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The application of SHERPA (Systematic Human Error Reduction and Prediction Approach) in the development of compensatory cognitive rehabilitation strategies for stroke patients with left and right brain damage

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Approximately 33% of stroke patients have difficulty performing activities of daily living, often committing errors during the planning and execution of such activities. The objective of this study was to evaluate the ability of the human error identification (HEI) technique SHERPA (Systematic Human Error Reduction and Prediction Approach) to predict errors during the performance of daily activities in stroke patients with left and right hemisphere lesions. Using SHERPA we successfully predicted 36 of the 38 observed errors, with analysis indicating that the proportion of predicted and observed errors was similar for all sub-tasks and severity levels. HEI results were used to develop compensatory cognitive strategies that clinicians could employ to reduce or prevent errors from occurring. This study provides evidence for the reliability and validity of SHERPA in the design of cognitive rehabilitation strategies in stroke populations.

Practitioner Summary: This study evaluated SHERPA (Systematic Human Error Reduction and Prediction Approach) as a means for predicting errors during the performance of daily activities in left and right brain-damaged patients. Results demonstrate that SHERPA is a useful technique that can be employed in the design of cognitive rehabilitation strategies.

Keywords: task analysis; human error identification; stroke; cognitive therapy

1. Introduction

1.1. *Stroke*

Stroke is the leading cause of long-term physical disability, with more than 20% of stroke survivors requiring institutional care three months after stroke onset (Rosamond et al. 2008). In addition to physical impairments, it has been reported that more than one third of stroke patients suffer from short-term (i.e., three months post stroke; Lawrence et al. 2001; Tatemichi et al. 1994) and long-term (i.e., three years post stroke; Brandstater 1990) impairments in cognitive function. These deficits in higher-order cognitive abilities often negatively affect the ability to perform activities of daily living (ADL; Giaquinto et al. 1999; Özdemir et al. 2001; Stephens et al. 2005), and play an important role in determining length of stay and functional status at the end of the hospital stay (Jongbloed 1986; Mysiw, Beegan, and Gatens 1989).

1.2. *Influence of stroke on activities of daily living*

Daily activities often require multiple tool-object interactions, and involve multiple sub-tasks that must be fulfilled in order to satisfy the desired task goal. In order to successfully complete a given ADL (i.e., making a cup of tea) the actor must organise a set of actions given spatial and temporal constraints (Goldenberg, Daumüller, and Hagmann 2001). Brain damage following a stroke incidence negatively affects the ability to perform ADL (Humphreys and Forde 1998; Luria 1966; Schwartz et al. 1991, 1995; Stephens et al. 2005). For example, Luria (1966) asked patients with extensive frontal lesions to light a candle, and observed that patients would continue striking a match after it had been lit, would light the candle and then snap it into two as though it were the match, or would 'smoke' the candle after it had been lit as though it were a cigarette or cigar (Luria 1966). Schwartz et al. (1991) reported that a patient with extensive bilateral frontal lesions who, when preparing coffee in a naturalistic setting, made errors such as putting breakfast cereal in the coffee mug (object substitution error) and attempting to pour from the cream container before opening it (anticipation/omission error). Similar impairments of naturalistic action have also been observed in other patient groups. Individuals with closed head injury

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(CHI; Schwartz et al. 1998), dementia (Giovannetti et al. 2002), left hemisphere stroke (Buxbaum 1998; De Renzi and Lucchelli 1988; Poeck and Lehmkuhl 1980; Rumiati et al. 2001), and right hemisphere stroke (Schwartz et al. 1999) often omit an action from a well-practiced sequence (e.g., attempting to brush one's teeth without first placing toothpaste on the toothbrush) or use an inappropriate object (e.g., using a fork to cut and slice a loaf of bread) during ADL performance. As such, it has been suggested that deficits in ADL performance following brain damage result from a general reduction in the cognitive resources required to perform everyday activities (Giovannetti et al. 2002; Schwartz et al. 1998, 1999).

Studies that have directly compared left and right brain-damaged (LBD and RBD) patients have, however, reported differences in tasks involving multiple objects and sub-tasks (Gainotti and Lemmo 1976; Hartmann et al. 2005; Vaina, Goodglass, and Daltroy 1995; Varney 1978). Patients with LBD are impaired when they are asked to use single familiar tools or tool-objects pairs (De Renzi, Pieczuro, and Vignolo 1968; Goldenberg and Hagmann 1998), match object pairs that sub-serve the same purpose (De Renzi, Scotti, and Spinnler 1969; Rumiati et al. 2001) or match objects to actions demonstrated without an object (Gainotti and Lemmo 1976; Vaina, Goodglass, and Daltroy 1995; Varney 1978). Differences have also been reported by Hartmann et al. (2005), who asked LBD and RBD patients to prepare coffee with a drip coffee maker and to fix a cassette recorder. The authors reported that both patient groups were equally impaired on both tasks, although LBD patients scored somewhat lower and needed more assistance than RBD patients. It was also reported that the difficulties exhibited by RBD patients was due to the attentional demands required to keep track of multi-step actions. In contrast, for LBD patients, difficulties in the coffee task were correlated with aphasia and defective retrieval of functional knowledge from semantic memory, whereas the cassette recorder task depended more on trial and error than on retrieval of instructions for use. Overall, it appears that there are both similarities and differences during the performance ADL in patients with LBD and RBD. The types and proportions of errors observed during the performance of ADL tasks are similar regardless of lesion hemisphere. However, patients with RBD exhibit greater difficulties than LBD patients during complex multi-step tasks.

1.3. Human error identification

Given numerous reports that brain-damaged individuals commit errors when performing ADL tasks, it is clear that error assessments should include multiple measures, and be structured so as to allow for transparent data comparison by other researchers. The currently available ADL performance tests – The Coffee Challenge (Giovannetti, Schwartz, and Buxbaum 2007); Multi-level Action Test (Buxbaum 1998; Giovannetti et al. 2002; Schwartz et al. 1999); Naturalistic Action Test (Schwartz et al. 2002) – lack such characteristics. Typically, these assessments often measure a single component of ADL performance, and rely on subjective assessments by evaluators. Moreover, there is no standardised error categorisation scheme, which makes it hard to compare results across studies. In this paper, it is argued that an assessment technique that features a systematic classification of error types would be of major benefit to the field of neuropsychological assessment and rehabilitation.

Fortunately, human factors research often uses human error identification (HEI) techniques to predict human or operator errors in complex and dynamic environments. Originally developed in response to nuclear, petrochemical and electricity power plant catastrophes (e.g., Three Mile Island disaster, Chernobyl), HEI techniques have been applied to domains such as air traffic control (Shorrock and Kirwan 2000), aviation (Marshall et al. 2003), naval operations, military systems, public sector technologies (Baber and Stanton 1996) and medicine (Lane, Stanton, and Harrison 2006; O'Sullivan et al. 2011; Phipps et al. 2008). A number of HEI techniques have been developed – e.g., Human Error Assessment and Reduction Technique (HEART; Williams 1986); Human Error Template (HET; Marshall et al. 2003); Task Analysis for Error Identification (TAFEI; Baber and Stanton 1996); Systematic Human Error Reduction and Prediction Approach (SHERPA; Embrey 1986, Kirwan 1992a, 1992b) – that can be used to describe potential errors, consequences associated with those errors, recovery potential, error criticality and strategies to reduce or eliminate those errors. The aforementioned HEI techniques were developed to predict ways in which activity might fail due to what might be considered 'normal' types of human error (i.e., slips, lapses and mistakes). These errors could arise from failures of attention, lack of control or the inability to understand the task. Underlying this analysis is the unwritten assumption that the behaviour is performed by neurotypical actors who, should the error be brought to their attention, would be able to either avoid such an error in the future or correct the error on performance. It is not immediately obvious, therefore, that these techniques could be applied to individuals who suffer from neurological deficits. Thus, this paper is also concerned with the broader question of the generalisability of Ergonomics techniques to neurologically impaired actors.

Of the available HEI techniques developed, SHERPA has been shown to be the most promising general-purpose technique available to the human factors analyst. For example, Kirwan (1992b) reported that SHERPA achieved the highest overall performance rankings compared to five other HEI techniques (i.e., Cognitive Reliability Error Analysis [CREAM], Generic Error Modelling System [GEMS], HEI in Systems Tool [HEIST], Predictive Human Error Analysis [PHEA] and

TAFEI), indicating that when combined with expert judgments SHERPA is a robust HEI approach. SHERPA has been shown to have concurrent validity statistics between 0.74 and 0.8 and inter-rater reliability statistics between 0.65 and 0.9, depending on the nature of the task being examined (Baber and Stanton 1996; Stanton and Stevenage 1998).

SHERPA was developed by Embrey (1986) as a structured HEI technique that uses Hierarchical Task Analysis (HTA; Annett et al. 1971) in conjunction with an error taxonomy to identify credible errors associated with human activities. The advantage of SHERPA is that it is a structured and comprehensive technique that can be easily taught and applied, is substantially more time economic than observation methods, and yields acceptable inter-rater reliability values. SHERPA has been applied successfully to a number of situations, including the handling and transportation of hazardous chemicals (Kirwan 1994), offshore oil and gas exploration and exploitation (Stanton and Wilson 2000), aircraft flight deck (Harris et al. 2005), evaluation of medical devices (Bligård and Osvalder 2014), analysis of the usability of ticket vending machines (Baber and Stanton 1996), cooker timer controls (Crawford, Taylor, and Po 2001) and car audio equipment (Stanton and Young 1999). The disadvantage of SHERPA (although this is true of the majority of HEI techniques) is that it relies on the observation of physical behaviour, and thus analysts must use inferences drawn from such behaviour when considering the cognitive functions that underlie task performance.

There are eight steps in the SHERPA analysis. In the first step (HTA), the analyst uses HTA to break down the overall task into subordinate sub-tasks, and introduces plans that indicate potential sequences of sub-task performance. From the decomposition of an activity into discrete tasks, the analysis works towards a Failure Mode Effects Analysis by assuming that each task can be considered in terms of classes of failure modes or errors. For example, an 'action' could fail by being performed on the wrong object or at the wrong time. Thus, the second step (task classification) involves classifying each task operation into one of the following taxonomies (action, retrieval, checking, information communication, selection). This classification then allows the analyst to consider likely errors associated with that operation (step 3: HEI). Consequently, the analyst describes the consequences (step 4: consequence analysis) and the recovery potential (step 5: recovery analysis) associated with each error. Once the consequence and recovery potential of each error has been identified, the analyst then rates the probability of the error occurring (step 6: ordinal probability analysis) using information obtained from empirical data and/or input from a subject matter expert. Step 7 (criticality analysis) requires the analyst to note if the consequences associated with an error are critical (e.g., substantial damage to the product, injury to personnel). In the final step (remedy analysis), the analyst uses a structured brainstorming exercise to develop ways of eliminating or reducing the effects of the error.

1.4 Present study

Although SHERPA has been used to identify errors in a number of domains, there have been no published reports where the method has been applied to the analysis of action errors committed during ADL in special populations. We therefore, used SHERPA to predict errors and consequences during ADL performance in left and right brain-damaged populations, and used the gathered information to design cognitive rehabilitation strategies.

2. Methods

2.1. Participants

Forty patients with lesions following a single cerebrovascular accident (CVA) participated in the study. Patients were included if they showed typical neuropsychological symptoms following right or left brain damage (LBD or RBD), such as aphasia, limb apraxia or visuo-spatial deficits such as neglect. In 27 patients the stroke had affected the left hemisphere (mean age = 57.8 years, SD = 12.6; 4 left-handed, 23 right-handed; 14 men, 13 women) and in 13 patients the right hemisphere (mean age = 64.9 years, SD = 11.0; 1 left-handed, 12 right-handed; 9 men, 4 women). Eleven patients suffered a left hemisphere lesion which resulted in right hand hemiparesis and were able to perform the task with only the left hand. Six patients suffered a left hemisphere lesion which resulted in left hand hemiparesis and were able to perform the task with only the right hand. The remaining 22 patients were able to use both hands to perform the task.

Forty-one neurologically healthy individuals (mean age = 45.9 years, SD = 20.7; 18 men, 23 women) served as control participants. Twenty-three participants were categorised as 'older controls' (mean age = 60.7 years, SD = 14.5; 10 men, 13 women; 3 left-handed, 20 right-handed), and 18 were categorised as 'younger controls' (mean age = 25.9 years, SD = 4.3; 8 men, 10 women; 3 left-handed, 15 right-handed). All control participants used both hands to perform the task. None of the participants had any history of neurological disorders or any constraints of upper limb movements.

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 participants, and the study was conducted in accordance with the Declaration of Helsinki.

2.2. Apparatus and procedure

Participants sat at a table with a dimension of 100 cm × 60 cm. The spatial arrangement of the objects on the table is shown in Figure 1a, with a total of 14 objects located on the work surface. Each participant was asked to perform a two-cup tea-making task, in which one cup of tea required milk and two sweeteners, and the other cup of tea required lemon and one sugar cube (Figure 1b). Subjects were informed that all the things required to make the tea are on the table, and no time constraints were placed on task performance. Assistance was given if participants asked for help stabilising an object, or when there was immediate danger of personal injury. Two trials were performed. Actions were recorded by a video camera (Panasonic HDC-SD909) located 45° to the right side of the table.

3. SHERPA application

3.1. Hierarchical Task Analysis

3.1.1. Data analysis

An HTA diagram for the ADL task is shown in Figure 2. The HTA diagram was drawn up by the lead author, and reviewed by the second author and two researchers from the Technical University of Munich. The root of the tree is referred to as the

Figure 1. (a) Spatial arrangement of objects and the (b) visual stimulus depicting the ingredients required to successfully complete for the two-cup tea-making task.

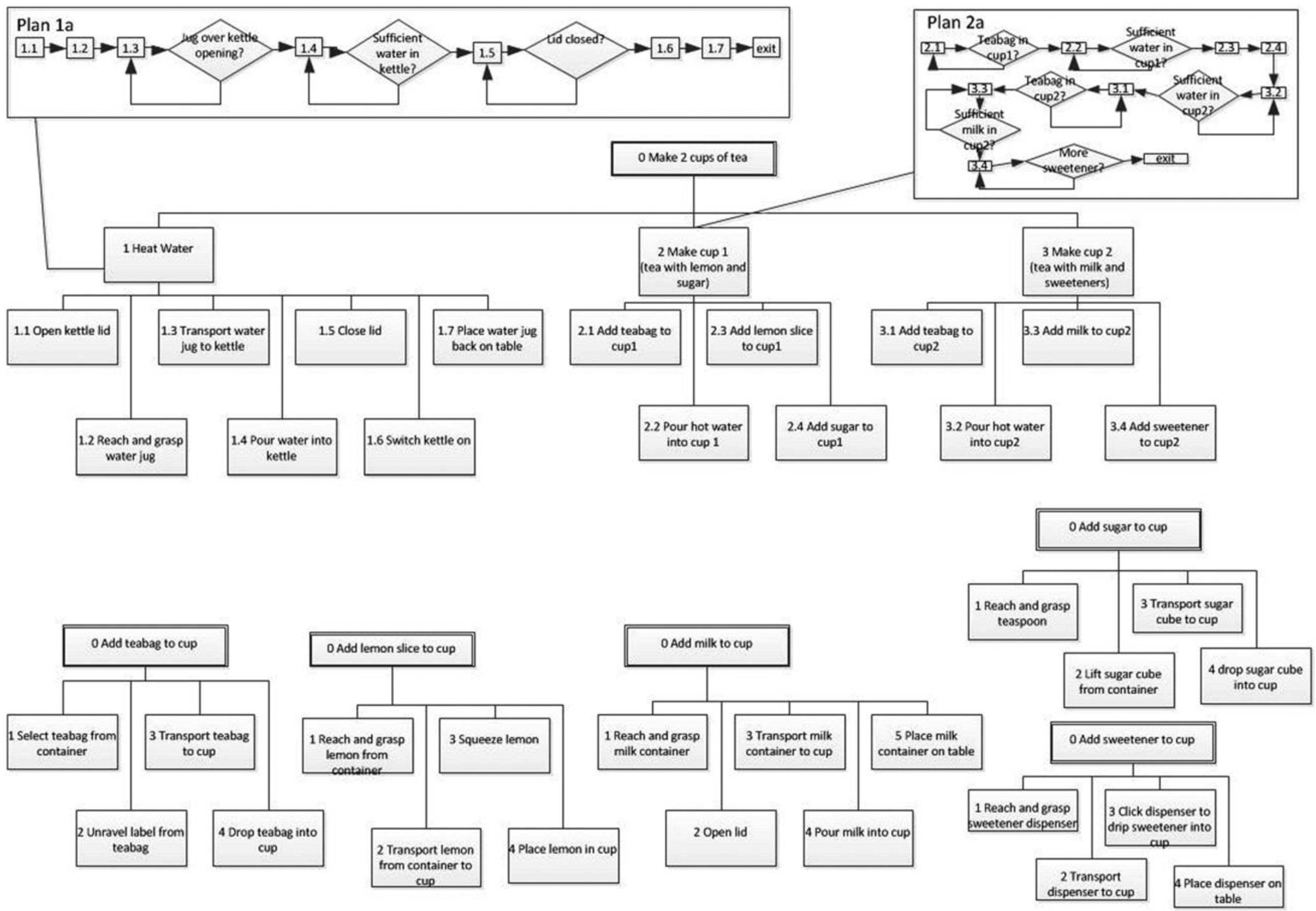

Figure 2. HTA for the two-cup tea-making task.

task end-goal. In this study the task end-goal was to make two cups of tea, in which the participant was required to add milk and two sweetener tablets to one cup, and a slice of lemon and one sugar cube to the other cup. The actions required to complete this task (i.e., sub-tasks) are shown in the second level of the hierarchy.

3.1.2. Results

The observed action sequences that resulted in successful task completion for controls and patients are displayed in Appendix 1.

3.1.2.1. Control participants. Control participants employed eight different action sequence plans (younger controls = 7, older controls = 7) for the 'heat water' sub-task, with an overlap in six action plan sequences. Younger controls were more likely to use action sequence plan 1a (36%) or 1e (21%), whereas older controls favoured action sequence plan 1a (28%), 1b (23%) and 1 h (20%). The same action sequence plan was employed in both trials by 41% of control participants (younger controls = 33%, older controls = 48%).

For the sub-goal 'make tea' control participants employed 39 different action sequence plans (young controls = 20, older controls = 22), with an overlap in 4 action plan sequences. Neither the younger or older control participants showed a preference for a particular action sequence plan. The data revealed that 23% of control participants (young controls = 28%, older controls = 17%) used the same action sequence plan in both trials.

3.1.2.2. Patients. Considering only the data in which patients successfully completed the sub-task, analysis showed that patients employed a total of 10 different action sequence plans (LBD = 9, RBD = 8) for the 'heat water' sub-task. There was an overlap in four action plan sequences between patient groups. However, LBD patients were more likely to use action sequence plan 1a (29%) or 1 g (21%), whereas RBD patients favoured action sequence plan 1c (42%). With regards to plan consistency (i.e., using the same action sequence for both trials), the data indicated that four patients (10%) used the same 'heat water' action sequence plan (LBD = 1, RBD = 3).

For the 'make tea' sub-task, patients employed 27 different action sequences (LBD = 19, RBD = 8). There was no overlap in action sequence plans, indicating that LBD patients used one set of action plans, and RBD patients used another. Moreover, with the exception of one LBD individual, patients employed a different action sequence plan for both trials. Patients were more likely to commit errors in both the first trial and the second trial (overall = 34%, LBD = 38%, RBD = 26%), compared only the first (overall = 13%, LBD = 18%, RBD = 0%) or only the second trial (overall = 20%, LBD = 18%, RBD = 26%).

3.1.2.3. Control versus patients. Of the 11 different action sequences used in the 'heat water' sub-task, there was an overlap in 9 plans (82%), indicating that control participants and patients used similar sets of action plans. In contrast, for the 'make tea' sub-task there was an overlap in only 10 of the 55 observed action plans (18%), indicating that control participants preferred one set of action plans, whereas patients preferred another.

3.2. Human error analysis

3.2.1. Data analysis

In order to classify errors in ADL performance, the lead author considered possible errors that that could occur at each sub-goal based on errors reported in previous literature (Table 1; De Renzi and Lucchelli 1988; Poeck and Lehmkuhl 1980; Rumiati et al. 2001; Schwartz et al. 1991), feedback from focus groups (participation from 45 therapists) and questionnaires (participation from 96 clinicians) on the nature and frequency of error types encountered in practice, and personal interviews with three subject matter experts with extensive experience (i.e., each with more than 20 years' experience) in the evaluation and rehabilitation of apraxia and related neuropsychological disorders. Through the personal interviews we were able to derive information about the types of errors experienced by rehabilitation practitioners in the course of their treatment of apraxia and related difficulties.

The possible errors (column 2 of Appendix 2) of the HEI outcome table were reviewed by another researcher who has extensive experience classifying errors committed by brain-damaged patients during ADL performance. Inter-rater reliability was calculated separately for potential errors, error severity and sub-goal. The mean percent agreement was 93% (range 90–97%).

Table 1. Human error taxonomy for classifying action errors committed during ADL.

Error type	Definitions	Example
Addition (AD)	Adding an extra component action that is not required in the action sequence	Adding instant coffee to cup 2
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 cup 1
Misestimation (ME)	Using grossly too much or too little of some substance	Pouring half of the milk jug contents into cup 2
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 cup 2
Pantomime (PA)	Pantomimes of object use where use of an object is demonstrated with the empty hand	Pantomiming pouring water into cup 1, without having grasped the kettle
Perplexity (PLX)	A delay or hesitation in performing an action	Picking up a tea bag and then pausing for an extended amount of time before placing it into a cup
Perseveration (PER)	The unintentional repetition of a step or sub-task	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-cup 1 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 sub-task is not performed, despite the lack of any intention to omit the step or sub-task	Turning the kettle on without having inserted water

A description of the error and its corresponding error classification is provided in the HEI outcome table (columns 2 and 3 of Appendix 2, respectively). The HEI outcome table also contained information regarding the sub-goal and severity in which each error occurred (columns 1 and 4 of Appendix 2, respectively). Level 1 severity errors refer to errors that are recoverable, such as not pouring enough hot water into cup 1. Level 2 refers to errors that prevent the participant from successfully completing the task (e.g., adding coffee to cup 1). Level 3 refers to recoverable errors that result in potential harm to the participant (e.g., switching the kettle on before pouring water into the kettle). Finally, level 4 errors are those that prevent the participant from successfully completing the task and also result in potential harm to the participant (e.g., dropping the kettle when moving it into position over cup 1).

There were a total of 48 identified possible errors that could be executed. It was predicted that 24% of errors would occur in the 'heat water' sub-task, 38% in the 'make cup 1' sub-task, and 44% in the 'make cup 2' sub-task. When errors were categorised by error severity, it was predicted that 16% would be level 1 errors, 68% would be level 2 errors, 10% would be level 3 errors and 14% would be level 4 errors.

3.2.2. Results

SHERPA analysis successfully predicted 30 of the 38 observed errors (79% hit rate). Moreover, there were eight errors that we observed, but were not predicted (21% miss rate). These errors typically fell into the perplexity ($n = 3$, e.g., noticeable pause after grabbing the milk jug), toying ($n = 3$, e.g., repeatedly handling [e.g., touching, picking up and then placing it back down] the coffee jar without using the object to complete either a sub-task or task goal) and execution categories ($n = 2$, i.e., tangling the tea bag in the teaspoon in cup 2 so it was wrapped around the teaspoon).

3.2.2.1. Control participants. Analysis indicated that control participants successfully completed the task in 90% of trials (younger controls = 100%, older controls = 83%). Chi square analysis indicated that this difference was not statistically significant, $\chi^2_{(df=1)} = 0.001$, $p < 0.10$. Older controls committed 11 errors: three ingredient substitution errors (e.g., adding sugar cubes instead of sweetener to cup 2), three ingredient addition errors (e.g., adding coffee to cup 1), two misestimation errors (e.g., pouring too much milk into cup 2), one ingredient omission error (e.g., failing to add milk to cup 2), one sequence anticipation error (e.g., switching the kettle on before pouring water in the kettle), and one sequence omission error (e.g., failing to turn on the kettle). The two errors committed by younger controls were categorised as ingredient substitution errors (adding sugar cubes instead of sweetener to cup 2) and were committed by a single individual.

3.2.2.2. Patients. Patients committed errors in 43% of trials, with a total of 114 errors recorded. Chi square analysis indicated that the difference in error commission between LBD (45%) and RBD patients (39%) was not statistically significant, $\chi^2_{(df=1)} = 0.001$, $p < 0.10$. The number of errors per trials ranged from 0 to 10 (mean errors: LBD = 1.9, RBD = 2.4). LBD and RBD patients were more likely to commit errors that hindered successful task completion in both the first and second trial (overall = 42%, LBD = 45%, RBD = 35%), compared only the first trial (overall = 20%, LBD = 18%, RBD = 26%) or only the second trial (overall = 18%, LBD = 18%, RBD = 17%). This difference was confirmed via Chi square analysis, $\chi^2_{(df=2)} = 6.15$, $p < 0.046$.

In general, the distribution of errors was similar regardless of whether patients had LBD or RBD. Analysis indicated that the most frequently occurring error was that of omission (32%), with patients either failing to add an ingredient to either cup (18%) or omitting a necessary step in the action sequence (14%). Patients also often committed errors of misestimation (27%), by placing too much of too little of an ingredient into either cup. There were also a number of trials in which patients substituted an unnecessary ingredient for a necessary one (substitution = 13%), performed an action earlier than usual (anticipation = 10%) or added an unnecessary ingredient (7%). There was a small number of execution (4%), perseveration (3%), perplexity (3%), quality (1%), toying (1%) and sequence addition (1%) errors. Patients did not commit errors of mislocation.

Next, we compared the predicted errors to those that were actually observed. As can be seen in Figure 3, the number of observed omission errors for both LBD and RBD patients (32% for both groups) was much larger than what was predicted (16.6%). The same pattern of results was obtained for misestimation errors, with a much lower number of predicted errors (9.3%) compared to that observed for LBD (26.3%) and RBD patients (28.9%). Predicted anticipation errors (3.6%) were much lower than that observed for LBD (14.5%), but not RBD patients (0%). We predicted a higher number of substitution and execution errors (24.1% and 16.6%, respectively) than were observed (substitution: LBD = 15.8%, RBD = 7.9%; execution: LBD = 1.3%, RBD = 7.9%). Finally, the number of predicted addition errors (13%) was close to that observed for the RBD patients (10.5%), but slightly higher than that observed for LBD patients (6.6%).

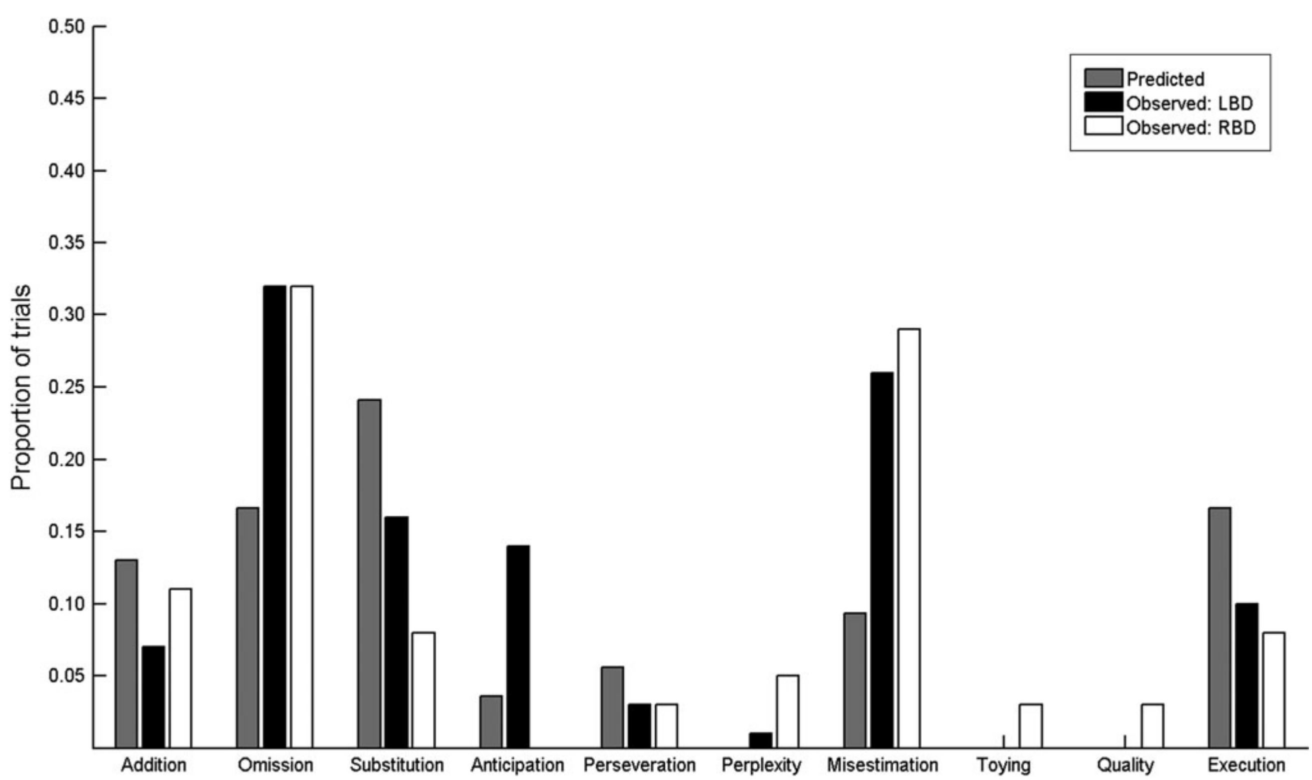

Figure 3. Proportion of errors per trial.

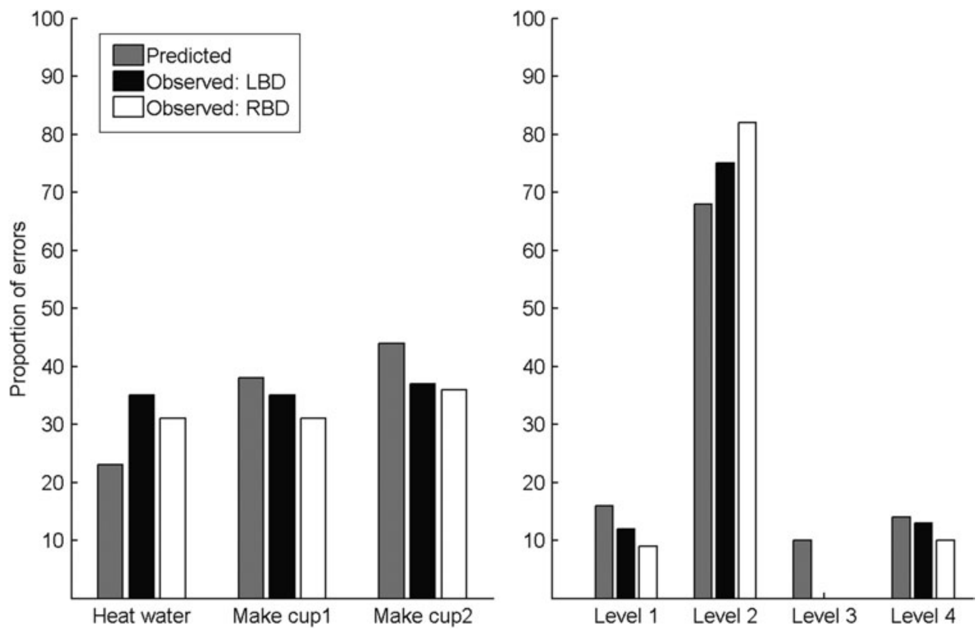

Figure 4. Proportion of predicted and observed errors by classified by sub-task and severity.

Errors committed by patients were also categorised based on sub-task. 35% of errors were performed during the ‘heat water’ sub-task, 35% during the ‘make cup 1’ sub-task, and 37% during the ‘make cup 2’ sub-task. Comparing patient groups, the number of errors was higher for RBD patients during both the ‘heat water’ (LBD = 31%, RBD = 40%) and ‘make cup 1’ sub-tasks (LBD = 31%, RBD = 40%). In contrast, the proportion of errors during ‘make cup 2’ was similar for both groups (LBD = 36%, RBD = 38%). The proportion of predicted and observed errors was similar for all three sub-tasks (Figure 4a).

When errors were classified by error severity, it was evident that the vast majority of errors resulted in a fatal error that prevented the successful completion of the task (level 2, 75%, LBD = 82%, RBD = 69%). There was also a small number of trials involving level 1 (recoverable errors: 12%, LBD = 9%, RBD = 16%) and level 4 (fatal errors that also resulted in potential harm to the user: 13%, LBD = 10, RBD = 16%) There were no recoverable errors that resulted in potential harm to the participant (level 3). LBD patients committed a higher proportion of level 2 errors (difference = 13%), whereas RBD patients committed a slightly higher proportion of level 1 and level 4 errors (difference = 7% and 6%, respectively). As can be seen in Figure 4b, the proportion of predicted and observed errors was similar for all four severity levels.

3.3. *Consequence analysis*

3.3.1. Data analysis

Based on the possible errors identified in the previous section, it was possible to predict the consequences for each specific error (column 5 of Appendix 2). For example, if the participant switched the kettle on without adding water (sequence anticipation error) this would burn out the element in the kettle (consequence). The list of potential consequences was developed by the first author, and reviewed by an assistant familiar with the two-cup tea-making task and trained to use SHERPA. The level of rater agreement was 97%.

3.3.2. Results

SHERPA was particularly useful when the predicted consequences were compared with what was actually observed. With the exception of one error and its associated consequence (switch kettle on an incorrect time which leads to the burn out of the element), all consequences were observed after their respective error occurred (97.3% successful prediction).

3.4. *Error reduction strategies*

Results of the SHERPA analysis allowed us to generate a list of possible error reduction strategies that could implemented by clinicians in the rehabilitation of stroke (column 8 of Appendix 2). These strategies were devised by co-authors from

Headwise, who have extensive clinical experience (>20 years) in occupational therapy and neuropsychological rehabilitation.

Rather than developing techniques for recovery of praxis function, the error reduction strategies outlined in this section involve teaching compensatory techniques for impairments (Buxbaum et al. 2008), and focus on teaching the patient internal and/or external methods to compensate for the impairment (Tempest and Roden 2008). These strategies can be divided into four categories: (1) antecedent control (AC), (2) verbal rehearsal (VR), (3) visual markers (VM) and (4) multimodal prompts (MP). Many of the outlined strategies can be employed for a range of different error types, and can be combined for optimal effectiveness in certain instances.

3.4.1. *Antecedent control*

ADL performance is affected by various factors, including noisy environments (e.g., street noise, too many people in the room) or cluttered workspaces. Therefore, therapy should first consider reducing the potential for errors associated with distractibility and confusion (e.g., ingredient substitution, omission, addition). AC involves reducing events or stimuli that lead to problem behaviours in the task environment (i.e., physical, interpersonal, task-based) or replacing these with triggers for more adaptive behaviours. This is an effective rehabilitation tool for children with attention deficit hyperactivity disorder (ADHD; Powell and Nelson 1997), older individuals with dementia (Spira and Edelstein 2006) and patients with traumatic brain injury (TBI; Wood 1990). In a practical scenario this might entail eliminating auditory interference by turning off the radio before starting an activity or limiting the number of objects on a work surface to only those required for task execution or arranging them in the order that they need should be used to improve sequencing.

In situations where it is impractical to remove all task-irrelevant stimuli, consideration should be given to minimising perceptual and semantically based errors. The more salient or similar an irrelevant stimulus is to a task-critical stimulus the more likely it is to divert task-related processing resources away from the task goal. In a case study involving an individual with apraxia, Morady and Humphreys (2009) examined the influence of semantically related and semantically unrelated distractors on error production. That study found that the patient committed more omission errors when semantically related distractors were present in the workspace, indicating that distractor items/objects that are related, but not necessary, to the task increase the attentional demands required to support task performance. Due to insufficient available resources, patients may be unable to maintain the required action steps in memory, and as such, some of the steps may be omitted. Given the attentional demands necessary to complete many ADL tasks, clinicians should adjust the workspace such that only items necessary to the task are present in the environment, as cluttered work environments may cause the patient to become confused and distracted.

3.4.2. *Verbal rehearsal*

It is widely recognised that at least some errors in everyday actions are due to faulty recall of action scripts (Schwartz 2006), for which interventions based on providing substitute verbal cues should be effective. The term VR covers single word prompts to overcome deficits in planning or initiation of action up to more detailed verbal scripts for complex sequences of behaviour (Wood and Worthington 2001).

3.4.2.1. Single word prompts/mnemonics. Another useful technique by which patients can remember task ingredients or steps is to employ mnemotechniques. Although not a standard rehabilitation technique in patients with apraxia, mnemotechniques are the most frequently used and best-evaluated techniques in memory rehabilitation in various populations, including institutionalised elderly individuals (Piccolini et al. 1992) and patients with TBI (Burke et al. 1991; Cavallini, Pagnin, and Vecchi 2003; van der Linden and Van der Kaa 1989). We believe that this technique would cue memory encoding and retrieval processes required to remember the critical ingredients in a given task. For example, teaching a patient to verbalise the acronym TEA (teabag for each adult) while performing the task can help them remember to add a teabag to a cup.

3.4.2.2. Verbal scripts/songs. Difficulty in recalling the correct sequence of actions (e.g., pouring water into kettle before turning the kettle on) or the ingredients required for the task (e.g., a cup of tea requires a tea bag) may be improved by asking the patient to verbally rehearse what is required for a task (Bickerton, Humphreys, and Riddoch 2006; Wilson 1996). For example, Bickerton, Humphreys, and Riddoch (2006) employed a verbalisation strategy in the rehabilitation of a stroke patient with action disorganisation syndrome (ADS) who showed deficits in ADL performance. The patient was taught a poem that cued the individual steps in making a cup of tea, and trained to recall the script prior to task performance. Results indicated that action sequencing was improved, and that the patient began to self-correct his action errors on trials in which the poem was recalled. There is also anecdotal evidence that popular tunes can be adapted idiosyncratically to provide action cues in sequence that patients can sing or hum as they perform a task. This may have special relevance for apraxic patients with aphasia who may retain singing ability despite losing speech fluency. In another study (Donkervoort et al. 2001), patients with apraxia were taught to self-verbalise their actions during ADL performance. They found that self-verbalisation lead to improved ADL performance compared to standard occupational therapy treatments. However, they also found a relationship between apraxia severity and ADL performance, indicating that self-verbalisation may not be an effective strategy for patients with more severe apraxia.

3.4.2.3. Self-regulation training. For many patients with brain damage, difficulties in carrying out routine daily tasks arise, not from a lack of knowing what to do, but from an inability to put their plans into action. A number of error profiles can be found, but they are essentially characterised by deficits in monitoring and regulating action sequences. This is invariably attributed to limitations of working memory, attentional resources, executive control and self-awareness (Humphreys, Forde, and Riddoch 2001; Schwartz et al. 1999).

Various methods have been used to enhance self-regulation in adults with brain injury, focusing on task goals (Levine et al. 2000) and developing self-awareness (Alderman, Fry, and Youngson 1995). These methods include teaching the patient specific mastery cues such as ‘wait to you hear the kettle whistle/beep before pouring water into the cup’, and training verbalisations such as ‘wait for click, water is hot. If no click, then water is not’. These methods are similar to VR; however, given that there is no guarantee that the patient can execute the task ability when verbalising a script, a therapist should be physically present in early training sessions to ensure the technique is applied appropriately in context, thereby eliminating potentially fatal errors. This involves the therapist articulating the prompts which the patient repeats while they perform the action. The patient learns to repeat the prompts aloud unaided, and in time internalises the sequence. In summary, VR can improve not only errors associated with sequencing (i.e., substitution, omission, addition) but also error monitoring processes in patients who exhibit typical apraxic error profiles.

3.4.3. Visual markers

Another tool that clinicians can use to reduce errors is to make existing visual cues more salient, and introduce novel VM to manipulated objects and tools. VM is a helpful technique that can be used to exaggerate important perceptual cues to improve task performance. Therefore, they should be considered for all patients with low vision problems and higher-order apperceptive deficits. The nature of the cues should be supplemented by phenomenological information regarding the patient and his or her experience, as this undoubtedly also informs the choice of cueing strategy. Thus, for a patient who has difficulty with perceptual discrimination, adding a black line to the inside of the cup will serve to remind them precisely how much water to pour into the cup. The use of this VM may reduce the number of misestimation errors (e.g., not pouring enough water into the kettle). Conversely VM may help override perseverative tendencies and repetition errors by providing more potent cues to inhibit action. Verbal labels, pictures and action symbols should all be considered, depending on the error category.

3.4.4. Multimodal prompts

A therapist will often be required to use a range of prompts and cues to achieve optimal treatment effectiveness. This is because many brain-damaged patients will present with multiple deficits due to the brain lesion impinging upon neighboring anatomical regions that subserve various cognitive functions (e.g., language and object recognition). Consequently, errors may require different forms of cueing and other interventions. Therapists should therefore be familiar with a range of strategies and how to combine these effectively. Virtually any of the aforementioned cues for action could be used in combination with any other. Naturally, as patients progress across the rehabilitation period, it is expected that these techniques will evolve and become more refined.

An increasing number of studies have evaluated the potential benefit of external cuing devices for memory-impaired patients. For example, Evans, Emslie, and Wilson (1998) confirmed the beneficial effect of the pager system on the execution of target tasks in a patient with a severe dysexecutive syndrome (characterised by impaired attention to action, difficulty with action planning and ritual-like dysfunctional behaviours). After introduction of the pager, the patient showed a significant increase in the probability to carry out the target actions on time. Such prompts do not necessarily have to explicitly prompt an action, as the mere process of being alerted can sometimes be sufficient to cue action in dysexecutive patients (Fish et al. 2007).

Auditory prompts can be a particularly effective form of cueing and many of the strategies discussed above rely on verbal feedback. Digital pictures and custom-recorded audio or video messages can provide step-by-step instructional support. Indeed, there is anecdotal evidence that some patients benefit from additional audio cueing (in the form of training scripts and phrases) that they can learn outside the formal therapy sessions and practice each time they engage in specific task. Another form of audio cueing that has been under-researched is the use of environmental sounds to trigger actions (e.g., a pouring sound to accompany an action or a visual prompt). These may be useful in accessing semantic representations for action where visual and verbal access is compromised.

The options for combining cueing techniques are almost limitless, but there are some constraints to bear in mind. Clearly prompts should not conflict with one another (i.e., cueing mutually incompatible actions). In addition, the principle of parsimony should apply, so that multiple prompts should only be used when the combination is demonstrably more effective that either prompt or *any other cue* in isolation. The more prompts used the greater the risk of increasing information processing load beyond the capabilities of the patient. However, there are occasions (e.g., when presented with a marked lack of initiation) where the initial use of multiple prompts is more effective in triggering action patterns, which can be scaled back without loss of performance once the action sequence is learned, as demonstrated by Worthington et al. (1997) in gait retraining after stroke.

4. Discussion

The idea that the breadth of errors committed by brain-damaged patients could be predicted was initially greeted with some skepticism by our research partners. In this paper, while we do not claim that it is possible to predict all possible errors, we have shown that the majority of errors made by LBD and RBD patients were predictable. This finding has the potential to change both the manner in which task performance and difficulties (i.e., errors) are evaluated, and how compensatory strategies are developed.

Overall, SHERPA accurately predicted errors (and their associated consequences) during the performance of daily activities in stroke patients. SHERPA successfully predicted 36 of the 38 observed errors, with analysis indicating that the proportion of predicted and observed errors was similar for all sub-tasks and severity levels. In addition, congruent with prior research (Baber and Stanton 1996) inter-rater reliability values were high (range 90–97%), indicating that analysts were consistent in their classification of error, error severity and sub-goal categorisation.

SHERPA analysis indicated that the pattern of errors was similar regardless of lesion hemisphere (left or right hemisphere). Congruent with previous studies (Bickerton, Humphreys, and Riddoch 2007; De Renzi and Lucchelli 1988; Humphreys and Forde 1998; Schwartz et al. 1998, 1999), the most commonly committed error was that of omission (ingredient omission = 18%, sequence omission errors = 14%), suggested to arise when there are insufficient cognitive resources to support task performance. A particularly interesting result is the high proportion of misestimation errors committed by both patient groups. This finding is interesting, given that previous studies have reported misestimation rates around 1–4% in individuals with CHI, LBD and RBD (Schwartz et al. 1999). It is likely that misestimation errors are more apparent in tasks requiring estimations of ingredients (e.g., amount of water, peanut butter) or article (e.g., scotch/cello tape, toothpaste) compared to those lacking such details (e.g., posting a letter, dressing [Humphreys and Forde 1998; Schwartz et al. 1998]). In comparison to omission and misestimation errors, approximately 10% of errors were of the substitution, anticipation and addition variety. Execution, perseveration, perplexity, quality, toying and sequence errors accounted for less than 13% of total errors.

It has been suggested that errors in ADL performance result from the depletion of attentional resources, which are not bound to any specific location but depend on the integrity of the whole brain (Pick 1905; Schwartz et al. 1998, 1999). The idea that ADL errors are not bound to a specific brain location is supported by research demonstrating similar error proportions in different patient groups: CHI patients (Schwartz et al. 1998), LBD patients (Buxbaum 1998), RBD patients (Schwartz et al. 1999) and dementia patients (Giovannetti et al. 2002). By this resource limitation hypothesis, neurological insult affects the capacity of cognitive resources errors, which are further compounded by the demands of the task and context. Thus, the more severe the resource limitation (due to brain injury and task complexity) the higher the rate of error and ratio of omission to commission errors. In complex tasks, patients may not be able to maintain the activation levels of all of the sub-tasks required to successfully complete the task, and as a result one or more of the steps 'drops out' of the action sequence (Schwartz et al. 1999). Two lines of evidence support the resource limitation hypothesis. First, the competition to select the appropriate object for the action increases when semantic distractor objects are present, which is evidenced by the significantly greater proportion of commission errors when distractors are located on the workspace (Morady and Humphreys 2009). Moreover, studies with neurologically healthy individuals have revealed increased error rates when participants are momentarily distracted during task performance (Humphreys, Forde, and Francis 2000).

A major concern of human reliability analysis (HRA) is to identify performance influencing factors (PIFs, also known as performance shaping factors [PSFs]) that enhance or degrade human performance and provide the basis for considering influence on human performance. PIFs can be classified as internal (i.e., mood, stress level, etc.) or external (i.e., noise, work practices, etc.), and can be directly measured (direct PIF) or determined only through the use of subjective or multivariate measures (indirect). Based on prior work, it is clear that the main PIFs influencing the likelihood and type of errors committed by brain-damaged patients are the presence of neurological insult (Schwartz et al. 1998, 1999), and damage to systems responsible for mechanical problem solving (Spatt et al. 2002) and motor planning (Buxbaum, Johnson-Frey, and Bartlett-Williams 2005; Harrington and Haaland 1992). Known external PIFs include the presence of semantically related distractor items (Morady and Humphreys 2009), and increased task demands (i.e., when performing a secondary task, Forde and Humphreys 2002). It is also likely that other PIFs (e.g., fatigue, stress, time constraints) influence task performance during ADL tasks. Future research should evaluate the extent to which these PIFs influence ADL behaviour in brain-damaged populations using HRA techniques such as HEART (Williams 1988), THERP (Technique for Human Error Rate Prediction; Swain and Guttmann 1983) and ASEP (Accident Sequence Evaluation Program; Swain 1987), as well as other human factors techniques (e.g., task analysis and cognitive task analysis).

It is well known that the rehabilitation of errors arising cognitive, rather than physical, impairments is a significant challenge to clinicians and therapists (see Buxbaum et al. [2008] for a review), and that training is task specific and does not transfer well to other non-trained tasks (Goldenberg, Daumüller, and Hagmann 2001; Goldenberg and Hagmann 1998). Based on the information contained within the HEI outcome table, two SMEs were able to develop a set of compensatory rehabilitation strategies that focus on teaching internal and/or external methods to compensate for the impairment in order to reduce the likelihood of committing an error (Buxbaum et al. 2008). In contrast to the implementation of HEI in neurologically healthy individuals, it was not possible to map error types onto specific rehabilitation strategies, as error types are the final outcome of a complex process, with similar errors having potentially different causes. For example, failing to pour water into the kettle before clicking the on button (sequence omission error) could be due to inattention, forgetfulness or the inability to recognise the function of an object. Indeed, common practice amongst therapists is to intuit the internal and external PIFs that lie behind an error and derive a common sense strategy accordingly. That said, although compensatory strategies were (for the most part) specific to the committed error, it would be possible to revise the HEI table if clinical researchers were to implement the proposed error reduction strategies into their rehabilitation protocol. Such work on a large sample of brain-injured patients might elucidate not only effective error reduction strategies but also whether there exists a link between specific strategies and errors.

SHERPA provided valuable information about severity of the committed error. Video analysis revealed that when consequences were observed, patients either failed to realise that their actions (or lack thereof) resulted in an event that was potentially hazardous to their safety until the experimenter stepped in, or not at all (Humphreys and Forde 1998; Luria 1966). Given that ADL performance by brain-injured patients often leads to safety hazards after hospital discharge (Hanna-Pladdy, Heilman, and Foundas 2003), practitioners could use this information to focus their rehabilitation efforts on errors of higher severity (i.e., fatal errors that also resulted in potential harm to the user, e.g., level 4).

One area of SHERPA that was less effective was the determination of action sequences that resulted in successful task completion in brain-injured participants. Errors of commission (i.e., substitution) were not listed in the two tea-making HTA, and thus trials with fatal errors were not included in the resulting action plan sequence table. Despite this, analysis of action sequencing did provide some useful insights. First, it was observed that control participants and patients used similar sets of action plans during the 'heat water' sub-task, but that during the 'make tea' sub-task control participants preferred one set of action plans, whereas patients preferred another. Second, there was a preference for the two patient groups to favour different action plans during the 'heat water' sub-task, and there was no overlap in action sequence plans during the 'make tea' sub-task, such that LBD patients used one set of action plans, whereas RBD patients used another. Moreover, patients often employed a different action sequence plan for both trials, suggesting a high degree of variability in action sequencing (Hughes et al. 2013). The observation that patient groups favoured different action plans is intriguing, and has to the best of our knowledge, not been reported before.

Based on prior research we expected that SHERPA would be a time-consuming process (Stanton et al. 2006), with analysis taking several hours. In the present study, analysts reported that the determination of the possible errors that could occur and transcription of the action sequence plans were the most time-consuming SHERPA processes. In contrast, determining the consequences of each error and categorising errors by severity level did not take much time. The SMEs also stated that developing the possible error reduction strategies was time consuming, with approximately eight hours required to complete that part of the outcome table. By comparison, analysing the videos did not consume too much time. Each trial was completed within 2–5 minutes, and it took about 10–15 minutes to analyse the plans, errors and consequences contained within that video. Overall, the time required for video analysis decreased with experience, indicating that the time required for analysts to become familiar with and feel comfortable using SHERPA occurred within a few hours.

An acknowledged disadvantage of HEI techniques is that the observed specific errors are specific to the analysed task (Stanton and Young 1999). Furthermore, given that ADL errors in brain-injured populations are highly influenced by the number of objects and steps required for successful task completion the acquired error analysis knowledge is unlikely to generalise to tasks outside of food/beverage preparation. Given the usefulness of SHERPA in accurately predicting errors (and their associated consequences) during the performance of daily activities in stroke patients, it would certainly be worthwhile to evaluate whether SHERPA performs well in other ADL. We believe that food/beverage preparation tasks seem particularly well suited for SHERPA analysis because the ability to successfully complete these tasks have immediate and tangible positive effects on patient independence and well-being, and often involve the use of electronic devices (e.g., kettle, toaster, stovetop) and objects (e.g., knives) that increase safety hazards in the home environment. Furthermore, prior research has examined many different food/beverage preparation tasks (e.g., making tea or coffee, making a sandwich or toast; Bickerton, Humphreys, and Riddoch 2007; Humphreys and Forde 1998; Schwartz et al. 1999), and as such including these sorts of task would afford the opportunity to evaluate error rates across methodologies. That said, it would certainly be worthwhile to apply SHERPA to the examination of task performance in a number of daily activities. In doing so, it would be possible to evaluate whether the proportion of errors (overall, as well as when classified by sub-task and severity) generalise across tasks.

Limitations notwithstanding, using SHERPA we were able to delineate similarities and differences in ADL performance in brain-injured populations that other error categorisation methods have failed to discern. Specifically, results of the present study revealed that patients, regardless of whether they have LBD or RBD, are most likely to commit omission and misestimation errors. In contrast, there are observable differences in action plan sequencing between LBD and RBD patients. In summary, this study suggests that SHERPA is a useful technique to predict errors and subsequent consequences in ADL performance, and that this knowledge can be easily applied to the development of cognitive rehabilitation strategies in brain-damaged populations. Application of SHERPA in similar populations would provide a more complete understanding of the errors associated with ADL performance, and therefore result in the development of more effective error reduction strategies.

References

Alderman, N., R. K. Fry, and H. A. Youngson. 1995. “Improvement of Self-monitoring Skills, Reduction of Behaviour Disturbance and the Dysexecutive Syndrome: Comparison of Response Cost and a New Programme of Self-monitoring Training.” *Neuropsychological Rehabilitation* 5: 193–221.

Annett, J., K. D. Duncan, R. B. Stammers, and M. Gray. 1971. *Task Analysis*. London: HMSO.

Baber, C., and N. A. Stanton. 1996. “Human Error Identification Techniques Applied to Public Technology: Predictions Compared with Observed Use.” *Applied Ergonomics* 27: 119–131.

Bickerton, W. L., G. W. Humphreys, and J. M. Riddoch. 2006. “The Use of Memorized Verbal Scripts in the Rehabilitation of Action Disorganization Syndrome.” *Neuropsychological Rehabilitation* 16 (2): 155–177.

Bickerton, W. L., G. W. Humphreys, and J. M. Riddoch. 2007. “The Case of the Unfamiliar Implement: Schema-Based Over-riding of Semantic Knowledge from Objects in Everyday Action.” *Journal of the International Neuropsychological Society* 13: 1035–1046.

Bligård, L. O., and A. L. Osvalder. 2014. “Predictive Use Error Analysis – Development of AEA, SHERPA and PHEA to Better Predict, Identify and Present Use Errors.” *International Journal of Industrial Ergonomics* 44 (1): 153–170.

Brandstater, M. E. 1990. “An Overview of Stroke Rehabilitation.” *Stroke* 213 (suppl. II): 40–42.

Burke, W. H., A. H. Zenicus, M. D. Wesolowski, and F. Doubleday. 1991. “Improving Executive Function Disorders in Brain-Injured Clients.” *Brain Injury* 5: 241–252.

Buxbaum, L. J. 1998. “Ideational Apraxia and Naturalistic Action.” *Cognitive Neuropsychology* 15: 617–641.

Buxbaum, L. J., K. Y. Haaland, M. Hallett, L. Wheaton, K. M. Heilman, A. Rodriguez, and L. J. Gonzalez Rothi. 2008. “Treatment of Limb Apraxia: Moving Forward to Improved Action.” *American Journal of Physical Medicine and Rehabilitation* 87: 149–161.

Buxbaum, L. J., S. H. Johnson-Frey, and M. Bartlett-Williams. 2005. “Deficient Internal Models for Planning Hand-Object Interactions in Apraxia.” *Neuropsychologia* 43 (6): 917–929.

Cavallini, E., A. Pagnin, and T. Vecchi. 2003. “Aging and Everyday Memory: The Beneficial Effect of Memory Training.” *Archives of Gerontology and Geriatrics* 37 (3): 241–257.

Crawford, J. O., C. Taylor, and N. L. W. Po. 2001. “A Case Study of On-Screen Prototypes and Usability Evaluation of Electronic Timers and Food Menu Systems.” *International Journal of Human Computer Interaction* 13 (2): 187–201.

De Renzi, E., and F. Lucchelli. 1988. “Ideational Apraxia.” *Brain* 111: 1173–1185.

De Renzi, E., A. Pieczuro, and L. A. Vignolo. 1968. “Ideational Apraxia: A Quantitative Study.” *Neuropsychologia* 6: 41–55.

De Renzi, E., G. Scotti, and H. Spinnler. 1969. “Perceptual and Associative Disorders of Visual Recognition.” *Neurology* 19: 634–642.

Donkervoort, M., J. Dekker, F. C. Stehmann-Saris, and B. G. Dellman. 2001. “Efficacy of Strategy Training in Left Hemisphere Stroke Patients with Apraxia: A Randomised Clinical Trial.” *Neuropsychological Rehabilitation* 11: 549–566.

Embrey, D. 1986. “SHERPA: A Systematic Human Error Reduction and Prediction Approach.” Proceedings of the International Topical Meeting on Advances in Human Factors in Nuclear Power Systems, Knoxville, Tennessee.

Evans, J. J., H. Emslie, and B. A. Wilson. 1998. “External Cueing Systems in the Rehabilitation of Executive Impairments of Action.” *Journal of the International Neuropsychological Society* 4: 399–408.

Fish, J., J. J. Evans, M. Nimmo, D. Kersel, A. Bateman, B. A. Wilson, and T. Manly. 2007. "Rehabilitation of Executive Dysfunction Following Brain Injury: 'Content-Free' Cueing Improves Everyday Prospective Memory Performance." *Neuropsychologia* 45: 1318–1330.

Forde, E. M. E., and G. W. Humphreys. 2002. "Dissociation of Routine Behaviour Across Patients and Everyday Tasks." *Neurocase* 8: 151–167.

Gainotti, G., and M. A. Lemmo. 1976. "Comprehension of Symbolic Gestures in Aphasia." *Brain and Language* 3: 451–460.

Giaquinto, S., S. Buzzelli, L. Di Francesco, A. Lottarini, P. Montenero, P. Tonin, and G. Nolfe. 1999. "On the Prognosis of Outcome After Stroke." *Acta Neurologica Scandinavica* 100 (3): 202–208.

Giovannetti, T., D. J. Libon, L. J. Buxbaum, and M. F. Schwartz. 2002. "Naturalistic Action Impairments in Dementia." *Neuropsychologia* 40: 1220–1232l.

Giovannetti, T., M. F. Schwartz, and L. J. Buxbaum. 2007. "The Coffee Challenge: A New Method for the Study of Everyday Action Errors." *Journal of Clinical and Experimental Neuropsychology* 29 (7): 690–705.

Goldenberg, G., M. Daumüller, and S. Hagmann. 2001. "Assessment and Therapy of Complex Activities of Daily Living in Apraxia." *Neuropsychological Rehabilitation* 11: 147–169.

Goldenberg, G., and S. Hagmann. 1998. "Tool Use and Mechanical Problem Solving in Apraxia." *Neuropsychologia* 36: 581–589.

Hanna-Pladdy, B., K. M. Heilman, and A. L. Foundas. 2003. "Ecological Implicates of Ideomotor Apraxia: Evidence from Physical Activities of Daily Living." *Neurology* 60: 487–490.

Harrington, D. L., and K. Y. Haaland. 1992. "Motor Sequencing with Left Hemisphere Damage: Are Some Cognitive Deficits Specific to Limb Apraxia?" *Brain* 115: 857–874.

Harris, D., N. A. Stanton, A. Marshall, M. S. Young, J. Demagalski, and P. Salmon. 2005. "Using SHERPA to Predict Design-Induced Error on the Flight Deck." *Aerospace Science and Technology* 9 (6): 525–532.

Hartmann, K., G. Goldenberg, M. Daumueller, and J. Hermsdörfer. 2005. "It Takes the Whole Brain to Make a Cup of Coffee: The Neuropsychology of Naturalistic Actions Involving Technical Devices." *Neuropsychologia* 43: 625–637.

Hughes, C. M. L., M. Tenorth, M. Bienkiewicz, and J. Hermsdörfer. 2013. "Action Sequencing and Error Production in Stroke Patients with Apraxia: Behavioral Modeling Using Bayesian Logical Networks." HEALTHINF2013; 6th International Conference on Health Informatics.

Humphreys, G. W., and E. M. E. Forde. 1998. "Disordered Action Schema and Action Disorganisation Syndrome." *Cognitive Neuropsychology* 15: 771–811.

Humphreys, G. W., E. M. E. Forde, and D. Francis. 2000. "The Organization of Sequential Actions." In *Control of Cognitive Processes: Attention and Performance XVIII*, edited by Stephen Monsell and Jon Driver, 427–442. Cambridge, MA: MIT Press.

Humphreys, G. W., E. M. E. Forde, and M. J. Riddoch. 2001. "The Planning and Execution of Everyday Actions." In *The Handbook of Cognitive Neuropsychology*, edited by B. Rapp, 565–589. Philadelphia: Psychology Press.

Jongbloed, L. 1986. "Prediction of Function after Stroke: A Critical Review." *Stroke* 17: 765–776.

Kirwan, B. 1992a. "Human Error Identification in Human Reliability Assessment. Part 1: Overview of Approaches." *Applied Ergonomics* 23: 299–318.

Kirwan, B. 1992b. "Human Error Identification in Human Reliability Assessment. Part 2: Detailed Comparison of Techniques." *Applied Ergonomics* 23: 371–381.

Kirwan, B. 1994. *A Guide to Practical Human Reliability Assessment*. London: Taylor & Francis.

Lane, R., N. A. Stanton, and D. Harrison. 2006. "Applying Hierarchical Task Analysis to Medication Administration Errors." *Applied Ergonomics* 37 (5): 669–679.

Lawrence, E. S., C. Coshall, R. Dundas, J. Stewart, A. G. Rudd, R. Howard, and C. D. Wolfe. 2001. "Estimates of the Prevalence of Acute Stroke Impairments and Disability in a Multiethnic Population." *Stroke* 32 (6): 1279–1284.

Levine, B., I. H. Robertson, L. Clare, G. Carter, J. Hong, B. A. Wilson, J. Duncan, and D. T. Stuss. 2000. "Rehabilitation of Executive Functioning: An Experimental-Clinical; Validation of Goal Management Training." *Journal of the International Neuropsychological Society* 6: 299–312.

Luria, A. R. 1966. *Higher Cortical Functions in Man*. London: Tavistock.

Marshall, A., N. Stanton, M. Young, P. Salmon, D. Harris, J. Demagalski, T. Waldmann, and S. Dekker. 2003. *Development of the Human Error Template – A New Methodology for Assessing Design Induced Errors on Aircraft Flight Decks. Final Report of the ERRORPRED Project E! 1970*. London: Department of Trade and Industry.

Morady, K., and G. Humphreys. 2009. "Comparing Action Disorganization Syndrome and Dual-Task Load on Normal Performance in Everyday Action Tasks." *Neurocase* 15: 1–12.

Mysiw, W. J., J. G. Beegan, and P. F. Gatens. 1989. "Prospective Cognitive Assessment of Stroke Patients before Inpatient Rehabilitation: The Relationship of the Neurobehavioral Cognitive Status Examination to Functional Improvement." *American Journal of Physical Medicine and Rehabilitation* 68: 168–171.

O'Sullivan, O., A. Aboulafia, G. Iohom, B. D. O'Donnell, and G. D. Shorten. 2011. "Proactive Error Analysis of Ultrasound-Guided Axillary Brachial Plexus Block Performance." *Regional Anesthesia and Pain Medicine* 36 (5): 502–507.

Özdemir, F., M. Birtane, R. Tabatabai, G. Ekuklu, and S. Kokino. 2001. "Cognitive Evaluation and Functional Outcome after Stroke." *American Journal of Physical Medicine & Rehabilitation* 80: 410–415.

Phipps, D., G. H. Meakin, P. C. W. Beatty, C. Nsoedo, and D. Parker. 2008. "Human Factors in Anaesthetic Practice: Insights from a Task Analysis." *British Journal of Anaesthesia* 100 (3): 333–343.

Piccolini, C., L. Amadio, L. Spazzafumo, S. Moroni, and A. Freddi. 1992. "The Effects of a Rehabilitation Program with Mnemotechniques on the Institutionalized Elderly Subject." *Archives of Gerontology and Geriatrics* 15: 141–149.

Pick, A. 1905. *Studien zur motorischen Apraxia und ihr nahestende Erscheinungen; ihre Bedeutung in der Symptomatologie psychopathischer Symptomenkomplexe*. Leipzig und Wien: Franz Deuticke.

Poeck, K., and G. Lehmkuhl. 1980. "Ideatory Apraxia in a Left-Handed Patient with Right-Sided Brain Lesion." *Cortex* 16: 273–284.

Powell, S., and B. Nelson. 1997. "Effects of Choosing Academic Assignments on a Student with Attention Deficit Hyperactivity Disorder." *Journal of Applied Behavior Analysis* 30 (1): 181–183.

American Heart Association Statistics Committee and Stroke Statistics Subcommittee, W. Rosamond, K. Flegal, K. Furie, A. S. Go, K. Greenlund, N. Haase, S. M. Hailpern, et al. 2008. "Heart Disease and Stroke Statistics-2008 Update: A Report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee." *Circulation* 117 (4): e25–e146.

Rumiati, R. I., S. Zanini, L. Vorano, and T. Shallice. 2001. "A Form of Ideational Apraxia as a Selective Deficit of Contention Scheduling." *Cognitive Neuropsychology* 18: 617–642.

Schwartz, M. F. 2006. "The Cognitive Neuropsychology of Everyday Action and Planning." *Cognitive Neuropsychology* 23 (1): 202–221.

Schwartz, M. F., L. J. Buxbaum, M. W. Montgomery, E. Fitzpatrick-DeSalme, T. Hart, M. Ferraro, S. S. Lee, and H. B. Coslett. 1999. "Naturalistic Action Production Following Right Hemisphere Stroke." *Neuropsychologia* 37: 51–66.

Schwartz, M. F., M. W. Montgomery, L. J. Buxbaum, S. S. Lee, T. G. Carew, H. B. Coslett, M. Ferraro, E. Fitzpatrick-DeSalme, T. Hart, and N. Mayer. 1998. "Naturalistic Action Impairment in Closed Head Injury." *Neuropsychology* 12: 13–28.

Schwartz, M. F., M. W. Montgomery, E. Fitzpatrick-DeSalme, C. Ochipa, B. Coslett, and N. H. Mayer. 1995. "Analysis of a Disorder of Everyday Action." *Cognitive Neuropsychology* 12: 863–892.

Schwartz, M. F., E. S. Reed, M. Montgomery, C. Palmer, and N. H. Mayer. 1991. "The Quantitative Description of Action Disorganization after Brain-Damage – A Case-Study." *Cognitive Neuropsychology* 8: 381–414.

Schwartz, M. F., M. Segal, T. Veramonti, M. Ferraro, and L. J. Buxbaum. 2002. "The Naturalistic Action Test: A Standardised Assessment for Everyday Action Impairment." *Neuropsychologica Rehabiliation: An International Journal* 12 (4): 311–339.

Shorrock, S. T., and B. Kirwan. 2000. "Development and Application of a Human Error Identification Tool for Air Traffic Control." *Applied Ergonomics* 33: 319–336.

Spatt, J., T. Bak, S. Bozeat, K. Patterson, and J. Hodges. 2002. "Apraxia, Mechanical Problem Solving and Semantic Knowledge: Contributions to Object Usage in Corticobasal Degeneration." *Journal of Neurology* 249: 601–608.

Spira, A. P., and B. A. Edelstein. 2006. "Behavioral Interventions for Agitation in Older Adults with Dementia: An Evaluative Review." *International Psychogeriatrics* 18 (2): 195–225.

Stanton, N. A., D. Harris, P. M. Salmon, J. M. Demagalski, A. Marshall, M. S. Young, S. W. A. Dekker, and T. Waldmann. 2006. "Predicting Design Induced Pilot Error Using HET (Human Error Template) – A New Formal Human Error Identification Method for Flight Decks." *Aeronautical Journal* 110 (1104): 107–115.

Stanton, N. A., and S. V. Stevenage. 1998. "Learning to Predict Human Error: Issues of Acceptability, Reliability and Validity." *Ergonomics* 41 (11): 1737–1756.

Stanton, N. A., and J. Wilson. 2000. "Human Factors: Step Change Improvements in Effectiveness and Safety." *Drilling Contractor* Jan./Feb.: 36–41.

Stanton, N. A., and M. Young. 1999. *A Guide to Methodology in Ergonomics: Designing for Human Use*. London: Taylor & Francis.

Stephens, S., R. A. Kenny, E. Rowan, R. N. Kalaria, M. Bradbury, R. Pearce, K. Wesnes, and C. G. Ballard. 2005. "Association between Mild Vascular Cognitive Impairment and Impaired Activities of Daily Living in Older Stroke Survivors without Dementia." *Journal of the American Geriatrics Society* 53 (1): 103–107.

Swain, A. D. 1987. *Accident Sequence Evaluation Program: Human Reliability Analysis Procedure*. Albuquerque, NM: Sandia National Labs.

Swain, A. D., and H. E. Guttmann. 1983. *Handbook of Human-Reliability Analysis with Emphasis on Nuclear Power Plant Applications*. Final Report. Albuquerque, NM: Sandia National Labs.

Tatemichi, T. K., D. W. Desmond, Y. Stern, M. Paik, M. Sano, and E. Bagiella. 1994. "Cognitive Impairment after Stroke: Frequency, Patterns, and Relationship to Functional Abilities." *Journal of Neurology, Neurosurgery, and Psychiatry* 57: 202–207.

Tempest, S., and P. Roden. 2008. "Exploring Evidence-Based Practice by Occupational Therapists when Working with People with Apraxia." *The British Journal of Occupational Therapy* 71 (1): 33–37.

Vaina, L. M., H. Goodglass, and L. Daltroy. 1995. "Inference of Object Use from Pantomimed Actions by Aphasics and Patients with Right Hemisphere Lesions." *Synthese* 104: 43–57.

Van der Linden, M., and M. Van der Kaa. 1989. "Reorganization Therapy for Memory Impairments." In *Cognitive Approaches in Neuropsychological Rehabilitation*, edited by X. Seron, and G. Deloche, 105–158. New York: Lawrence Erlbaum Associates.

Varney, N. R. 1978. "Linguistic Correlates of Pantomime Recognition in Aphasic Patients." *Journal of Neurology, Neurosurgery, and Psychiatry* 41: 564–568.

Williams, J. C. 1986. "HEART – A Proposed Method for Assessing and Reducing Human Error." In 9th Advances in Reliability Technology Symposium, University of Bradford.

Williams, J. C. 1988. "A Data-Based Method for Assessing and Reducing Human Error to Improve Operational Performance." In *Conference Record for 1988 IEEE Fourth Conference on Human Factors and Power Plants, 1988,* Monterey, CA, USA, June 5–9, 436–450. IEEE. doi:10.1109/HFPP.1988.27540.

Wilson, B. A. 1996. "A Practical Framework for Understanding Compensatory Behaviour in People with Organic Memory Impairment." *Memory* 4 (5): 465–486.

Wood, R. L. 1990. "Conditioning Procedures in brain injury rehabilitation." In *Neurobehavioural Sequelae of Traumatic Brain Injury*, edited by R. L. Wood, 153–174. London: Taylor & Francis.

Wood, R. L., and A. D. Worthington. 2001. "Neurobehavioural Rehabilitation in Practice." In *Neurobehavioural Disability and Social Handicap Following Traumatic Brain Injury*, edited by R. L. Wood, and T. M. McMillan, 133–155. Hove: Psychology Press.

Worthington, A., C. Williams, K. Young, and J. Pownall. 1997. "Re-training Gait Components for Walking in the Context of Abulia." *Physiotherapy Theory and Practice* 13: 247–256.

Appendix 1. Observed action sequences that resulted in successful task completion for the two-cup tea-making task

Plan no.	Action sequence	Control (young, old)	Patients (LBD, RBD)
Heat water			
1a	1.1 > 1.2 > 1.3 > 1.4 > 1.5 > 1.6 > 1.7 > exit	21 (12, 9)	8 (7, 1)
1b	1.1 > 1.2 > 1.3 > 1.4 > 1.5 > 1.7 > 1.6 > exit	14 (3, 11)	1 (1, 0)
1c	1.1 > 1.2 > 1.3 > 1.4 > 1.7 > 1.5 > 1.6 > exit	5 (2, 3)	9 (4, 5)
1d	1.2 > 1.1 > 1.3 > 1.4 > 1.5 > 1.6 > 1.7 > exit		2 (0, 2)
1e	1.2 > 1.1 > 1.3 > 1.4 > 1.5 > 1.7 > 1.6 > exit	7 (7, 0)	1 (0, 1)
1f	1.2 > 1.1 > 1.3 > 1.4 > 1.7 > 1.5 > 1.6 > exit	5 (1, 4)	5 (4, 1)
1g	1.2 > 1.3 > 1.1 > 1.4 > 1.5 > 1.6 > 1.7 > exit	1 (0, 1)	5 (5, 0)
1h	1.2 > 1.3 > 1.1 > 1.4 > 1.5 > 1.7 > 1.6 > exit	13 (5, 8)	2 (1, 1)
1i	1.2 > 1.3 > 1.1 > 1.4 > 1.7 > 1.5 > 1.6 > exit	6 (3, 3)	2 (1, 1)
1j	1.6 > 1.1 > 1.2 > 1.3 > 1.4 > 1.5 > 1.7 > exit		1 (1, 0)
Make tea			
2a	2.1 > 2.2 > 2.3 > 2.4 > 3.1 > 3.2 > 3.3 > 3.4 > 3.5 > exit	1 (0, 1)	1 (0, 1)
2b	2.1 > 2.2 > 2.3 > 2.4 > 3.2 > 3.1 > 3.3 > 3.4 > 3.5 > exit	3 (1, 2)	
2c	2.1 > 2.2 > 2.3 > 2.4 > 3.2 > 3.1 > 3.4 > 3.5 > 3.3 > exit	2 (1, 1)	
2d	2.1 > 2.2 > 2.3 > 3.2 > 2.4 > 3.1 > 3.3 > 3.4 > 3.5 > exit	1 (1, 0)	
2e	2.1 > 2.2 > 2.4 > 2.3 > 3.2 > 3.1 > 3.4 > 3.5 > 3.3 > exit	2 (2, 0)	
2f	2.1 > 2.3 > 2.4 > 3.2 > 3.3 > 3.4 > 3.5 > 2.2 > 3.1 > exit	1 (1, 0)	
2g	2.1 > 2.4 > 3.2 > 3.4 > 3.5 > 2.2 > 3.1 > 2.3 > 3.3 > exit	1 (0, 1)	
2h	2.1 > 2.4 > 2.2 > 2.3 > 3.2 > 3.4 > 3.5 > 3.1 > 3.3 > exit	2 (1, 1)	
2i	2.1 > 3.1 > 2.4 > 3.4 > 3.5 > 2.2 > 3.1 > 2.3 > 3.3 > exit	1 (0, 1)	
2j	2.1 > 3.2 > 2.2 > 2.3 > 2.4 > 3.1 > 3.3 > 3.4 > 3.5 > exit	1 (0, 1)	1 (0, 1)
2k	2.1 > 3.2 > 2.2 > 2.4 > 2.3 > 3.1 > 3.4 > 3.5 > 3.3 > exit	1 (0, 1)	
2l	2.1 > 3.2 > 2.2 > 3.1 > 2.3 > 2.4 > 3.4 > 3.5 > 3.3 > exit	2 (0, 2)	
2m	2.1 > 3.2 > 2.2 > 3.1 > 2.4 > 2.3 > 3.3 > 3.4 > 3.5 > exit	1 (1, 0)	1 (1, 0)
2n	2.1 > 3.2 > 2.2 > 3.1 > 2.4 > 2.3 > 3.4 > 3.5 > 3.3 > exit	1 (0, 1)	
2o	2.1 > 3.2 > 2.2 > 3.1 > 2.2 > 2.4 > 2.3 > 3.3 > 3.4 > 3.5 > exit	1 (0, 1)	1 (0, 1)
2p	2.1 > 3.2 > 2.2 > 3.1 > 2.3 > 2.4 > 3.3 > 3.4 > 3.5 > exit		1 (1, 0)
2q	2.1 > 3.2 > 2.2 > 3.1 > 2.3 > 3.3 > 3.4 > 3.5 > 2.4 > exit		1 (1, 0)
2r	2.1 > 3.2 > 2.3 > 2.4 > 3.3 > 3.4 > 3.5 > 2.2 > 3.1 > exit		1 (1, 0)
2s	2.1 > 3.2 > 2.3 > 2.4 > 3.4 > 3.5 > 2.2 > 3.1 > 3.3 > exit	2 (2, 0)	
2t	2.1 > 3.2 > 2.3 > 2.4 > 3.4 > 3.5 > 3.3 > 2.2 > 3.1 > exit		1 (1, 0)
2u	2.1 > 3.2 > 2.4 > 2.3 > 3.3 > 3.4 > 3.5 > 2.2 > 3.1 > exit		1 (0, 1)
2v	2.1 > 3.2 > 2.4 > 3.4 > 3.5 > 2.2 > 3.1 > 2.3 > 3.3 > exit		2 (0, 2)
2w	2.1 > 3.2 > 2.4 > 3.4 > 3.5 > 2.3 > 3.3 > 2.2 > 3.1 > exit	3 (2, 1)	
2x	2.1 > 3.2 > 2.4 > 3.4 > 3.5 > 3.3 > 2.3 > 2.2 > 3.1 > exit	1 (1, 0)	1 (1, 0)
2y	2.1 > 3.2 > 3.3 > 3.4 > 3.5 > 2.3 > 2.4 > 2.2 > 3.1 > exit		1 (1, 0)
2z	2.1 > 3.2 > 3.3 > 3.4 > 3.5 > 2.4 > 2.3 > 3.1 > 3.2 > exit	1 (1, 0)	1 (0, 1)
2aa	2.1 > 3.2 > 3.4 > 3.5 > 2.3 > 2.2 > 3.1 > 3.3 > 2.4 > exit	1 (1, 0)	
2ab	2.1 > 3.2 > 3.4 > 3.5 > 2.4 > 2.2 > 2.3 > 3.2 > 3.3 > exit	2 (2, 0)	
2ac	2.1 > 3.2 > 3.4 > 3.5 > 2.4 > 2.2 > 3.1 > 2.3 > 3.3 > exit	2 (2, 0)	
2ad	2.1 > 3.2 > 3.4 > 3.5 > 3.3 > 3.1 > 2.2 > 2.4 > 2.3 > exit		1 (1, 0)
2ae	2.2 > 2.4 > 3.1 > 3.2 > 2.4 > 2.3 > 3.4 > 3.5 > 3.3 > exit	3 (0, 3)	
2af	2.2 > 3.1 > 2.1 > 2.4 > 2.3 > 3.2 > 3.3 > 3.4 > 3.5 > exit		1 (1, 0)
2ag	2.2 > 3.1 > 2.1 > 2.4 > 3.2 > 3.4 > 3.3 > 2.3 > 3.5 > exit		1 (1, 0)
2ah	2.2 > 3.1 > 2.1 > 2.4 > 2.3 > 3.2 > 3.4 > 3.5 > 3.3 > exit		1 (1, 0)
2ai	2.3 > 3.2 > 2.2 > 3.1 > 2.2 > 2.3 > 2.4 > 3.3 > 3.4 > 3.5 > exit		1 (1, 0)
2aj	2.4 > 2.2 > 2.1 > 2.3 > 3.1 > 3.2 > 3.4 > 3.5 > 3.3 > exit	1 (0, 1)	
2ak	2.4 > 2.3 > 2.1 > 2.2 > 3.2 > 3.3 > 3.4 > 3.5 > 3.1 > exit		2 (2, 0)
2al	2.4 > 2.3 > 3.3 > 3.4 > 3.5 > 2.2 > 3.1 > 2.1 > 3.2 > exit	1 (1, 0)	1 (1, 0)
2am	2.4 > 3.4 > 3.5 > 2.1 > 3.2 > 2.2 > 3.1 > 2.3 > 3.3 > exit	2 (2, 0)	
2an	2.4 > 3.4 > 3.5 > 2.3 > 3.3 > 2.1 > 3.2 > 2.2 > 3.1 > exit	1 (0, 1)	1 (1, 0)
2ao	3.2 > 2.1 > 2.2 > 3.1 > 2.4 > 2.3 > 3.4 > 3.5 > 3.3 > exit	1 (1, 0)	1 (1, 0)
2ap	3.2 > 2.1 > 3.3 > 3.4 > 3.5 > 2.4 > 2.3 > 2.2 > 2.3 > exit		1 (0, 1)
2aq	3.2 > 2.1 > 2.2 > 3.1 > 2.4 > 2.3 > 3.3 > 3.4 > 3.5 > exit	2 (0, 2)	
2ar	3.2 > 2.1 > 2.3 > 2.4 > 3.4 > 3.5 > 3.3 > 2.2 > 3.1 > exit	4 (0, 4)	1 (1, 0)
2as	3.2 > 2.1 > 2.4 > 2.3 > 3.4 > 3.5 > 3.3 > 2.2 > 3.1 > exit	1 (0, 1)	
2at	3.2 > 2.1 > 2.4 > 3.4 > 3.5 > 2.3 > 3.1 > 2.2 > 3.3 > exit	1 (0, 1)	
2au	3.2 > 2.1 > 3.1 > 2.2 > 3.4 > 3.5 > 2.3 > 2.4 > 3.3 > exit	1 (0, 1)	
2av	3.2 > 2.1 > 3.4 > 3.5 > 3.1 > 2.2 > 3.3 > 2.3 > 2.4 > exit	1 (0, 1)	1 (1, 0)
2aw	3.2 > 2.1 > 3.4 > 3.5 > 2.4 > 2.3 > 3.1 > 2.1 > 3.3 > exit		1 (0, 1)
2ax	3.2 > 2.1 > 2.4 > 3.4 > 3.5 > 3.3 > 2.3 > 2.2 > 3.1 > exit	3 (0, 3)	

Appendix 1 – *continued*

Plan no.	Action sequence	Control (young, old)	Patients (LBD, RBD)
2ay	3.2 > 2.1 > 3.4 > 3.5 > 2.4 > 2.2 > 3.1 > 2.3 > 3.3 > exit	1 (1, 0)	
2az	3.2 > 3.4 > 3.5 > 2.1 > 2.4 > 2.3 > 3.1 > 2.2 > 3.3 > exit	1 (1, 0)	
2ba	3.4 > 3.5 > 2.4 > 2.1 > 3.2 > 2.2 > 3.1 > 2.3 > 3.3 > exit	1 (1, 0)	
2bb	3.4 > 3.5 > 2.4 > 2.1 > 3.2 > 2.2 > 3.1 > 3.3 > 2.3 > exit	1 (1, 0)	
2bc	3.4 > 3.5 > 2.4 > 2.3 > 3.1 > 2.2 > 3.2 > 2.1 > 3.3 > exit		1 (1, 0)

Note: The ‘ > ’ signifies ‘followed by’ to indicate sequence, numbers indicates the sub-task in the hierarchy, and text indicates ‘conditions’.

Appendix 2. Outcome of human error analysis using the SHERPA method.

Task step	Description	Error category	Error severity	Consequence	No. of trials, LBD	No. of trials, RBD	Error reduction strategies
1: Heat water	Pour water directly from jug into either cup 1 or 2	AN	2	Tea ingredients will not fully infuse	6	1	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance, AC: Reduce number of objects on workspace to decrease cognitive demands
	Fail to put water into kettle	SO	4	Unable to heat water	5	4	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Pour water from kettle without water in kettle	AN	2	No water will pour from kettle	4	2	MP: Before initiation of each action step. VR: Rehearse action sequence before task performance. Self-regulation training to encourage evaluation
1.4: Pour water into kettle	Not pouring enough water into kettle	ME	1	Unable to make 2 full cups of tea	9	7	VM: Add black line to the inside of cup indicating how much water is required
	Pour water onto table	ML	4	Cup contents spilled onto table and/or person	0	1	AC: place kettle close to water source VM: Visual prompt or verbal label indicating action VR: Patient verbalises script while performing action
1.5: Close kettle lid	Fail to close kettle lid	SO	2	Steam may burn the person, water could spill onto table	0	1	MP: Before initiation of each action step
1.6: Switch kettle on	Switch kettle on at incorrect time (e.g., without water)	SA	4	Possible kettle element burn out	5	1	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Fail to click kettle heat button	SO	2	Unable to heat water	3	1	MP of key indicators (e.g., light on, sound) that patient should attend to. Auditory prompt after 30 seconds to check kettle was switched on
2: Cup 1	Add coffee into cup 1	AD	2	Incorrect ingredient added	0	1	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
2.1: Add teabag to cup	Fail to add teabag to cup 1	IO	2	Required ingredient not added	5	2	VR: Rehearse action sequence before task performance, use *TEA* mnemotechnique
	Add coffee instead of tea bag to cup 1	IS	2	Incorrect ingredient added, Required ingredient not added	4	0	AC: Remove tea if only coffee being made VM: Increase salience of target ingredient VR: Verbalise action script during performance
2.2: Pour heated water into cup 1	Not pouring enough water into cup 1	MIS	2	A full cup of tea will not be made	9	2	VM: Add line near rim of cup indicating fill level
	Pantomimed pouring water from kettle into cup 1	PA	2	Required ingredient not added Tea ingredients will not fully infuse	1	0	VR: Self-monitoring script to include checking water is in cup
	Pour water onto table	EX	4	Cup contents spilled onto table and/or person	0	1	AC: Place cup on absorbent surface VR: Patient verbalises checking routine

Appendix 2 – *continued*

Task step	Description	Error category	Error severity	Consequence	No. of trials, LBD	No. of trials, RBD	Error reduction strategies
2.3: Add lemon slice to cup 1	Add more than one lemon slice to cup 1	ME	2	Tea will be too lemon flavoured, Unable to complete task	2	0	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Add lemon to non-cup 1 object	ML	2	Incorrect ingredient added, Required ingredient not added	2	1	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Fail to add lemon slice to cup 1	IO	2	Required ingredient not added	6	1	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Remove lemon from cup 1 immediately after adding	IR	2	Lemon flavour will not infuse tea will have incorrect taste	1	0	VR: Rehearse action sequence before task; verbal script to include cue to leave in lemon *'don't forget lemon slice, leave it in so tea tastes nice'*
2.4: Add sugar to cup 1	Add more than one sugar cube to cup 1	PER	2	Incorrect ingredient added	2	2	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Add sweetener instead of sugar	IS	2	Incorrect ingredient added, Required ingredient not added	1	0	VR: Rehearse action sequence before task performance
	Fail to add sugar to cup 1	IO	2	Required ingredient not added, tea will have incorrect taste	2	0	VM: Visual cue to indicate which cup needs sugar; VR: Script to include cue to add sugar.
3: Cup 2	Add sugar to cup 2	AD	2	Incorrect ingredient added, tea will have incorrect taste	1	1	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Add lemon slice to cup 2	AD	2	Incorrect ingredient added, tea will have incorrect taste	0	1	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
3.1: Add teabag to cup	Fail to add teabag to cup 2	IO	2	Required ingredient not added	5	1	VR: Rehearse action sequence before task performance, use *TEA* mnemotechnique
	Add coffee instead of tea bag to cup 2	IS	2	Incorrect ingredient added, Required ingredient not added	5	0	AC: Remove tea if only coffee being made VM: Increase salience of target ingredient VR: Verbalise action script during performance
	Ripping open tea bag and pouring leaves into cup 2	Q	2	Tea leaves will infuse water but make the tea hard to drink	0	1	MP: Picture cues, written prompts on box of tea bags, VR beforehand, SR script: 'tea tastes better sipped, when the tea bag isn't ripped'
3.2: Pour heated water into cup 2	Not pouring enough water into cup 2	ME	2	A full cup of tea will not be made	9	2	VM: Add line near rim of cup indicating fill level
	Fail to pour water into cup 2	SO	2	Required ingredient not added	1	0	VR: Self-monitoring script to include checking water is in cup
3.3: Add milk to cup 2	Pour too much milk into cup 2	ME	2	Tea ingredients will not fully infuse	2	0	AC: modify flow of milk from container VM: Add line to cup indicating fill level

	Pour milk into non-cup 2 object (e.g., cup 1)	OS	2	Milk placed in incorrect object	1	0	VM: Label/symbol on cup indicating action to be performed VR: Patient rehearses, then verbalises action
	Adding Milk after already doing so	PER	2	Tea will have incorrect taste	2	1	VR: Rehearse action beforehand and verbalise script during task including prompt to check if milk already added. Once added, cue needed to replace milk.
	Fail to add milk to cup 2	IO	2	Required ingredient not added	2	1	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Put lemon in cup 2 instead of milk	IS	2	Incorrect ingredient added, Required ingredient not added	0	1	MP: Before initiation of each action step, including visual cues, VR: Rehearse action sequence before task performance
3.4/3.5: Add sweetener to cup 2	Add only one sweetener tablet to cup 2	ME	2	Incorrect ingredient added	1	1	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Add more than two sweetener tablets to cup 2	ME	2	Incorrect ingredient added	0	1	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Add sugar instead of sweetener	IS	2	Incorrect ingredient added, Required ingredient not added	4	0	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Fail to add sweetener to cup 2	IS	2	Required ingredient not added	4	5	MP: Before initiation of each action step, VR: Rehearse action sequence before task performance
	Spilled the 2nd sweetener on the table	EX	2	Contents spilled onto table and/or person	0	1	AC: Ensure clutter-free work surface VR: Script to include a check that sufficient sweetener added to drink VR/VC: Prompt to check spillages cleaned at end