Virtual reality and stroke rehabilitation: a tangible interface to an every day task

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ABSTRACT

At the University of Nottingham, UK, a project is currently in progress which is exploring the application of virtual environments for supporting stroke rehabilitation. The project has focussed on a user centred design approach and has involved consultation with stroke survivors, therapists and stroke researchers. Seminars held during the initial phase of the project offered an insight into the priorities and perspectives of these individuals, from which we identified the activity of making a hot drink as a suitable every day task to study. Although the longer term aim is to investigate a possible role of a virtual environment to support the rehabilitation of a sequential task, our immediate concern is to select a method of interacting with the virtual environment, which is both appropriate and acceptable for stroke survivors. Responding to a preference for naturalistic action and realistic scenarios, a tangible user interface to a hot drink making activity was piloted with stroke survivors resident in the community. The results of this study have improved our understanding of how stroke survivors interact with simulations and highlighted aspects in need of improvement.

1. INTRODUCTION

1.1 Rehabilitation Of Activities Of Everyday Living Following Stroke

Stroke is used as a broad term to describe a sudden focal neurological insult. The effect a stroke has on the person experiencing the trauma is dependent upon a number of contributing factors including severity and location within the brain. In the early stages following a stroke, perceptual deficits are a barrier to learning however as these recover, the role of the occupational therapist (O.T.) becomes increasingly important in helping the patient towards maintaining a full and independent life.

In order to achieve this goal, the stroke survivor must be capable of demonstrating an ability to perform tasks safely. In hospital or transitional rehabilitation this may involve periodic sessions during which the patient is accompanied by the O.T. and performs various activities of everyday living such as dressing, making a drink or preparing a meal.

1.2 Virtual Environments In Stroke Rehabilitation

Virtual environments may offer a method of rehearsing everyday activities during which progress through the activity can be monitored objectively and physical danger is removed from the scenario. One of the compelling attributes of a VE is that the activities may be meaningful and set in the context of realism, or ecological validity. Virtual environments have been demonstrated to be reliable in the assessment and rehabilitation of cognitive functioning (Pugnetti et al, 1995; Rose et al., 1996; Rizzo and Buckwalter, 1997; Riva, 1998). VR has also been shown to be capable of improving spatial skills (Stanton et al., 1998) and learning and practice of everyday life skills (Christiansen et al., 1998; Brown et al., 1999). A hot beverage activity was the subject of a study by Davies et al (1998).

Virtual Reality is often cited as a method of replicating activities in a simulation of three-dimensional physical space. In the context of rehabilitation, controlling the time taken to complete a subtask may also be an important factor and it is has been suggested that a virtual environment may encourage the learner to complete the action by reducing the opportunity for distraction or discontinuation of the activity through what Norman (1986) calls loss of activation.

1.3 A User Centred Approach

There would be little value in developing environments that are useful if they are unusable by the client group they are designed to support. The current phase of the project involves exploring suitable methods of interacting with the environments.

The initial stages of this project involved the acquisition of expert knowledge, attitudes and advice from a consortium of healthcare professionals who are involved in stroke rehabilitation and research. Seminars were held for consultants and occupational therapists, and they responded by offering advice and guidance in the choice of suitable tasks and interface requirements. The results from these seminars were presented at ICDVRAT 2000 (Hilton et al 2000). Our focus groups identified fidelity in the virtual representation of the real world environment and the control interface used as areas of particular importance.

The seminars with subject specialists were followed by seminars with stroke survivors and their carers. Two community based stroke self-help groups became involved in the project. A variety of virtual environments were demonstrated to members of these groups and these were followed up by audio taped group discussion.

1.4 Selecting An Every Day Task

The user requirements of the members of these discussion groups pointed towards a desire for more access to practising everyday tasks at a phase prior to return into the community. It had already been recognised by the therapists that virtual reality might be beneficial for simulating activities which included dangerous subtasks. It was concluded that a useful every day activity that appeared to satisfy the user requirements would be that of practising how to make a hot beverage. This activity has definable boundaries with respect to sequential subtasks and has potentially dangerous consequences if performed incorrectly.

One of the concerns expressed by stroke survivors was that a VR simulation task would require additional learning in order to use the computer. This was of particular concern to some of the older clients who did not have much computing experience prior to their stroke. A potential solution was found in a project previously used with young adults with learning disability, in which a tangible interface was developed to allow manipulation of real objects to activate the sequence of subtasks, simulated within a virtual environment, for making a cup of coffee (Cobb et al., 2001).

2. THE TANGIBLE USER INTERFACE

2.1 Consultation with Occupational Therapists

Consultation was held with occupational therapists based in community rehabilitation to discuss a feasible approach to developing a virtual environment to the coffee-making task. Observations were made of stroke survivors being assessed carrying out a hot drink making activity in their own home environments. Members of a community nursing team accompanied these visits.

A coffee making activity had been the basis of an undergraduate project in which the apparatus required to complete the activity was simulated by toy equivalents. These were mounted ingeniously such that when an action was performed a mechanical key-press of a keyboard character was effected (Starmer 2000). Software to complement the interface had been developed using Superscape VRT which offered verbal instruction and visual feedback. The environment was a kitchen work top with the various items required to make a cup of coffee. The tangible user interface (TUI) was developed further by Tymms (2001) in an undergraduate project in which the toy objects were replaced by real world objects such as an electric kettle, jar of coffee etc., and these are shown in figure 1. The O.T.s considered that this might be a suitable starting point and confirmed that when assessing a stroke survivor they would use a kitchen scenario that was familiar to the patient prior to the stroke.

Figure 1. *The tangible user interface to a coffee making activity.*

2.2 Overcoming technical problems of existing devices

The existing tangible user interface required some modification before a pilot study could commence. Unfortunately it was found that some of the interactions (such as putting the kettle under the tap) resulted in a sustained string of characters rather than the single trigger that was required. Feedback sequences were continuously activated until a reset was given. Also it was found that some of the interactions were not very naturalistic. For example to spoon coffee out of a jar, required a firm push onto a fairly heavy spring loaded metal piston which was mounted inside the jar. Constructing a monostable or "one shot" multivibrator and connecting it between the TUI worktop and computer solved the problem of continuous activation of input signal. This electronic device triggers on an input signal and delivers a 500mS pulse, irrespective of the input duration.

The coffee jar lid also provided some problems as it did not operate when the lid was removed or replaced. In order to solve this, a light sensitive switch was mounted inside the coffee jar which. However it was found that when an arm stretched across the jar to pour milk, it activated the light sensor in error and the computer was given conflicting inputs, one for the milk being poured and one for the lid of the jar being removed. Finally a solution was found by simply placing a magnet on the perimeter of the jar lid and using a reed switch to make the contact.

3. DESCRIPTION OF THE ACTIVITY

3.1 Instruction, User Response And Feedback

The design for the VE coffee making activity was based was based on a hierarchical task analysis (HTA) conducted by Starmer (2000). This was verified against the O.T's activity analysis in order to confirm that this was appropriate for stroke rehabilitation (Turner 2002).

The activity is initiated by a verbal instruction delivered by the computer inviting the participant to place the kettle under the tap. The correct user response would be to pick up the kettle and place it on the worktop beneath the tap. A micro-switch is consequently triggered which signals the completion of that particular subtask. The computer responds by playing a simulation of the activity, comprising of both visual and audible analogues. For example filling the kettle will result in the sound of water and a visual demonstration showing the kettle being filled.

The simulation continues by prompting the user to proceed to the next subtask, again by verbal instruction. An incorrect or inappropriate response is countered with a verbal correction and the user may not proceed until the correct action with the correct hardware is effected.

The subtasks that the user must complete (which correspond to the instructions), and the action required to effect the subtask are presented in table 1.
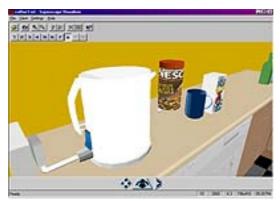
Figure 2. *An example of the screen.*

Table 1. *Subtask description and user action.*

Subtask Description	User Action
Place kettle under tap	Pick up kettle Place on worktop underneath tap
Fill the kettle	Press down on the tap
Switch on the Kettle	Pick the kettle up and place on the base Press the switch on the kettle Wait for kettle to boil
Open coffee jar	Unscrew lid of jar
Spoon coffee out of the jar	Pick up the spoon Push down lightly on surface of coffee
Spoon coffee into the mug	Push the spoon gently into the mug
Replace the lid on the coffee jar	Pick up the lid and screw clockwise onto jar
Pour water into the cup	Pick up the kettle Place on the tilter Tip the kettle towards the mug
Pour milk into the cup	Pick up milk carton Tip the spout when above mug

4. METHOD

4.1 The Pilot Usability Study

Once it could be demonstrated that the TUI was technically reliable, a pilot usability study was organised. Community self-help groups were contacted and seven stroke survivors volunteered to take part in the study by self-selection. The tangible interface worktop and a Toshiba laptop computer were set up at a location which was convenient for the participants. The proceedings were videotaped using a Panasonic camcorder which was positioned to focus only on hand movements. Consent was obtained from all participants and countersigned by a carer. Two therapists were on hand in order to ensure that the instructions and activities were appropriate and to discuss the implications of results.

The procedure was demonstrated to the group and then individuals were invited to work through the activity unaided (except in circumstances where prompting was necessary). Observation notes were taken during throughout the event. A usability criteria checklist was completed, the following being of particular importance:

- Did the user respond appropriately? (correct response to the instruction)

- Errors made

- Nature of errors

5. RESULTS

5.1 The Participants

Seven stroke survivors took part in the study, of which five were male. All seven participants suffered from expressive aphasia. This is typically seen in patients with frontal lobe lesions and is often associated with errors of sequencing and attention deficits in the early stages following a stroke. All participants were living in the community where they lived independently or with support from a carer. Six participants had negligible or no use of their right arm. All participants completed the task within four minutes, with a mean time of 2min 38.46sec, however errors were frequently made and these are presented below.

5.2 Errors and nature of errors

The subtask description and errors made or problems encountered are presented in table 2 based upon results from all participants on first attempt following demonstration.

Table 2. *Errors and problems encountered.*

Subtask Description	Error and Problems Encountered	instances
Place kettle under tap		
Fill the kettle	Did not respond to instruction	2
	Problem with weight of kettle	1
	Problem operating switch	1
Switch on the Kettle	Placing kettle on tilter instead of base	4
	Poured water before instruction given	3
Open coffee jar		
Spoon coffee out of the jar	Ineffective user response	4
	Put spoon on worktop after taking coffee	2
Spoon coffee into the mug	Ineffective user response	1
Replace the lid on the coffee jar	Required instruction to be repeated	1
	Difficulty replacing lid	1
Pour water into the cup	Inappropriate action to pour water	2
Pour milk into the cup	Ineffective user response	5

6. DISCUSSION

6.1 location of objects

The TUI worktop appeared to serve as a focal point and also a physical boundary to the activity. Participants who had full or partial use of their right hand tended to use their right hand to pick up the kettle which was situated near the right boundary of the worktop. However participants with loss of movement to their right arm did not position themselves such that their left hand was aligned to the kettle. Instead they tended to reach across to the right to pick up the kettle with their left hand. Discussion of this result with O.Ts would suggest that versatility in locating items is a key factor in successful design and it is desirable to be able to relocate objects to suit the patient.

6.2 Instruction

All participants had expressive aphasia. They could respond to verbal instruction although it was pointed out by a speech therapist present that single mode instruction has limitations and patients with receptive aphasia would not respond to the spoken word. It was suggested that we should consider alternative modes such as textual instruction. Two O.T.s who were later consulted also suggested that a strength of the virtual environment would be in demonstrating the desired action prior to participants response.

Most participants followed the instructions that were given and did not try to anticipate future actions, however when the kettle had boiled the participants were given a verbal confirmation and three participants responded by pouring water before the instruction was given.

Another problem was that one of the instructions was directing two separate subtasks. The instruction to place the kettle on the base and switch on the kettle caused problems. One of the reasons was comprehension of terminology and in four instances the base was confused with the assistive tilting device. In one case the participant placed the kettle on the base correctly but had forgotten the second part of the instruction. This indicates that simple instructions using familiar terminology and single subtasks are important features of the instruction.

Conversely, one subtask instruction was in two parts. Putting the spoon into the jar of coffee and lifting out a spoonful was considered as one action. Pouring the coffee from the spoon into a cup was treated as another action. However two participants put the spoon down on the surface between these actions, not linking them to the same overall subtask.

6.3 Physical Constraints

The kettle was too heavy for one person to lift and this causes somewhat of a paradoxical situation. Therapists have told us that the environment should represent a scenario familiar to the patient prior to their stroke, however the stroke itself may have caused a physical impairment which prevents them from carrying out the activity as they did previously. The physical constraints of the TUI are important factors to successful design and the capabilities of the user must be taken into account. A solution may be to develop a TUI in which objects are representative of real world objects but easier to manipulate. This would not conflict with the purpose of the TUI for practising sequential tasks providing the actions were similar to the real world task.

6.4 Ineffective user response

For certain interactions participants experienced some difficulty effecting a subtask completion trigger. Spooning coffee out of the jar and into the cup relied upon the user pressing down into the vessels in order to operate a micro-switch. Pouring milk required the user to use a pouring action with the carton. It is apparent from video analysis that object recognition is not an issue in these circumstances. The appropriate apparatus is employed however it appears that participants may be cautious about pressing too hard and are not activating the switches effectively. A more sensitive yet robust and discriminating method of actuation is possibly required.

6.5 The Virtual Environment

Participants appreciated the visual and auditory feedback but they felt that the layout could be improved. From certain angles objects were partially obscured. For example in one scene the coffee cup obscured the coffee jar label. They suggested that an improvement would be to show the liquid levels corresponding to user input. Both the therapists present and the therapists consulted later suggested that they felt that there was little point in playing back a prepared sequence, but that the virtual reality aspect would be useful if the feedback was more representative of the consequence of the action. However they added that value would probably be added to the system if tracking of the actual hand movements throughout could be played back to the patient upon completion of the activity.

7. CONCLUSION

Following a cycle of consultation involving OTs, stroke researchers and stroke survivors we have acquired perspectives and criteria which are considered of importance in the design and development of virtual environments for the rehabilitation of the stroke survivor. As a result we have identified making a hot drink as an everyday task to study and proceeded by exploring the interaction between the patient and the virtual environment.

In order to reduce the need to learn a new skill we have pursued the development of a tangible user interface to the environment and studied user acceptance and usability. The initial study has provided us with an insight into the important aspects of designing V.E.s when the primary user has experienced the trauma of a stroke. The objective of the exercise was to identify criteria for a future design and therefore we are not intending to demonstrate any improvement or deterioration in performance at this stage.

The immediate plan for this project is to redesign the tangible interface and the environment taking into account the improvements suggested by our consultation groups. The hardware performance will be reviewed and improved. The environment will endeavour to offer suitable and adequate feedback for each subtask, corresponding to the result of the action performed, rather than imitating the action. A further development that is under investigation is that of hand tracking and therapists confirmed that they would consider the ability to record and play back the patient's hand movements as having substantial value.

8. REFERENCES

Brown, D. J., Neale, H. R., Cobb, S. V. G., & Reynolds, H. (1999). Development and evaluation of the virtual city. *International Journal of Virtual Reality, 4*(1), 28-41.

Christiansen, C., Abreu, B., Ottenbacher, K., Huffman, K., Massel, B., & Culpepper, R. (1998) Task performance in virtual environments used for cognitive rehabilitation after traumatic brain injury. *Archives of Physical Medicine and Rehabilitation*, 79, 888-892.

Cobb, S.V., Starmer, T., Cobb, R.C., Tymms, S., Pridmore, T. and Webster, D. (2001) Interfacing tactile input devices to a 3D virtual environment for users with special needs. In: MJ Smith, G Salvendy, D Harris and RJ Koubek (eds) *Usability Evaluation and Interface Design: Cognitive Engineering, Intelligent Agents, and Reality. Volume 1 of the Proceedings of HCI International* 2001, 36-40.

Davies, R. C., Johansson, G., Boschian, K, Lindén, A., Minör, U., & Sonesson, B. (1998). A practical example using virtual reality in the assessment of brain injury. In P. Sharkey, D. Rose, & J. Lindstrom (Eds.), *Proceedings of the 2ⁿᵈ European Conference on Disability, Virtual Reality and Associated Technologies,* Sköve, Sweden, pp. 61-68.

Hilton, D., Cobb, S., Pridmore, T. (2000) Virtual reality and stroke assessment: therapists perspectives *Proceedings of the 3ʳᵈ International Conference on Disability Virtual Reality and Associated Technologies* 2000, Alghero, Sardinia

Norman, D. (1986) Cognitive Engineering IN Norman D and Draper S (eds*) User Centred System Design: New perspectives on Human-Computer Interaction.* Hillsdale New Jersey, Erlbaum Associates

Pugnetti, L., Mendozzi, L., Motta, A., Cattaneo, A., Barbieri, E., Brancotti ,S. (1995) Evaluation and retraining of adults cognitive impairments: which role for virtual reality technology ? *Computers in Biology and Medicine* Vol 25(2) 1995 pp213-227

Riva, G. (1998) Virtual Environments in Neuroscience*, IEEE Transactions on Information Technology in Biomedicine,* vol 2, No 4, 275-281.

Rizzo, A. A., & Buckwalter, J. G. (1997). Virtual reality and cognitive assessment and rehabilitation: The state of the art. In G. Riva (Ed.), *Psycho-neuro-physiological Assessment and Rehabilitation in Virtual Environments: Cognitive, Clinical, and Human Factors in Advanced Human Computer Interactions* (pp. 123-146). Amsterdam: IOS Press.

Rose, FD., Attree, EA., Johnson, DA. (1996) Virtual reality: an assistive technology in neurological rehabilitation. *Current Opinion in Neurology ,* 9(6):461-7, 1996 Dec.

Stanton, D., Foreman, N., & Wilson, P. N. (1998). Uses of virtual reality in clinical training: Developing the spatial skills of children with mobility impairment. In G. Riva, B. K. Wiederhold, & E. Molinari (Eds.), *Virtual Environments in Clinical Psychology and Neuroscience: Methods and Techniques in Advanced Patient-Therapist Interaction* (pp. 219-232). Amsterdam: IOS Press.

Starmer, T. J. (2000) Design and development of an alternative computer input device for children with special needs. B Eng Thesis, school of M3EM, University of Nottingham UK

Turner, A. (2002) Occupational therapy and physical dysfunction. Principle skills and Practice.5th ed. Edinburgh, Churchill Livingstone.

Tymms, S.J. (2001) Design of tangible input devices for special needs users. B Eng Thesis school of M3EM, University of Nottingham UK