the statistical maps with a Z-value above Z = 1.64, which corresponds to an uncorrected probability below 0.05.

4.1.1.2 Results

4.1.1.3

Lesion overlap:

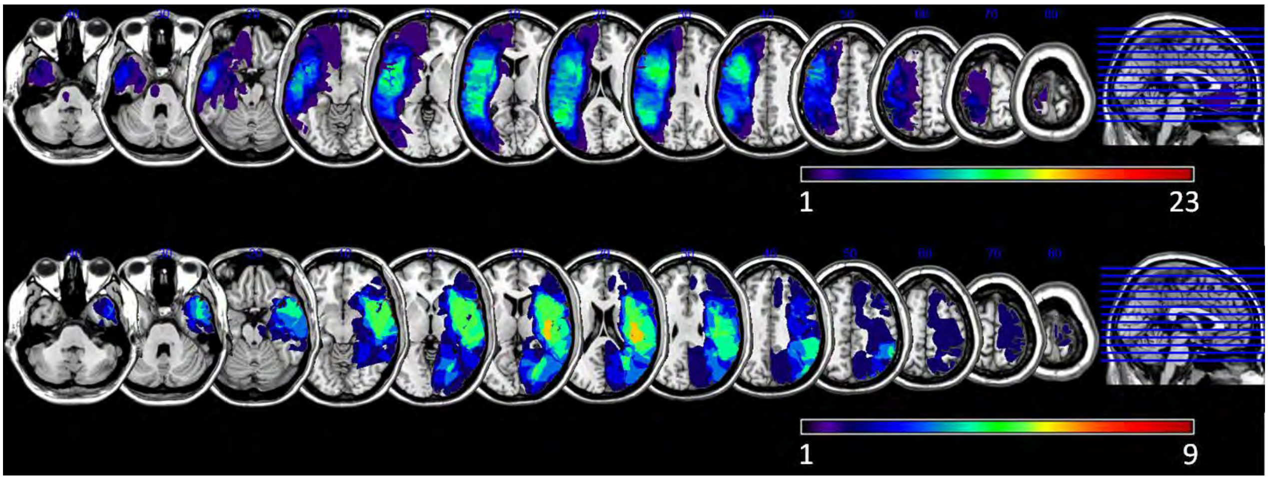


Figure 38: Lesion overlap

The preliminary results include the data from 23 LBD patients and 9 RBD patients and the lesion overlay of these patients is shown in Figure 38. The summed lesions in the LBD patients cover a wide area of the left hemisphere with the strongest overlap across patients in the inferior frontal gyrus (13 patients), insula (12 patients) and the middle temporal lobe (12 patients). In the RBD patients the overlap is strongest in the superior temporal gyrus (6 patients), in the inferior frontal gyrus (5 patients), insula (6 patients) and the supramarginal gyrus (6 patients). Due to the small number of RBD patients, the following lesion analysis did not reveal results with higher Z values of 1.64.

Lesion analysis for the tea making task:

The lesion analysis for the tea making task only revealed results surviving the threshold for the analysis of the sequencing errors. The brain areas, which show the strongest association between the task and the lesion site, are the inferior parietal gyrus, the angular gyrus, the middle and inferior frontal gyrus and also parts of the insula (*Figure 39: Lesion maps of tea making*).

Figure 39: Lesion maps of tea making

Statistical map of the lesion analysis for the tea making task for sequencing errors in LBD patients. Only voxels are shown with a higher Z-value of 1.64 and which are damaged in at least 15 % of the patient group.

Lesion analysis for the document filing task:

Figure 40 displays the statistical maps showing the brain areas with a significant ($p<0.05$; higher Z-value than Z=1.64) association between the presence of errors during the document filing task separated for the three mentioned error types in LBD patients. The brain areas with the strongest association with conceptual errors in the document filing task seem to be the insula, the inferior and middle frontal gyrus, the middle and inferior temporal gyrus and the angular gyrus, supramarginal gyrus and the inferior parietal gyrus. For errors in the sequencing of tasks the temporal pole, the middle and inferior temporal gyrus, the postcentral gyrus and the inferior parietal gyrus show the strongest association between behavior and the lesion location. Lesions which are associated with spatial-temporal errors mainly cover frontal centers including the superior, middle and inferior frontal gyrus, but also the insula.

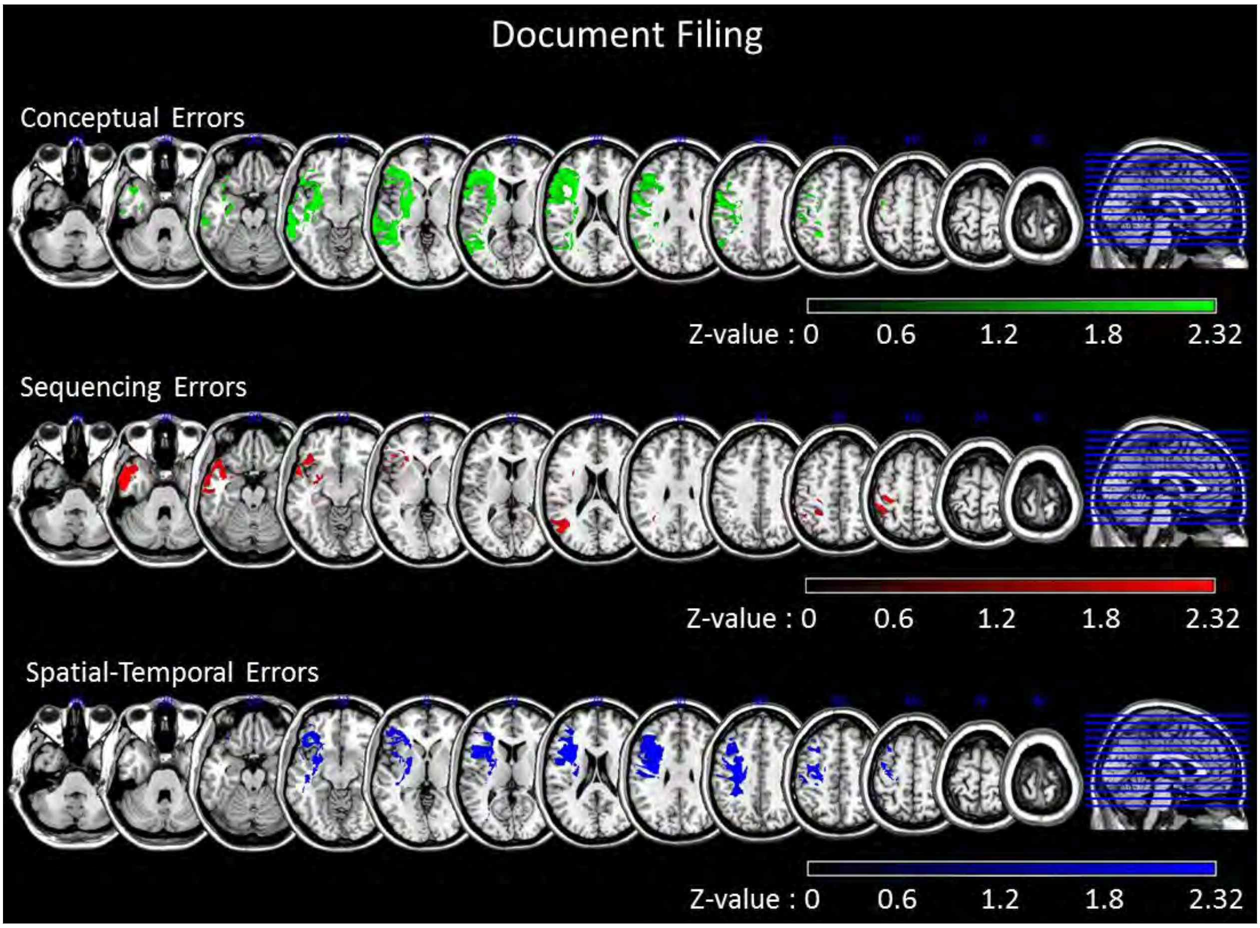


Figure 40: Lesion analysis of filing task

Statistical map of the lesion analysis for the document filing task for all error types in LBD patients. Only voxels are shown with a higher Z-value of 1.64 and which are damaged in at least 15 % of the patient group

4.1.1.4 Conclusion and Future Analysis

The preliminary results support the assumptions, that the three different aspects of actions, namely the conceptual understanding of and action, action sequencing and the spatial-temporal component of actions have different underlying neural patterns in LBD patients. Frontal, temporal and parietal regions known to be affected in patients suffering from apraxia and ADS are related to the three different behavioural deficits to a different extend and this association also varies in the two actions of daily living. Due to the limited number of RBD patients in this preliminary phase of the analysis, we cannot make any assumption for this patient group.

The future aim of this study is to increase the sample size in order to get a more detailed look on the brain areas which are specific but also in common for each of the three error types. Especially the comparison between the lesion sides will be of interest.

4.1.2 Lesion correlates with gesture deficits

Background: Gesture tasks are a common way to measure apraxia (De Renzi *et al,* 1980). They are standardised and measure single rather than the multiple actions (criticism of

ADLs). They are easy to administer and promote further refinement of the taxonomy of apraxia. Multiple neuropsychological studies found a distributed network, predominantly in the left hemisphere (illustrated) for gesture tasks (Goldenberg 2009): However these studies were criticised: small sample sizes; rarely compared across all three Gesture Tasks (production, recognition and imitation). Controversy surrounds imitation as a valid measure of apraxia (see Gross & Grossman, 2008 for an overview)

The current study aimed 1) to describe how apraxia, measured by three gesture tasks, relates to performance on other cognitive tasks, and their relation to activity of daily living. 2) To establish the validity of imitation as a measure for apraxia; and 3) To delineate the neural systems underlying different component of apraxia using function-lesion mapping of gesture tasks.

4.1.2.1 Methods

Participants: 293 stroke survivors at sub-acute phase (2-90 days post stroke). This data was acquired as part of the BCoS trial (Humphreys et al., 2012). The sample **included** patients who had a good quality CT scan, were able to consent and can attend for at least 25 minutes. For the analysis of this study we excluded left handed and patients who completed only 1 gesture tasks.

Materials: We used data obtained through the Birmingham Cognitive Screen (Humphreys *et al*, 2012), in addition to the Hospital Anxiety Depression Scale, Barthel Index of activity of daily living. The experimental tests were the three gesture tasks: ***gesture production*** (based on written/auditory verbal command, 12 items), ***gesture recognition*** (input examiner gesture output verbal command or force choice, 6 trials), ***imitation*** of meaningless gestures (input examiner gesture output patient produce a gesture, 12 items).

Other cognitive measures: picture naming (language), orientation in time and space, spatial attention: apple cancellation (neglect), Birmingham frontal (executive functions), numerical ability: calculations, auditory sustained attention, multi-step object use (action sequencing and interaction with real objects).

Analyses: We first assessed the correlations *(rho)* between our experimental tests, the cognitive control tasks and the Barthel and HADS. As the three gesture tasks were highly correlated we used*,* principal component analysis to tease apart the underlying cognitive functions. Finally we computed function-lesion mapping using voxel-based morphometry. Analysis was preformed SPM8, pre-processing included normalization using a modified version of the unified segmentation algorithm (Chechlacz, Rotshtein, Roberts, Bickerton, Lau & Humphreys, 2012) behavioural data was then used to predict changes in grey matter density within the general linear model framework.

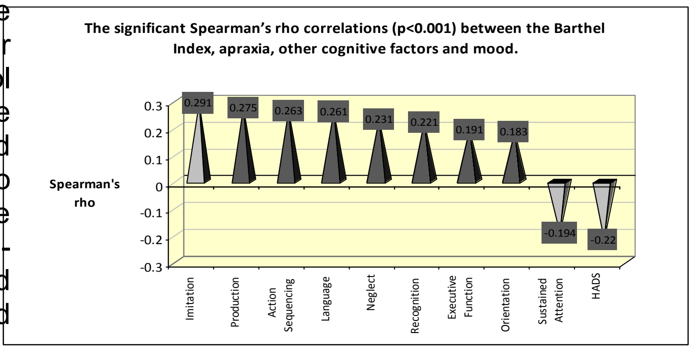


Figure 41: Cognitive predictors of Barthel

The figure shows the strength of association between ADL measured by Barthel and various cognitive-emotion measures.

4.1.2.2 Results

We first tested how activity of daily living measured using Barthel is associated with the gesture tasks and the other cognitive domain tasks (Figure 41). We found that the gesture production and imitation tasks were more strongly linked with activity of daily living (i.e. Barthel score) than other emotional cognitive factors, explaining about 8% of the variability in ADL; while other explained less than 7% of variability.

We note however that there was moderate relations between gesture tasks and: language (i.e. picture naming), action sequence (multi-step object), calculation; and weak relations with neglect (apple cancelation), executive function (i.e. Birmingham frontal), and auditory sustained attention. But the three gesture tasks highly correlated with each other. In order to tease apart shared and unique mechanisms of the gesture task we computed the principle components underlying these tasks.

	Lang: Pic Name	Action seq: Obj use	Calc	Exec Func	Neglect	Sus Att	Gesture Prod	Gesture Rec
Production	0.516	0.448	0.386	0.308	0.135	-0.308		.458
Recognition	0.37	0.346	0.329	0.285	0.121	-0.285	.458	
Imitation	0.419	0.492	0.344	0.428	0.227	-0.257	.561	.402

Table 11 Gesture and other cognitive correlations

All correlation were reliable at p <0.001, surviving Bonferroni corrections

	PC1: Motor schema	PC2: Semantic	PC3: Visual/verbal
Production	0.63	-0.24	-0.74
Recognition	0.41	-0.7	0.58
Imitation	0.66	0.67	0.35
Explained variability	82.12%	9.56%	8.32%

Table 12 PCA results for gesture tasks

The PCA revealed 3 components (see Table 12). The first which explained over 80% of the variability gesture task was a shared component. It was predominantly loaded on the production and imitation tasks – we assume therefore that this component relates to motor schemas or high level motor control where gestural knowledge is store. The second component explained about 9% of the variability and dissociated semantic/familiar from known familiar gesture task. The third component explained the remaining 8% of the variability and primarily contrasts familiar gesture production from recognition and imitation to a lesser degree. Hence we propose the 3rd component dissociate gesture processing depending on the input type: verbal, visual-movement.

Function-lesion mapping

We tested for the lesions associated with impairments in each of these three components.

Component 1 Figure 42, which was the shared components correlated with lesions to left middle temporal cortices and left inferior parietal (post-central sulcus).

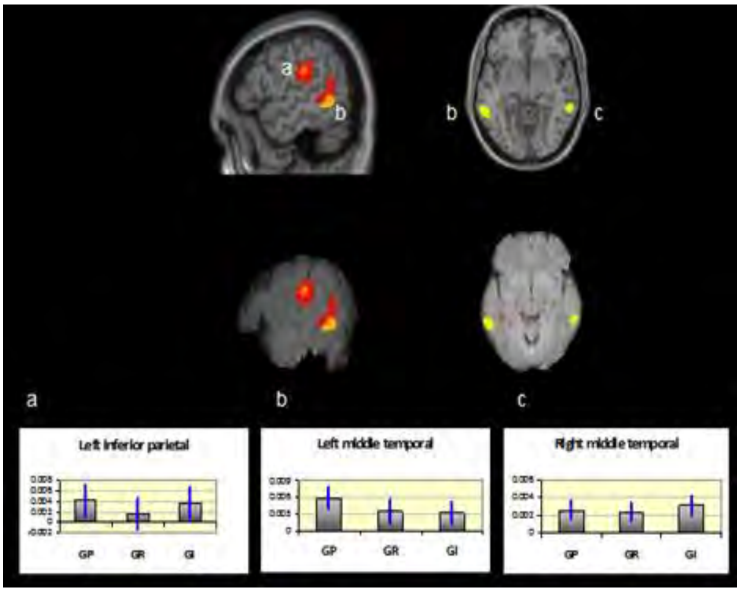


Figure 42: PC1 VBM results

Fig 42: SPMs depicting regions in which reduced grey matter integrity correlated with the shared component indicating impaired performances on all the three gesture tasks. Upper row results are overlaid on a canonical MR image, bottom row results are overlaid on a canonical CT image. Sagital present the left hemisphere; axial are presented in neurological convention (left on the left). The charts represent the effect size of each task within these clusters.

PC2 dissociated familiar from unfamiliar gesture, highlighting a semantic component. We observed that lesions to anterior cingulate, left superior temporal gyus and anterior hippocampus were associated with specific impairments in accessing semantic information relating to gesture, but did not affect imitation of meaningless gestures (Figure 44). In contrast, lesion to posterior cingulated and right inferior parietal were associated with impairment in imitation of meaningless gesture but not of meaningful.

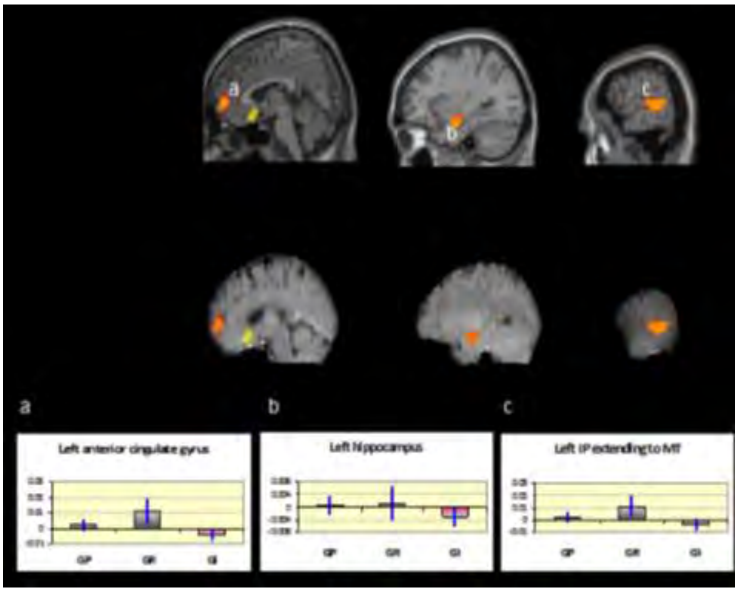


Figure 43: PC2 VBM results

Fig 43: SPMs depicting regions in which reduce grey matter integrity correlated with the shared component indicating impaired performances on all the three gesture tasks. Upper row results are overlaid on a canonical MR image, bottom row results are overlaid on a canonical CT image. Sagital present the left hemisphere; axial are presented in neurological convention (left on the left). The charts represent the effect size of each task within these clusters.

PC3 dissociated the input type (type of instructive cues: verbal – visual) in the three tasks. Lesion to the anterior cingulated, thalamus and inferior parietal affected the ability to process gestures from a visual cue (Figure 45). Lesion to the right occipito-parietal dorsal pathway impaired the ability to process gestures from a verbal cue.

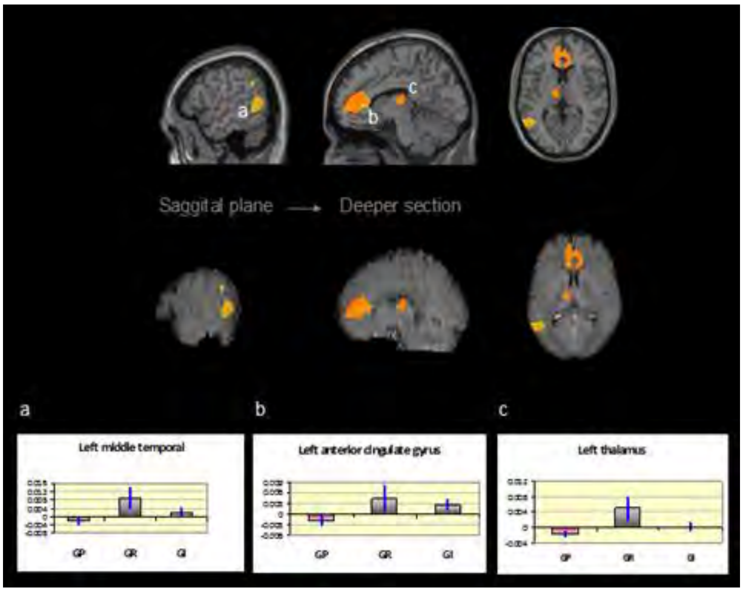


Figure 44: PC3, processing gestures from visual cues

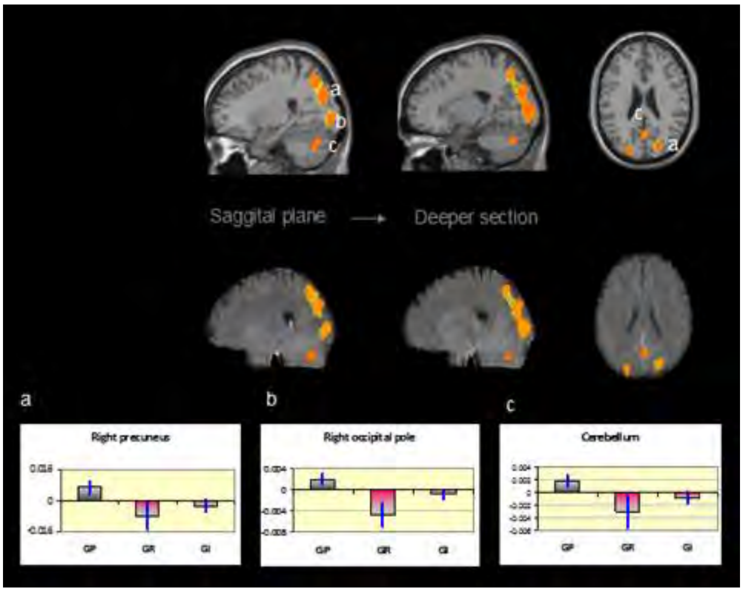


Figure 45: PC3 processing gestures from verbal cues

4.1.2.3 Conclusion and future plans

Behaviourally we found that functional independence correlated more strongly with imitation and production, out of 9 other cognitive controls (including language, neglect and executive function). This suggests that imitation is a relevant assessment for AADS, an issue that was contested in the literature.

The PCA analysis revealed several dissociated underlying mechanism for processing gesture information. PC2 (dissociating semantic from non-semantic) and PC3 (dissociating gestures based on the input type: verbal, visual) results are in line with current cognitive models for apraxia (e.g. Ruthi et al., 1991), however these models do not predict a shared component.

Results of the VBM suggested an apraxia network with a left hemisphere dominance. A shared component for all gesture tasks was mapped bilaterally onto the middle temporal lobes and onto the left inferior parietal lobe, forming part of the dorsal stream for action related processing. Lesion to medial occipital-parietal structure impairs the ability to translate a verbal command to a gesture, while lesion to thalamus, MT and anterior cingulate impairs the ability to process visually displayed gestures. Lesion to medial frontal and IPL impairs the ability to use semantic knowledge in gesture processing. In terms of future plans, this study is in its final preparation stage for publication. We hope to submit it shortly.

4.1.3 All you can do we objects: naming and. action deficits

Background. Our knowledge of tools and objects can be parsed into various components. The dual-route object processing model hypothesises that dorsal-stream structures support visuomotor processing necessary for actual object use, whereas ventral-stream structures are involved in processing information about object identity (Goodale et al. 1992).

The aim of **the current study** was to examine the dual-route hypothesis for object processing using Voxel Based Morphometry (VBM) in a large patient sample. We compared lesions associated with deficits in 4 tasks assessing different aspects of object processing: 1) naming (recognition of physical form); 2) actual use; 3) pantomimed use; 4) recognition from pantomimed actions.

4.1.3.1 Methods

Participants. 247 right-handed stroke patients (119 males, mean age: 70.43y ± 14.51std) at the sub-acute stage (<3 months post stroke) - they were all recruited as part of the BUCS (Birmingham University Cognitive Screen) trial (Humphreys et al., 2012).

Materials. We used data obtained through the Birmingham Cognitive Screen (Humphreys *et al*, 2012), in addition to the Hospital Anxiety Depression Scale. The experimental tests were the four tasks that required the use of object processing: ***object naming*** (name line drawing of manmade objects, 7 items), ***pantomime object use*** (produce a gesture to a verbal command, 'pantomime drinking' 6 items) ***object action recognition*** (input examiner gesture output verbal description, 3 trials), **use real objects** (assemble a torch, 1 trial, 15 points).

Analyses: We first assessed the correlations *(rho*) between the experimental tests We then computed function-lesion mapping using voxel-based morphometry. Analysis was preformed SPM8, pre-processing included normalization using a modified version of the unified segmentation algorithm (Chechlacz, Rotshtein, Roberts, Bickerton, Lau & Humphreys, 2012). Behavioural data was then used to predict changes in grey matter density within the general linear model framework. VBM analyses were performed to determine the neural correlates of various functions related to object processing. In all analyses, we controlled for: i) age, ii) gender, iii) years of education, iv) interval between stroke and CT scanning, v) interval between stroke and cognitive testing, and vi) measures of general cognitive state (i.e. tests on a patient's orientation).

Our analyses followed a TWO-STEP approach: 1) To determine common neural mechanism: we overlaid the SPMs computed separately for each task; 2) To distinguish unique mechanism for each task, we created a model that included all four tasks. Hence, function-lesion mapping for each object-related task was tested after controlling for the variability explained by the other three tasks.

4.1.3.2 Results

Performances on all three tasks were highly correlated (Table 13).

	Object Naming	Actual Object Use	Pantomimed Object Use	Object Action Recognition
Object Naming				
Actual Object Use	0.422**			
Pantomimed Object Use	0.503**	0.386**		
Object Action Recognition	0.443**	0.308**	0.459**	

Table 13: Relations between different object tasks

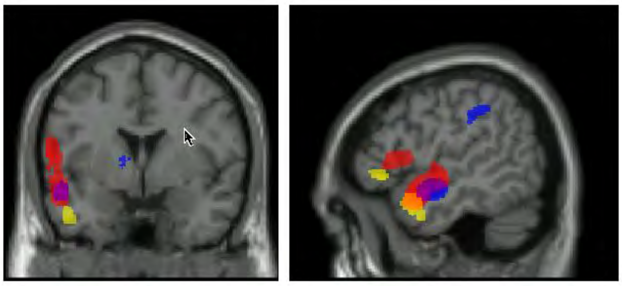


Figure 46: Shared component object processing

Fig 46: Colour coded SPM results from the separate model for each task are overlaid on a single subject T1 image. Red=object naming; yellow=object use; green=pantomime object use; blue = object-action recognition.

We first examine the lesions that reliably correlated with impairment in each of the four tasks. We found that lesion to the left anterior superior temporal cortices extending to inferior frontal gyrus impaired performances on all four tasks (*Figure 46: Shared component object processing*).

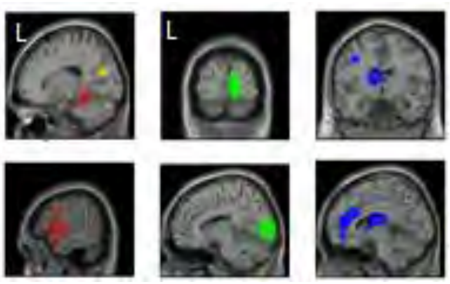


Figure 47: Dissociated object processing

Fig 47: Colour coded SPM results from the model which included all four tasks. Red=object naming, yellow=object use; green=pantomime of object use; blue=action recognition.

We next model all four tasks in the same model. By doing that we insured that any lesion we observed correlate with a specific task after controlling for the contribution of all other task (Figure 47). After controlling for all other tasks, we observed that parts of the left anterior superior temporal and inferior frontal gyrus contributed to object naming as well as the left inferior occipito-temporal cortex. In contrast all other four tasks which involved action were primarily associated with lesion to the dorsal stream. Real object use was associated with lesion to the parieto-occipital; pantomime an object use with lesion to the occipital cortex; while object-action recognition were associated with lesions to anterior cingulated, thalamus and inferior parietal cortex.

4.1.3.3 Conclusions and future plans

Shared neural correlates were identified in right medial occipital lobe (MOL) and an anterior portion of left temporal lobe (ATL). Patients with lesions to left ATL had difficulty in object naming, actual object use and recognition of objects from pantomimed actions. This is in accordance with the hypothesised role of ATL as a ‘representation’ hub, intermediating communication among regions specific for various perceptual, motor and lexical representations that constitute the cortical semantic network (Patterson et al. 2007. Nature Reviews Neuroscience). Patients with lesions to MOL showed difficulty in object naming, actual and pantomimed object use. This may be due to the need of intact visual processing for both perceiving objects (during recognition of the physical form and actual manipulation) and imagery of objects (during pantomime). Specific neural correlates for each task were also identified, supporting a dorsal-ventral dissociation: Recognizing objects from action gestures was associated with IPS and pulvinar lesions; Actual and pantomimed use of objects were associated with parietal and/or occipital lesions; On the contrary, naming from recognizing the object’s physical form was associated with lesions to the ventral temporal.

Future plans - this study is in the final stage of preparation and would be submitted to publication by the end of the summer.

4.2 fMRI studies

4.2.1 Neural correlates of monitoring tea making sequence

We are in the middle of data collection for an experiment we presented in previous deliverable (see WP1, deliverable 1.3). We have already collected data from 15 young and 11 elderly healthy, and 12 neurological patients. However, we have not started to analyse these data yet and we will present it in the final report.

4.2.2 Neural correlates of producing a tea making sequence

Background. Much of everyday behaviour involves performing routine tasks as washing, dressing, preparing and eating food. These tasks can be considered as a sequence of actions that are hierarchically structured. For example, a tea-making task consists of a superordinate goal (make tea), made up of several subgoals/tasks (e.g. Add water to kettle, Turn on the kettle, etc.). Obviously, the ability to learn such hierarchic sequences and form chunks of actions plays an important role in human life. While learning a simple motor sequence is extensively investigated field it is unclear how this type of learning relates to completion of more complex action sequences. This is an important question as AADS patients often need to re-learn action sequences of daily living activities. Hence understanding the relation between these two types of motor sequence learning can help design new rehabilitation avenues, where knowledge on motor sequence learning can be used in action sequence learning practices.

The current study aimed to understand the neural substrates involved in action sequence learning and explore whether different neural pathways underpin simple motor and complex action sequence learning. We design a study that required the same motor response in both condition – clicking with eight fingers in a sequence. In the ADL, tea condition, the sequence was based on selecting the correct steps in the right order for completing a tea with sugar and milk. Each finger in that case was spatially mapped to a picture depicting one step. Hence the order was generated based on prior knowledge (i.e. 'how to make a tea'). In the motor condition, a location was briefly highlighted and participants had to press with the corresponding finger. Thus the two conditions (ADL, motor) differed only with respect to whether responses were guided by external cues, or based on prior knowledge. In addition prior to the scanning participants were trained on one particular sequence of finger presses – which was identical for the ADL and motor condition. In the scanner they were tested on the sequence they were trained on and on novel sequences.

4.2.2.1 Methods

Participants. 15 young and 13 elderly healthy volunteer participated in this study. These same participants also completed the action sequence recognition experiment (4.2.1).

Materials. For The ADL action of tea making we used the still pictures used as cue in CogWatch. These depicted the 8 sub-tasks of making a cup of tea (*Figure 49: Pictures used in the ADL condition*). A scramble version of them was used in the motor condition. The pictures were organized on the screen in two semi-circles with underneath a picture of a hand (see Figure 48). This was done to help the spatial mapping between the fingers and the pictures.

Figure 48: Sequence production display

An example of the arrangement of pictures on the screen.

Figure 49: Pictures used in the ADL condition

Design and procedure. The experiment had a 2 (type of sequence: motor, ADL) x 2 (learned, unlearned) design. The type of sequence was manipulated by the pictures used in the display. In the ADL condition the display contained the sub-task stills; while in the motor condition scramble pictures were presented. In the learned sequence condition the sequence followed the trained sequence, while in the unlearned the sequence changed in each trail. The same motor sequence was used for both motor and ADL task. Participant learned this sequence prior to scanning by repeating 40 trials per condition. The conditions were manipulated across blocks. In the ADL condition, participants finger presses was indicated by briefly highlighting the selected pictures; in the motor condition a brief highlight of the picture indicated the finger that should be pressed. Participant had a maximum of 10sec to complete each trial.

fMRI data 3T Philip Achieva scanner was used to acquire the fMRI data. We repeated the experiment twice in the scanner. The data was analysed using SPM12.

4.2.2.2 Results

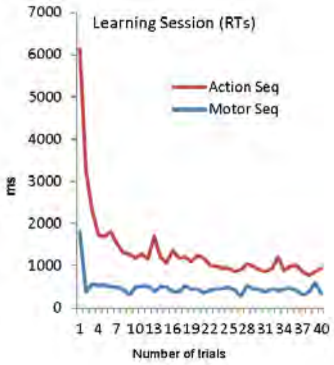


Figure 50: Learning effect during the training

Behavioural effects of learning. To date we analysed the behavioural data of 10 young participants.

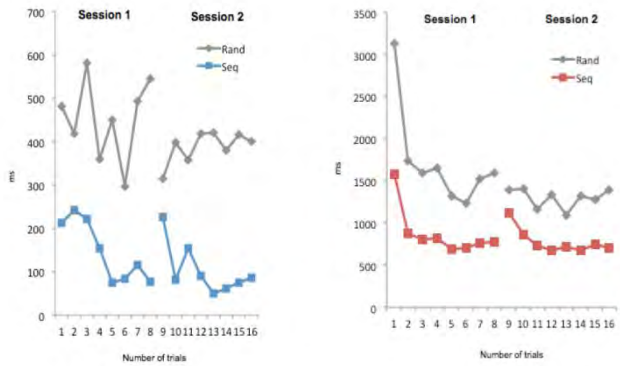


Figure 51: Learning effects during scanning

Response times plotted along trials. The plots on the left represent the response during the motor condition, blue for learned and grey for unlearned (note the RT axis maximum point is 700msec). The plots on the right represent RT during the ADL, tea task; red for the learned and grey for the unlearned note the RT axis maximum is 3500msec).

Evidence for rapid learning was observed already after 4 trials during the training. Here we present the average time for a single response (total length of trial / number of correct responses made). We note that producing the ADL sequence was slower than producing the motor sequence (Figure 51). Importantly a single response sequence was used in both conditions. Though, we should note that training always started with the ADL condition and then moved to the motor condition. Hence the fast responses in the motor relative to the ADL condition maybe an order confound. As expected during scanning, responses were faster for the learned sequence compared with the unlearned novel sequences (Figure 50) and more correct responses were made (Figure 52). Responses were also much slower for the ADL sequences relative to the motor sequence. Surprisingly, this was observed even for the learned sequences were the required sequence was identical in both conditions.

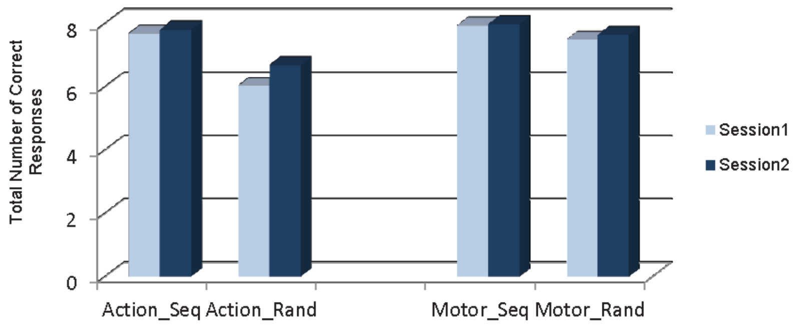


Figure 52: Number of correct responses

The charts present the number of correct responses for each condition and each fMRI session (time limit 10sec per trial). Maximum responses per trial were 8. Action Seq = ADL, learned; Rand = unlearned.

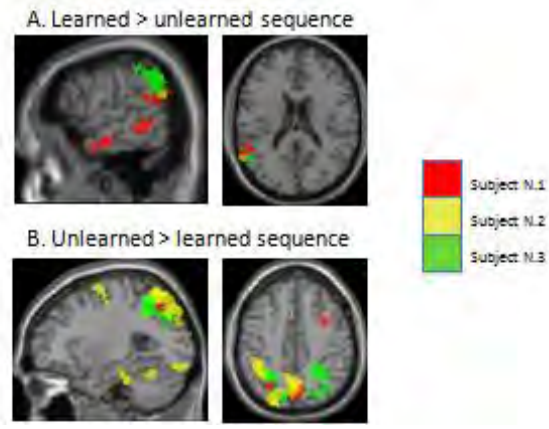


Figure 53: Main effect of sequence type

fMRI results. We present data of 3 single young participants. We present this initial analysis as replication of single cases, where we overlaid the results of all three participants, to be able to better assess the reliability of these effects

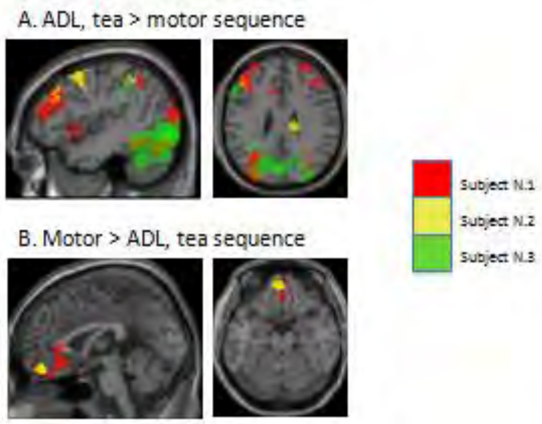


Figure 54: Main effect of learning

We first tested the effects of training, comparing responses to learned versus unlearned sequences across both conditions (Figure 54). Participants showed stronger responses in left lateral posterior parietal cortex for learned sequences compared with unlearned. The opposite pattern, stronger response to novel unlearned sequences relative to learned one, was observed in bi-lateral IPS, stronger on the left and medial superior parietal cortex.

Second we examined the main effect of sequence type, comparing the effects of ADL sequence guided based on internal knowledge to a motor sequence guided by external cue. We found that ADL sequences activated the lateral occipital cortex, posterior parietal and bilateral medial frontal gyrus more than motor sequences. The opposite was observed in medial orbital frontal cortex where motor sequences activated more relative to ADL sequence.

Finally we examined the interaction between the sequence type and training (Figure 55). We observed that in the right posterior parietal cortex, for the ADL sequence increased for the learned sequences vs. the unlearned was larger than for motor sequences. For the opposite interaction we observed that the left posterior parietal cortex showed stronger effects for the learned compared to the unlearned during the ADL trails than the motor trials.

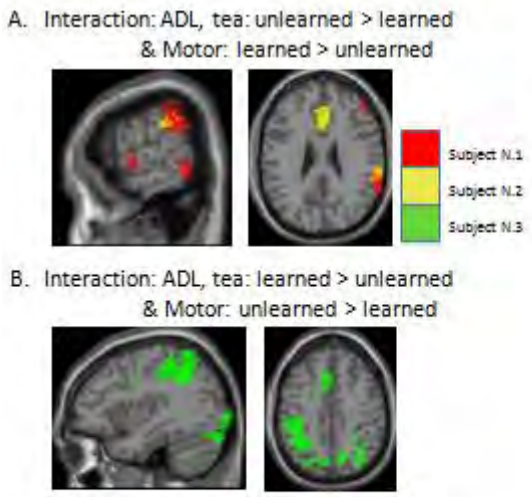


Figure 55: Interaction Sequence type and training

4.2.2.3 Conclusions and future planning

We first observed that producing a sequence based on prior semantic knowledge is much slower compared to base on external cues. This is even though the actual response sequence is identical. It also suggested that there is a minimal transference between the two types of sequences. In the fMRI, our findings suggest that learning simple motor sequence and ADL sequence is mediated by shared as well as dissociated network. With left posterior cortex involved more in guiding responses of learned sequences, while IPS and medial superior parietal cortex guide responses to novel sequences. However, stronger visual, parietal and frontal responses were observed for the ADL sequence relative to the motor. Together these results suggest that simple motor sequence learning and ADL sequence learning are potentially mediated by very different mechanism.

We plan to finalize the data collection by the end of the summer. And complete analysis and write the study up by the end of the year.

5. CONCLUSIONS

This deliverable has been concerned with increasing understanding of the AADS syndrome and evaluating needs of AADS patients, as users of the CogWatch system. Both aims feed into the design of the CogWatch prototypes and the development of strategies for the use of CogWatch in providing rehabilitation or assistive feedback.

Section 1 was concerned with recruitment and characterisation of AADS. Contrasts between left and right brain damage in terms of patterns of errors in sequential action (e.g. tea making) and correlations with other neuropsychological tests were described. The results provide a basis for tuning the CogWatch system to the needs of the individual patient.

Section 2 was concerned with describing tooth brushing, the activity selected as the scenario for the second prototype P2. Initial testing with AADS patients indicates classes of error to be expected include sequencing problems and omissions as well as movement accuracy or quality errors. This work provides the basis for the definition of system hardware and the software supporting action recognition, task model and patient and clinician professional interface.

Section 3 described experimental work that aimed to systematically test efficacy of different cueing and feedback strategies appropriate to either P1-tea making (includes a study of snack preparation) or to P2-toothbrushing (including use of other tools and reaching). These are summarised in Table 14. Five studies (3.1.1, 3.1.2, 3.1.3, 3.2.1, 3.2.2) were concerned with cue effects, for instance contrasting prospective (errorless) vs feedback (errorful) approaches with the suggestion that different patients may benefit from one or the other. Two studies (3.1.4, 3.1.5) involved simulations drawing on some of the principles of CogWatch. Such simulations are an efficient method for collecting data which, for example, showed similar omission errors to real tea making but may also prove, with further development, a useful method for training ADL skills.

Section 4 focused on understanding the neural correlates of activity of daily living using . functional imaging, and lesion-symptom mapping approaches with healthy and patient participants. This work provides insights into the neural architecture of processes involved in activities of daily living and the effects of neural impairment associated with AADS and may be expected to contribute to future development of more efficient rehabilitation procedures using CogWatch or similar approaches.

Sec	Task	Short title	Partner	Ps	Status
3.1.1	Tea	Errorless vs errrorful	UOB	10 patients	Further patient testing
3.1.2	Snack	Prospective cueing	TUM	6 patients; 5 controls	Further patient testing
3.1.3	Tea	Alert cues	UOB	4 elderly, 36 young controls	Further elderly testing
3.1.4	Tea	Simulated – click and drag	UOB	9 elderly, 21 young controls	Further elderly testing
3.1.5	Tea	Simulated – task model	UOB	12 elderly, 15 young	Further elderly and patient testing
3.2.1	Gesture	Cueing in gesture production	UOB	6 patients	Further elderly and patient testing
3.2.2	Tool use	Ecological sounds	TUM	16 patients, 20 elderly controls	Long term effects to be explored
3.2.3	Reach to target	Proprioceptive vs visual feedback	UOB	16 patients, 10 elderly	Further analysis

Table 14: Summary of experimental studies

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