VIRTUAL REALITY AND STROKE REHABILITATION: A MIXED REALITY SIMULATION OF AN EVERYDAY TASK

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ABSTRACT

This thesis is about the process of designing a computer simulation as a treatment tool for stroke rehabilitation. A stroke is a debilitating disease that is characterised by focal neural damage usually leading to physical and cognitive impairments. These impairments may severely compromise the stroke survivor's ability to perform everyday tasks of self-care such as dressing, washing and preparing meals. Safety issues are also an important consideration for the rehabilitation of the stroke survivor. Some everyday tasks can be hazardous, particularly when electrical equipment or hot liquids are involved.

Computer simulations are gaining interest as a tool for stroke rehabilitation because they offer a means to replicate assessments and everyday tasks within ecologically valid environments. Training the motor skills required to perform everyday tasks together with the cognitive component of the activity is desirable however this is not always achieved due to the limitations of the human computer interface. These limitations are addressed by a simulation that is presented in this thesis.

Stakeholders in stroke care contributed to the design and development of the simulation in order to ensure that it conformed to their requirements. The development culminated in a mixed reality system with a unique method of interaction in which real household objects were monitored by various electronic sensing technologies.

The purpose of controlling the computer simulation using real objects was to encourage users to practice an everyday task (making a hot drink) using naturalistic upper limb movement whilst performing the task in a safe and controlled environment. The role of the computer was to monitor and score user's progress, and to intervene with prompts and demonstrations as required.

The system was installed on a hospital stroke unit and tested by patients, something that had previously not been achieved. It was found to be acceptable and usable as a means of practicing making a hot drink. The system design, limitations and recommendations for future developments are discussed.

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Chapter 1: Introduction

1.1 Background

A stroke is a debilitating disease that is characterised by a sudden disruption to normal blood supply in the brain. The major causes are cerebral thrombosis, cerebral embolus or cerebral haemorrhage (Hildick-Smith, 2000). The effects of stroke are observed as an interruption to a combination of normal cognitive and physical processes, for example short term memory loss.

For people with a cognitive or physical impairment, performing activities of everyday living such as preparing a hot drink or a meal can be challenging and potentially dangerous. Tasks involving sequences can be demanding for people with short term memory impairments (Thomson, 2000). Handling vessels that contain hot liquids and using kitchen appliances present obvious hazards.

Although stroke is now amongst the top three causes of death globally, along with cancer and coronary heart disease, the survival rate is improving. For those individuals with a predicted outcome of recovery, early rehabilitation is generally accepted as good practice (Murray and Lopez, 1997).

In the hospital setting, stroke patients may practice everyday skills under supervision if the facilities are available however the opportunity to do so may be limited by resources in terms of both equipment and availability of an occupational therapist (OT).

An alternative approach to retraining the stroke survivor in everyday skills is to use simulations of suitable and relevant tasks and environments. This is achievable by employing computer generated three dimensional interactive simulations, commonly referred to as virtual reality (VR). The term VR is used in this thesis with reference to the various hardware and software technologies that are used to achieve the simulations. The audible and visible component of the computer simulation is referred to as a virtual environment (VE).

Virtual objects within the VEs are usually constructed to emulate their real world counterparts. They can also be enhanced by behaviours that are not normally associated with their real world counterparts, for example by the use of sound or colour to attract the user's attention.

Immersive VR, typical of the popular image of VR, reduces real world distractions and gives the user a sense of presence within the environment (Harrison and Jaques, 1996). A technology employed to achieve this is the head mounted display (HMD) which comprises two small visual display units mounted inside a helmet and positioned so that they are close to each of the wearer's eyes. The computer generated images presented to each eye are slightly different to give the user the illusion of depth of field within a three dimensional space.

Data gloves are a form of input device that are worn by the user as a means to interact with virtual objects in the VE. Sensors measure hand and finger movement and the movement data is used to control a simulated virtual hand that is replicated within the VE. This concept is also employed in full body pose systems in which sensors placed around the body control VEs in a similar way.

Non-immersive or desktop VR refers to three dimensional computer simulations that are presented in a two dimensional format and viewed using conventional display methods, for example computer monitor or data projection. Desktop VR provides a window into a world where simulated objects look and behave like real objects. In addition it offers engagement with an activity and enables the VE to be viewed by more than one person, facilitating collaboration.

Desktop VR requires no specialised hardware other than everyday computer technology. It is less expensive than immersive VR. The trade-off is that interaction involving desktop VR is more prone to real world distractions and the sense of presence is very much reduced compared with immersive VR (Harrison and Jaques, 1996).

The use of computer simulations as a potential tool to support stroke rehabilitation was discussed by the author with colleagues at the University of Nottingham in

1999. Following these conversations it was evident that this was an emerging field of research with the potential to produce new methods of assessing stroke patients and new tools for retraining cognitive and motor skills.

A literature search was conducted at the commencement of the project. In the late 1990s, applications of virtual reality in the assessment and rehabilitation of cognitive function following stroke were discussed by Pugnetti et al., (1995); Rose et al., (1996); Wann et al., (1997) and Riva et al., (1999). Learning and practice of everyday life skills was the focus of works by Christiansen et al., (1998) and Davies et al., (1998). Although these were typically laboratory based studies with small numbers of users as participants, a potential role for VR was emerging. The summary list of proposed benefits of VR for rehabilitation presented in Table 1.1 was adapted from Rizzo and Buckwalter (1997).

- Tasks can be administered within an ecologically valid setting.
- The learner can make mistakes in safety.
- Structured and timely support and feedback can be provided.
- The environment can be controlled.
- Varied levels of stimulus and feedback are possible.
- Learning can take place in stages.
- Errorless learning can be facilitated through cueing.
- Tasks can be repeated.
- The interface and presentation can be modified to suit the users Impairments.

Table 1.1 Benefits of VR for stroke rehabilitation.

Although it could be argued that many of the above can be applied to different forms of computer mediated learning without the need for three dimensional simulations, VR has the unique advantage of being able to present safe and controllable computer models of realistic environments that function in a similar way to their real world counterparts.

Despite these theoretical benefits, VR as a learning medium for stroke survivors also presents potential disadvantages. Stroke survivors would be required to interact with a computer simulation. They may not be experienced, proficient or willing computer users.

The physical controls and method of performing an action in the simulation may not map or relate to those of the real task. The problem of involving naturalistic movement and physical properties of objects in the context of relearning an everyday task are not addressed by VEs alone. Davies et al. (2002, p100) identify this as an issue, stating that "VR misses a physical vital component of training".

The focus of the research presented in this thesis was the development of a VR system for practicing an everyday task. It was a simulation of an everyday task that was controlled by a novel interface. The interface was designed to address the issues of natural movement and physical properties referred to above by employing real objects as input devices in the form of a tangible user interface (TUI). This is explained further in the following chapter and in chapter five. The complete system comprising a TUI controlling a VE is referred to as a mixed reality (MR) system.

The author's background is in human computer interaction and the work presented in this thesis became a study of the design process of developing an MR system for stroke rehabilitation rather than an evaluation of a viable end product. It is acknowledged that transfer of competence in everyday tasks between a simulation and the real world is of considerable importance however this would be a further substantial research project in excess of the work presented here.

1.2 Aims and Objectives

Two questions form the basis of the work presented in this thesis.

- What are the issues of designing an MR system for use by stroke survivors to practice an everyday task?

- What are the practical implications of implementing the MR system on a ward as part of a plan of stroke care?

The aims follow from these questions. They are:

- To design an MR system.
- To implement the system in a suitable rehabilitation environment.
- To review the design process.
- To investigate the benefits and drawbacks of implementing the system in the rehabilitation environment.

In order to achieve these aims a number of objectives were identified. These are presented below and are explained as the thesis develops. The objectives were:

- To consult with stakeholders in stroke care in order to select an appropriate activity to simulate.
- To work as part of a multidisciplinary team.
- To specify the task requirements and analyse the stages of the activity.
- To design and test VE software.
- To construct and test a TUI.
- To combine the TUI and VE to form a prototype MR system.
- To test the MR system with users.
- To identify successes and limitations of the system and the design process.
- To investigate the practical issues of using the system on a ward environment.

These objectives were used to form an action plan which is illustrated in figure 1.1. This plan shows the activities of design and the location of these activities within the thesis. It is used as a structure to the main body of work and is referred to in subsequent chapters.

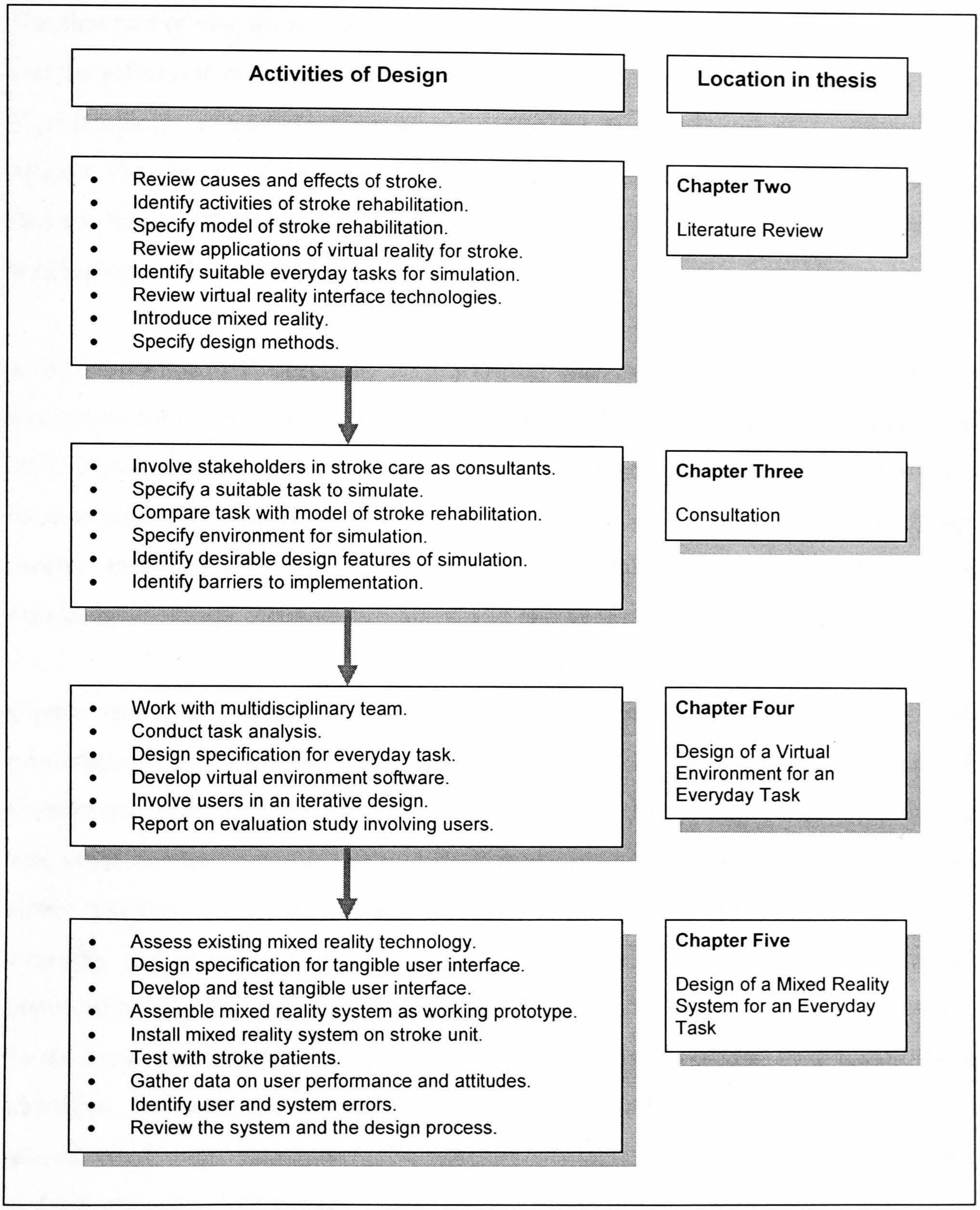

Figure 1.1 Activities of design and location in the thesis.

1.3 The Thesis Structure

This chapter has briefly introduced the concepts that form the basis of this thesis and presented the questions that this thesis seeks to answer.

The first part of chapter two presents the literature that was used to review the causes and the effects of stroke, in order to understand the stroke survivors' needs as users of technology. A model of stroke rehabilitation is introduced as a reference to support the choice of an everyday task to simulate, the task being specified in chapter three. VR technologies are introduced and the review examines different applications of VR to stroke.

A model of the MR spectrum is introduced that describes different methods of interaction for different applications across the divide between real environments and VEs. This is then developed to offer a rationale for an MR approach for simulating an everyday task. The final section of the literature review investigates the design process and presents a case for involving users in the design process. International standards for design methods are introduced and explained.

Chapter three reports on the consultation phase that formed the early part of the work presented here. Task requirements and user's needs were investigated through consultation with stakeholders. Initially a study of the rehabilitation environment was made on the hospital stroke unit. Meetings were held with therapists, former stroke patients, their representatives and consultants in order to introduce the concepts and technologies that supported the project. The meetings were an opportunity to gather feedback related specifically to VR as a tool for rehabilitation. From these consultations the kinds of tasks that users might find useful were identified. The concerns of stakeholders, barriers to use and timeliness of VR in rehabilitation were discussed. Following the consultation phase a task was selected as the focus of the MR system.

Chapter four presents the process of developing the VE and the underlying software component of the MR. This involved collaboration with an OT as part of a multidisciplinary team. The diverse roles of members of the design team are presented and the specific role of the author is explained. A task analysis was conducted and from this a VE was designed. The VE was developed by a process of iterative testing and development which included fifty stroke patients on a hospital stroke unit. In addition to the design of the VE a Stroke Association funded project was carried out by the OT which evaluated the VE. This had implications for the design of the TUI therefore a summary of the study and relevant findings are included.

Chapter five presents the design of the hardware that formed the TUI, showing how it was developed and tested prior to connection with the VE. The complete MR system was then installed on a hospital stroke unit. A series of observational studies involving fourteen stroke patients using the completed system was conducted by the author. User activity data was recorded by the computer and this was compared with observational data taken from video recordings. Users' experiences and attitudes were also collected using a standardised computer attitude assessment.

Chapter six is a discussion of the design process and the issues of implementing the MR system in the hospital ward environment.

Chapter seven is the concluding chapter. Recommendations are made to assist designers of MR systems who intend to develop simulations of everyday tasks for use by stroke survivors. Suggestions for further work are presented at the end of chapter seven.

Chapter 2: Literature Review

2.1 Introduction

In chapter one, stroke and the effects of impairment on skills required for everyday living were briefly introduced. Virtual reality was then considered as a technology for presenting computer simulations because these enable the user to practice tasks in a safe controlled environment. It was explained that the focus of research is the design and implementation of a novel method of interacting with the task, using a TUI as part of an MR system.

The causes, epidemiology and effects of stroke are considered in the first section of this review. Stroke assessment, rehabilitation and a model of rehabilitation are introduced. The latter was used as a reference tool to assess the suitability of activities chosen for the simulation.

The kinds of activities that are recommended during a programme of rehabilitation are introduced and the review investigates the theories of movement. Encouraging physical movement in context of simulated activities is discussed from which the design of an MR system was proposed as a possible means to facilitate this.

The review considers the role of VR in cognitive and motor assessment and rehabilitation, exploring published works in the field. It then focuses on the MR approach, reviewing different interaction methods and offering a rationale for developing a TUI.

The chapter concludes with the principles of design and explains the importance of a user-centred design approach, in which end users contribute in some way the development of a product.

The illustration in figure 2.1 shows the activities of design, with the particular section that is relevant to this chapter clearly identified.

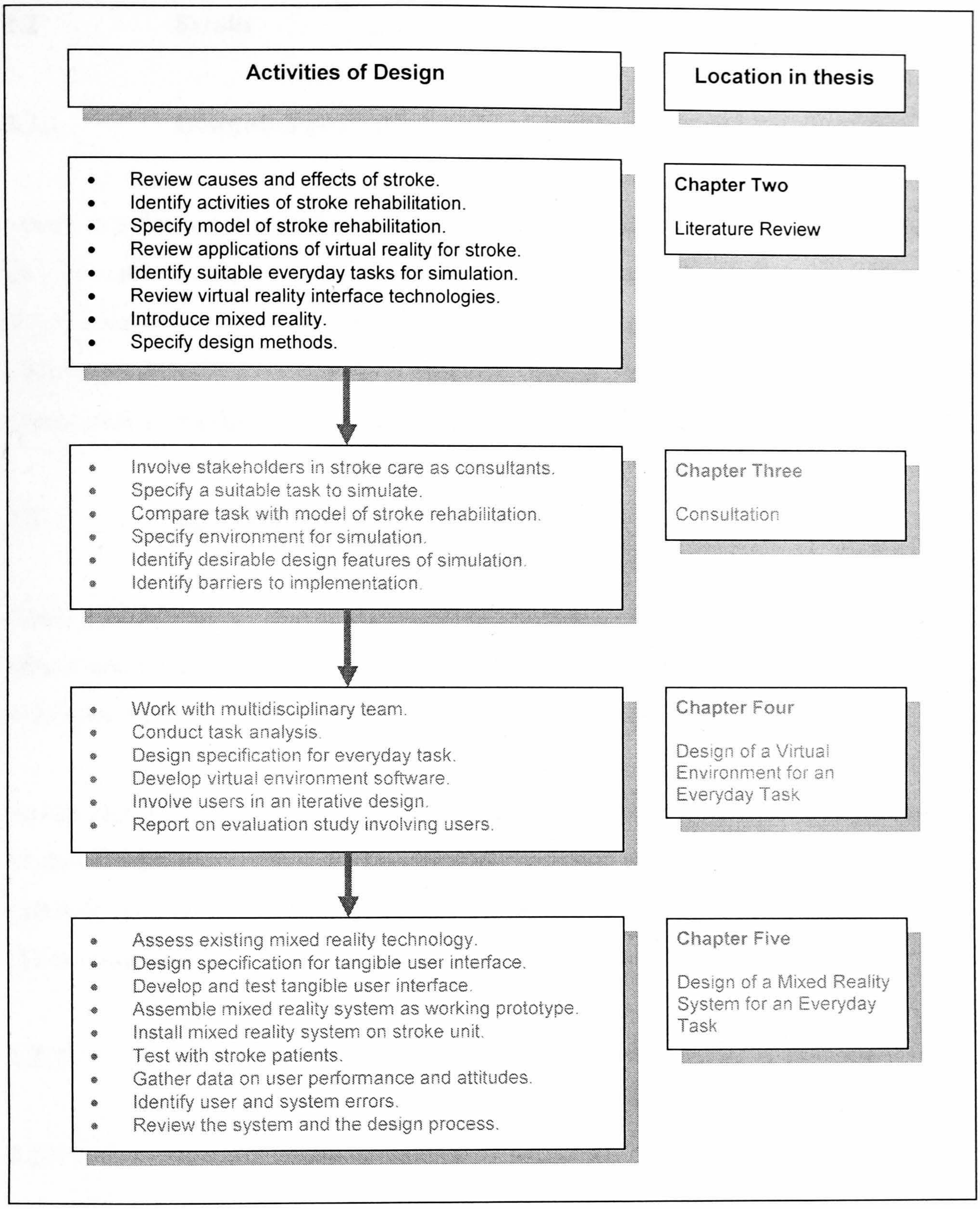

Figure 2.1 Activities of design presented in chapter two.

2.2 Stroke

2.2.1 Definition of stroke

Stroke is a disease that strikes without warning, causing focal brain cell death due to lack of nutrients as a result of disruption to normal blood supply in the brain. The World Health Organisation defines stroke as "rapidly developed clinical signs of focal (or global) disturbance of cerebral function, lasting more than 24 hours or leading to death, with no apparent cause other than of vascular origin" (Aho et al., 1980, p114).

2.2.2 Epidemiology

Kwan (2001) reports that 130,000 people suffer a stroke each year in the UK, of which approximately two thirds will survive to the end of the first year. Of the survivors, 40% will be disabled in some way.

Stroke can affect any person of any age however the World Health Organisation's Multinational Monitoring of Trends and Determinants in Cardiovascular Disease (MONICA) project found that the incidence of stroke increases sharply with age (Thorvaldsen et al., 1995).

2.2.3 Effects of Stroke

2.2.3.1 Cognitive Impairments

The focal destruction of brain cells leads to a variety of specific impairments of cognitive processes. Memory loss is commonly reported following stroke. In the home setting, memory loss can be dangerous if gas or electrical equipment is not switched off after use (Thomson, 2000). Memory loss affects ability to perform many activities that include sequential processing because the next step in an activity cannot be recalled.

Dysphasia is an impairment of language that affects the patient's ability to read, to write, to comprehend the spoken word and to communicate verbally. It does not affect memory or ability to plan (Marshall, 2000). Aphasia is the loss of communication skills although the term is often used interchangeably with dysphasia. Participation by the dysphasic patient in VR has implications for the design of interfaces that give instructions and feedback.

2.2.3.2 Visual Impairments

Problems related to vision are also a common consequence of stroke. The patient may not even be aware of their impairment (Hildick-Smith, 2000). Visual impairments have implications for the layouts of computer interfaces and the selection of suitable users.

Homonymous hemianopia is a condition in which the patient is unable to see an object that is placed in a certain region of the normal visual field. Patients with homonymous hemianopia can be made aware of their deficit and can learn to move their heads to compensate.

In contrast to patients with hemianopia, patients with visual neglect are unable to attend to stimuli in regions of the normal visual field and may be unaware that objects are present. A typical behaviour seen in patients with visual neglect is to leave half a plate of food that is in the affected half of the visual field. Chen Sea et al. (1993) have demonstrated that the inability to attend to objects in part of the visual field has a detrimental effect upon performance of simple every day tasks.

2.2.3.3 Motor Impairments

Activities that the patient would normally participate in for everyday living frequently require control of upper limb movement and also fine hand and digit manipulation. Koski et al. (2002) explain that motor problems associated with stroke are often a problem with the mental representation of an action rather than a physical musculoskeletal disability. Following a stroke the muscular tissue may be intact but motor control areas of the brain may be damaged. Motor problems manifest themselves as loss of either movement or the control of movement of limbs or digits.

Another disability affecting movement is known as a body scheme disorder. The patient with a body scheme disorder is unable to translate the intention to move into an appropriate physical action (Muir Giles and Clark Wilson, 1993). This is an important consideration in the selection of rehabilitation strategy. Verbal instruction could be inappropriate to these people, not because of lack of comprehension but because of lack of ability to connect the intention to perform a physical action with the motor skills to carry it out.

2.3 Stroke Rehabilitation

2.3.1 Adaptive and Restorative Rehabilitation

The role of stroke rehabilitation is to improve the quality of life of the stroke survivor by increasing ability to participate in useful activities. Two different approaches to rehabilitation are referred to as 'adaptive' rehabilitation and 'restorative' rehabilitation (Gladman et al., 2006).

Adaptive rehabilitation is the modification of the environment around the patient, using adjustments to existing equipment and facilities to assist the patient in their activities. It is considered appropriate for a progressive illness (for example dementia) in which recovery is unlikely (Gladman et al., 2006; Gladman et al., 2007).

Restorative rehabilitation aims to improve quality of life and participation in activities by improving the patient's function. It is appropriate for strokes where restoration of function is a realistic outcome (Gladman et al., 2006).

2.3.2 Adaptive and Restorative Rehabilitation Models

The International Classification of Function (I.C.F.) was devised by the World Health Organisation as a means of categorising and encoding concepts relating to function in order to ensure consistency in the description of activities and movement (WHO, 2001). Gladman et al. (2006) have developed models of both adaptive and restorative rehabilitation that are based upon the contributing factors to rehabilitation as identified within the ICF (see figures 2.2. and 2.3). Although these models were published in 2006 they were available to the author prior to this date.

The bold arrows show that environment, body functions and structures, and personal factors are key variables that contribute towards participation. Participation in this context is taking part in any form of activity including social activities and life skills.

The remaining textboxes connected to the key variables show rehabilitation and treatment options. Those in bold type indicate strategies that are important to the specific model.

Adaptive rehabilitation is an adjustment of the environment and activity to accommodate the patient's needs (see figure 2.2). For example specially adapted appliances such as suction grips for cups and jars could be offered to the patient to assist in everyday tasks.

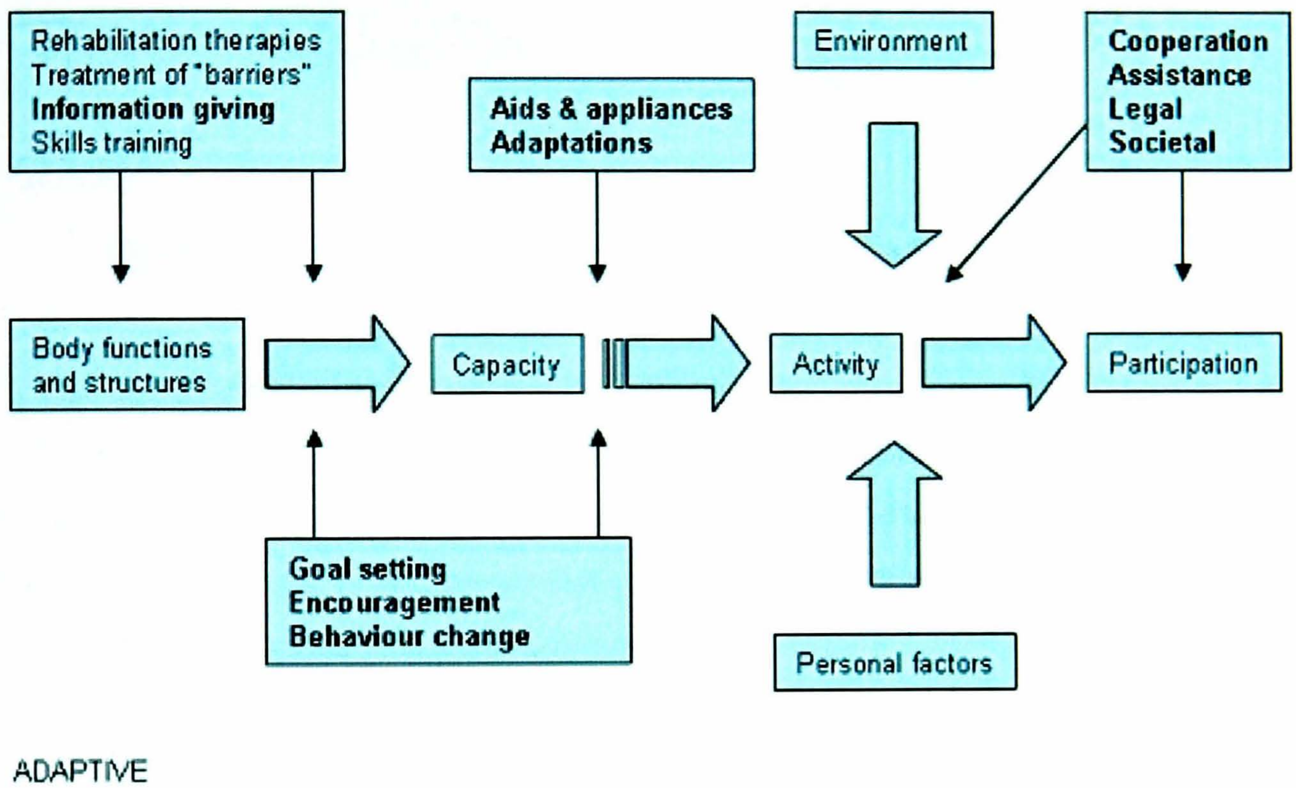

Figure 2.2 A model of adaptive rehabilitation (Gladman et al., 2006).

For those patients who show the potential to make a recovery the restorative model is more appropriate. A treatment for stroke patients aimed at improving function through practice is typical of the restorative model of rehabilitation (see figure 2.3).

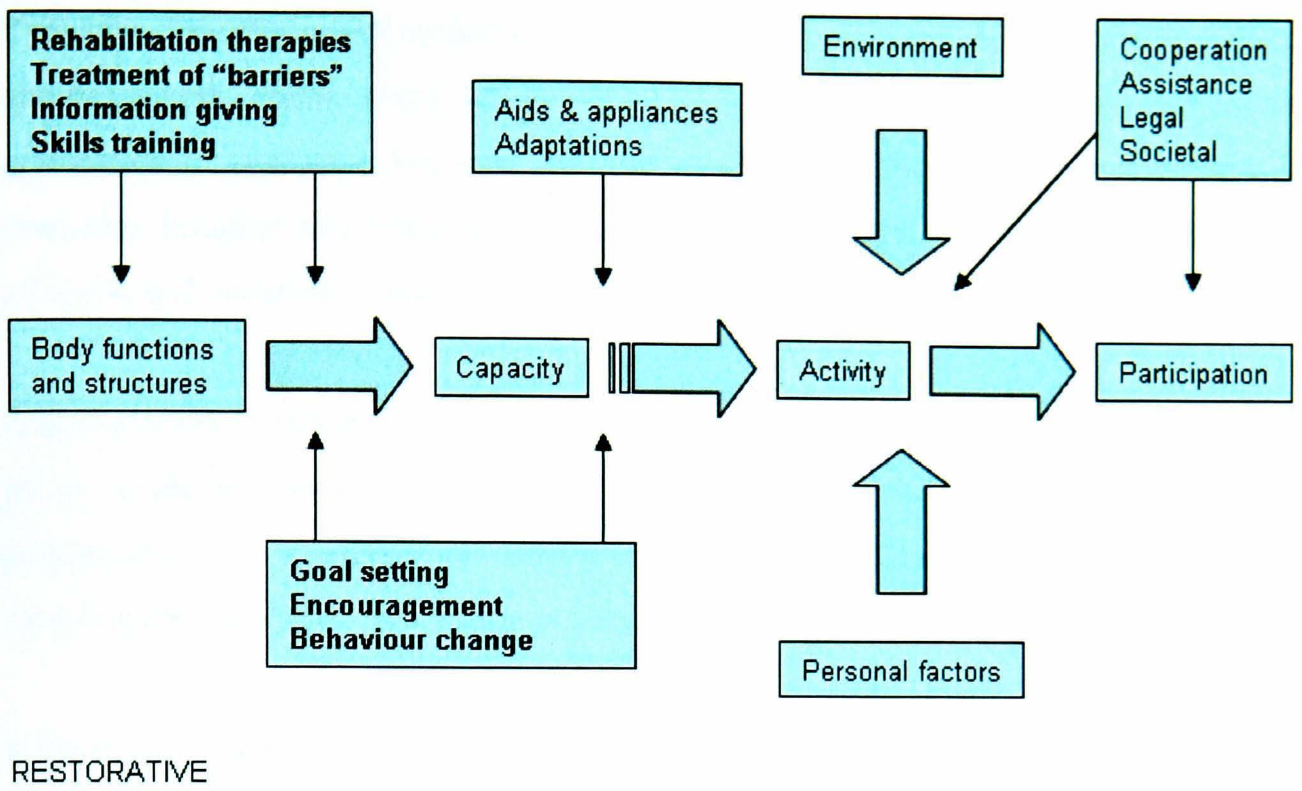

Figure 2.3 A model of restorative rehabilitation (Gladman et al., 2006).

Of the two rehabilitation approaches, the re-learning of skills required to perform an everyday task can be considered as a form of restorative rehabilitation. In figure 2.3 the themes in bold identify those aspects that are of particular importance to the restorative model and it can be seen that rehabilitation therapies, treatment of barriers, information giving and skills training are of particular importance to restoration of function, as are goal setting, encouragement and behaviour change.

2.3.3 Activities of Daily Living

Everyday tasks of self care and hygiene, such as eating, washing, dressing and toileting are basic requirements for independent living. These activities are referred to as Activities of Daily Living or ADLs.

A study by Trombly and Hui-ing Ma (2002) found that participation by patients in ADLs improved significantly for those patients who received training compared to subjects in a control group. They conclude that "task specific practice on activities [that] clients identify as important to them may be accepted cautiously as best practice" (Trombly and Hui-ing Ma, 2002, p258).

Executive function is the mental process involved in planning and organising actions and behaviours. Many every day activities such as cooking and shopping require the application of executive function. Edmans et al. (2001) propose that it is deficits in executive function more than any other cognitive processes that determine the extent of social and vocational recovery.

Honda (1999) reported that three patients with executive function deficits who were given treatment aimed at addressing these deficits improved significantly in performance in a range of activities including ADLs. Although this study demonstrates an effect, the sample is very small and it is not possible to generalise.

Instrumental Activities of Daily Living (IADLs) are activities that are involved in maintaining independence and include using a telephone, shopping, food preparation and housekeeping (Lawton and Brody, 1969). Performance in IADLs is commonly used an indicator of ability to live independently in the community (Khin-Heung Chong, 1995).

2.3.4 Motor Impairments and Activities of Daily Living

In a study by Mercier et al. (2001) in which elderly stroke survivors were assessed for functional autonomy, it was found that motor impairments had the greatest effect on regaining independence or autonomy, followed by perceptual and cognitive factors. Although cognitive and perceptual deficits impaired performance in tasks, those stroke patients with adequate motor skills showed an increased ability to perform everyday tasks compared to those with less physical ability.

Carr and Shepherd (1986, p.67) give a rationale for early motor training that includes taking "advantage of the learning capacity and adaptability of the brain" and preventing acquired or learned inactivity of the affected limb. According to Fisher and Sullivan (2001) specific intensive and complex movements to solve motor problems are fundamental to restorative rehabilitation.

Activities of Daily Living combine motor skills and cognitive skills. The direction, strength and the timing of the movement are important factors to successful execution of the action. Specific movements that form part of a sequence (for example reaching to pick up a cup) are thought to be represented in the brain as a collection of schemata. Schmidt (1975) proposes that motor skills are learned by acquiring new schemata and that loss of schemata can occur due to stroke. Schmidt also recommends that motor rehabilitation of a patient should include therapy that aims to replace the schemata that have been lost.

Norman (1981) takes the concept of schemata further by suggesting that individual motor programmes represented by schemata can be combined to form an action schema in which a complete sequence of different movements required to perform an activity are represented.

The schema theory is also important for learning motor and cognitive tasks because the idea of a schema is an adaptable representation of a task. Once a sequence for carrying out a task has been learned this can be easily adapted by the stroke patient for other situations. For example the skills required for pouring a small jug of milk into a mug are the same as those for pouring a kettle of water into a mug. The difference between the activities is essentially in the size, shape and weight of objects employed.

Carr and Shepherd (1989) recommend that rehabilitation therapy should be aimed at familiar and useful task specific activity. Therapy aimed at specific muscles rather than tasks may improve muscular strength where this has been reduced due to inactivity, but the movements that have been relearned in this manner may not be particularly useful to everyday living because they may not be relevant in the context of a useful task.

2.4 Virtual Reality and Stroke

2.4.1 Virtual Reality and Assessment

The assessment of cognitive and motor function is an important step in establishing goals for treatment (Edmans et al., 2001). The reported benefits of using VR in the rehabilitation process for brain injured people include the ability to assess the patient in relevant daily tasks, and the opportunity to learn these tasks in safe and controllable environments (Rizzo and Buckwalter, 1997).

Stroke assessments include pen and paper exercises in which patients are asked to perform different tasks, each exercise being designed to assess a specific disability. These are administered to the patient by the OT as a means to assess visual memory or visual field intactness.

Line bisection tasks assess the presence of visual field disturbance by requiring the patient to place a mark at the centre of a straight line drawn on a piece of paper (Bisiach et al., 1983). A person with normal vision will place the mark approximately central, the patient with loss of awareness in part of the visual field will place the mark closer to one end of the drawn line.

Cancellation tests require the patient to put a mark through simple characters drawn evenly across a sheet of paper. Patients with visual neglect or hemianopia will not cancel marks they are unaware of therefore unmarked symbols at the end of the exercise are used as an indicator of the presence of a visual field disturbance (Albert, 1973).

Rey figure testing requires the patient to draw a copy of a line diagram from memory after a brief period of exposure to the image. The image is a collection of lines forming simple shapes connected together. This test assesses both visual field and visual memory (Rey, 1959).

Rose et al. (1996) suggest that traditional assessments of cognitive function, typically pen and paper exercises described above, are too artificial or abstract. Many of these tests assess the existence of a problem but do not quantify it. VR may offer more realism and control of more variables in cognitive assessments.

This is supported by Baheux et al. (2005) who propose that tests that are currently used in the assessment of stroke patients with hemispatial neglect do not quantify the extent of the problem. They developed a VE in order to observe how stroke patients with neglect attempted to grab virtual objects. Control and manipulation of objects was through a haptic input device. Two groups of people were tested using the system. Performance of a trial group comprising of hemiplegic patients was compared with that of a control group of people without any recorded disability. Differences in trajectory of reach were identified between the patient group and control group. It was found that trajectories could be used to determine the degree of handicap in the patient group.

Patients with hemineglect do not attend to objects that are located in certain regions of the visual field. Myers and Bierig (2000) investigated the use of an HMD and tracker as interfaces to a VE in order to determine whether left hemineglect was observable in the VE. They conclude that by measuring the patient's interaction with a VE it is possible to determine the objects that are attended to and those that are not. Furthermore the positional data can be used to provide cues that encourage the patient to attend towards the neglected side.

The VReye system described by Gupta et al. (2000) replicated two tasks for identifying hemianopia in a VE. They found differences in cancellation test scores between the trial group (patients who had known hemianopia) and control group (healthy adults) who used the system. The authors suggest that this system might therefore be suitable as an assessment tool for visual field deficits.

Assessments of memory have been the focus of a number of studies. Andrews et al. (1995) conducted a study in which subjects who were not cognitively impaired were required to recall objects displayed on monitor under a variety of different conditions. These included objects within a virtual room, images of objects presented without other distracters and images that the participants had to move a mouse cursor over to view. Object recall was actually lower in the VE than other display conditions. They concluded that the richer environment was more distracting and this may have affected recall performance. This has implications for design as it suggests that users are susceptible to distracters, therefore in order to focus on a task the VE should minimise or eradicate superfluous objects.

Matheis et al. (2003) found that participants with traumatic brain injury performed similarly to normal controls in a study that required the participant to locate objects in a VE and to recall these later. All participants were assessed in an immersive environment wearing an HMD. The results suggest that the natural movement of a HMD reduces the cognitive demands of standard methods of navigating and locating items on a computer monitor (for example mouse, joystick) and this natural movement reduces distraction.

2.4.2 Virtual Reality and Rehabilitation

VR has been shown to have potential application for treating a variety of disabilities other than stroke including dementia, autism and phobias. VR is being used for training social skills in a variety of different situations with different users. People who have difficulty making a decision or coping with a social situation in the real world are being given the opportunity to practice these skills in a simulated interactive environment.

VEs for use by children with autism have been the focus of works by Trepagnier et al. (2006) and Andersson et al. (2006). Adults with social anxiety disorder used a VR system that was developed by Grillon et al., (2006). Eight people with the anxiety disorder participated in studies in which they interacted with simulated people. An improvement in eye contact was recorded in all cases.

Experiments with sound have demonstrated that this can be used as a means of enhancing the user's experience of a VE for people with visual impairment. Sound has been employed in systems used by children with severe physical disability (Brooks et al., 2002; Lopes-dos-Santos et al., 2006).

Home based rehabilitation is an emerging application of VR technology which is beginning to show promise. Advances in interaction and remote sensing have enabled researchers to study the way in which people interact with technologies that can be installed in the home setting. This has the potential to enable people in rehabilitation to continue their treatment at home under remote observation and supervision without the need to visit an OT for hospital rehabilitation therapies (Kizony et al., 2006; Zheng et al., 2006)

Devices that are emerging into mainstream technology are dramatically reducing the cost of VR. The Nintendo Wii™ is an example of a household product that has recently shifted the boundaries of the gaming console interface from the common user input methods (joystick, keyboard, tethered handset) to a wireless interface in which physical movements made by the user are used to control the gaming program. The Sony EyeToy™ has been used in rehabilitation as a means of capturing the user's image in real-time and combining it with virtual objects in an interactive VE as a form of augmented virtuality (Rand et al., 2004; Lallart et al., 2006).

2.4.3 Virtual Reality and Activities of Daily Living

Prior to the commencement of the work presented in this thesis the Virtual Reality Applications Research Team (VIRART) at the University of Nottingham, U.K., were conducting studies investigating the application of VR for retraining life skills in people with severe learning disabilities (Cromby et al., 1996; Brown et al., 1997; Brown et al., 1998; Neale et al., 1999). A particularly interesting application is the virtual city, a collection of different simulations of situations and environments that was designed to assess and facilitate practice in a variety of life skills, including leaving the house, catching a bus to a destination, navigating and shopping (Brown et al., 1999).

Greenleaf (1997) suggest that VR should be developed to provide interesting realistic environments and that they should include an objective measure of performance in ADLs. Kitchen tasks appear to be particularly suitable for simulations because these are useful skills for every day living. They address important issues such as training in a safe environment and the handling and appropriate use of utensils.

Preparing a hot drink in a VE was the focus of a study by Davies et al. (1998). It is suggested that this kind of simulation might be useful either as an early assessment tool or as a method of training individuals who have experienced traumatic brain injury (TBI).

A meal preparation task was the focus of research by Christiansen et al. (1998). A virtual kitchen was developed that included a meal preparation task comprising thirty stages. Thirty subjects with brain injury were recruited to the trial and carried out a soup-making task. The authors demonstrated that the virtual kitchen was reliable as an assessment tool for brain injury.

Three different VEs developed and tested with stroke survivors by Davies et al. (2002) in order to practice activities that are relevant to daily life. The first environment included kitchen tasks in which stroke patients could practice preparing food and drinks. In the second environment a virtual cash dispenser (also known as an automated teller machine or ATM) and a virtual transport ticket machine were used. In the third environment a navigation activity was the focus. Results from trials suggest that VR offers an alternative method of practising useful tasks when the real resources to do so are not available.

A kitchen assessment was used by Zhang et al. (2003) that included prompting, cues and instructions. Fifty four patients who had suffered traumatic brain injury were the subjects of the research. Subjects were required to prepare soup and a sandwich using a VE and a real kitchen. A measure of performance was developed with a range of 1 to 6 (6 being independent successful and 1 being dependent unsuccessful). Patient performance was measured and comparisons between the real environment and the VE task were compared. Time to complete task and errors made were also noted. Scores between real and virtual task were correlated and it was found that the VE shows adequate validity and reliability.

These studies demonstrate that VR offers a safe and controlled training environment in which people with a disability can practice skills of everyday living. What they do not show is that the physical movements required to perform these activities in the real world situation are successfully trained in the VE. This is simply because the interaction methods do not take account of the physical impairment. Interaction methods in the studies presented above include keyboard. mouse and joystick. In the following section natural movement and sensation are considered in the context of less conventional input devices.

2.4.4 Naturalistic and Haptic Interface Technologies

Some commonly used input technologies to VEs, for example mouse, joystick, keyboard, do not constrain or encourage the user to employ the fine upper limb movements to perform activities in the environment that they would in the real world. Furthermore they do not provide the user with any form of force feedback or sensation of weight that would be experienced by the user in the real world.

Alternative input devices exist that attempt to address these deficits by offering force and touch (haptic) feedback or by encouraging more natural actions. These are discussed below.

In a study by Hoffman (1998) subjects were invited to manipulate a kitchen plate in a VE and were assigned to either a group who used a wand to pick up the object, or to a group who used a haptic mechanism that provided a tactile sensation. Subjects who had used tactile augmentation were more accurate in predicting the physical properties of other objects in the virtual environment. The findings conclude that immediately prior to picking up an object its weight is approximately predicted as a component of the action.

Data gloves are gauntlets worn by the user that sense changes in finger and hand movement by using resistive transducers (Harrison and Jaques, 1996). Different types of sensory systems include mechanical linkages, resistive ink and optical fibre. In each of these technologies finger movement effects a change in electrical conductivity of the transducer. This analogue change in conductivity is converted to a digital value and input to the computer. This controls the hand and finger movement in the simulated hand viewed within the VE.

Data gloves have been used as input devices for rehabilitation in VEs (Broeren et al., 2002; Ku et al., 2003) however the physical property of the weight of an object is not easily fed back to the wearer. The data glove is also an encumbrance due to the sensors embedded within it.

Other technologies exist that provide tactile or haptic feedback, such as the SensAble PHANTOM™. This device comprises a hinged arm with a handle at one end. The user grasps the handle and moves a cursor in the VE by manipulating the hinged arm. Objects in the VE are given attributes of boundaries and strengths. The PHANTOM™ is used to navigate around objects and select and move objects within the VE. When simulated objects are encountered, contact with the surface is conveyed to the user by means of force feedback (Salisbury and Srinivasan, 1997).

A study with stroke patients using the PHANTOM™ was reported by Lövquist and Dreifaldt (2006). They constructed a small maze based on adjoining rooms, which they called the Labyrinth. In this program users were given a continuous score as they progressed through the maze, using the PHANTOM™ stylus as both the means of controlling direction and for boundary (edge) detection. Three stroke patients were observed using the system and their opinions were gathered. Effectiveness of the system as a treatment for rehabilitation was not measured however all three patients reported that they enjoyed using the system and could see an application for it in rehabilitation.

A criticism of the PHANTOM™ for stroke rehabilitation is that although force feedback and boundaries are conveyed to the user, the fine manipulation skills that are required for activities of everyday living are not monitored or even necessary in these scenarios.

An alternative approach to using data glove, gesture recognition or a haptic interface such as the PHANTOM™ exploits the physical properties of real objects. The generic name for this technology is a tangible user interface (TUI). A TUI is a form of input that is used in conjunction with a VE. Together the VE and TUI form an MR system.

2.4.5 Mixed Reality

Mixed reality refers to technologies that blend virtual and real components. A spectrum of MR technologies was proposed by Milgram and Kishino (1994) to illustrate the way different MR applications use different mixtures of real and virtual environments. This is presented in figure 2.4.

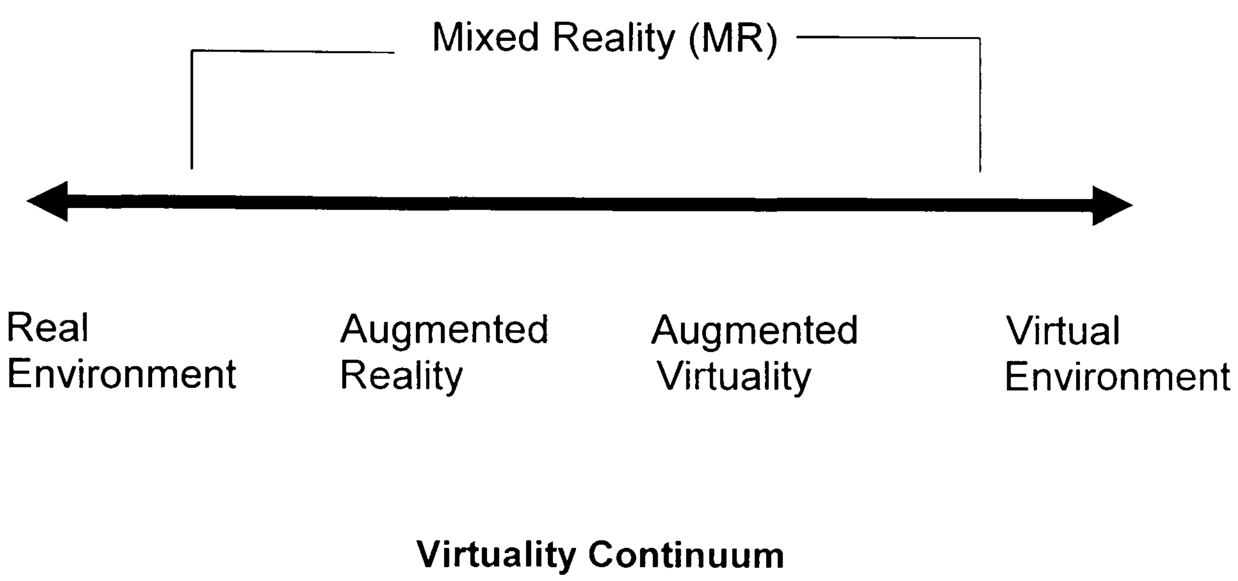

Figure 2.4 The mixed reality spectrum (Milgram and Kishino, 1994).

The 'virtuality continuum' is the range of experiences and technologies that span the gulf between the virtual and the real environment. Every day experience (the real environment) is situated at the far left side of the spectrum. Progressing to the right there is continually increased emphasis on technologies that use computer generated information to enhance or augment the user's experience. VEs that do not incorporate the real environment in any way, for example immersive VR systems, are situated at the far right of the spectrum.

In augmented reality the real world is the primary focus of the activity and this is enhanced through computer generated imagery which is projected onto a real world scene. This technique has been successfully employed in VR assisted surgery and medical training (Grantcharov et al., 2004; Seymour et al., 2002; Stenzl et al., 1998).

Augmented virtuality places a greater emphasis on the computer simulation than augmented reality. Images (or live video) captured from the real world may inhabit the simulation. For example a live image of the user may be integrated into the simulation as a means of interaction. This has been used as the basis of a VR system for stroke rehabilitation by Kizony et al. (2002) in which participants viewed images of themselves captured by video camera that were merged with a simulated environment with which the participants interacted.

To the far right side of the MR spectrum, VEs are computer simulations that do not involve artefacts from the real world other than the VR equipment. The focus of attention is entirely upon the simulated computer generated environment.

2.4.6 Tangible User Interfaces

TUIs control a computer through manipulation of graspable objects. The definition of TUIs attributed to Ullmer and Ishii (2000, p916) are that "they give physical form to digital information, employing physical artefacts as representations and controls of computational data".

The input is of the form of digital data relating to one or more properties of the object(s), such as position, orientation and proximity to other objects. This is achieved using different methods, for example by placing sensors in objects that are coupled to a host computer.

Employing real objects immediately removes the complexity of programming appropriate affordances and constraints into the VE. Furthermore it requires the user to interact with the object in a realistic way.

Affordance is the property of an object that informs the user what they are expected to do with it (Norman, 1988). For example a square button offers the affordance that it should be pressed rather than rotated.

A constraint is the physical property of an object that only permits an action to be performed in a certain way (Norman, 2002), for example a three pin electrical plug (UK type) may only be inserted into an electrical socket in a unique (and correct) way.

Mixed reality offers a method of developing a technology to enables a task to be performed using real objects without the encumbrance of data gloves and to encourage real hand and fine manipulation movements that are not necessary to operate haptic tactile feedback devices such as the PHANTOM™. The practicalities of developing and using an MR system in practice for training and/or assessing stroke were not known and a literature search was conducted to investigate MR with specific application to stroke rehabilitation.

The literature search revealed very few published studies that specifically discussed MR methods applied to stroke rehabilitation. Cognitive Cubes (Sharlin et al., 2002) comprised small cubes that had sensors to detect the attachment to other similar cubes. Simple configurations of cubes were programmed by the facilitator and construction tasks were delivered in which the participant (the stroke patient) replicated the original structure by placing cubes together. The cognitive cube TUI has also been used by Jacoby et al. (2006) to assess how children with coordination disorders construct shapes using the tangible bricks as an interface to a VE.

MR methods for the practice of every day skills may be complex to develop or impractical to implement in stroke rehabilitation. Without precedence it is difficult to know whether an MR system for practicing an every day activity would be usable, useful or practical.

2.5 Designing Virtual Environments for Stroke Survivors

2.5.1 Introduction to the Design

Employing VR as a medium for enabling stroke survivors to practice useful activities raises a number of diverse issues. In this thesis issues of design and implementation for stroke survivors as special users of technology are of primary concern. It was not the intention from the outset for the author to study clinical effectiveness of VEs in stroke care within this project.

The focus of research presented in this thesis takes the authors initial proposal that VR may be useful to support stroke rehabilitation and follows the design and installation of a prototype MR system that employs established design methods in accordance with international standards.

2.5.2 Design Models

The initial stage of the project was to establish a methodology for developing the MR system. Numerous design methods exist that are selected or developed to suit the purpose of the product, the manufacturing process and the user population. Examples are the Waterfall Model (Royce, 1970), the Spiral Model (Boehm, 1988) and the Star Model (Hix and Hartson, 1993).

The Waterfall Model has been adopted by manufacturing industries in which products are manufactured in a series of stages involving different processes and departments. The requirements of the design department are forwarded to manufacturing which follows a fixed sequence of production. Although the model was originally designed as an iterative model for production this can be time consuming and in practice there is often little communication between departments (Degoulet and Fieschi, 1996).

The Spiral Model is a cycle of assessment, planning, development and evaluation in which small changes are made at each stage. The process is repetitive so that the design develops through a succession of cycles. This is considered to be suitable for products in which there is scope for frequent adjustment during the development process but not where changes could be costly (Degoulet and Fieschi, 1996).

The Star Model places the evaluation at its centre and is popular in software development. Surrounding the evaluation are components of design process which feed into the evaluation as a central theme.

These examples exemplify the basic components of a design process. The initial stage is an assessment of requirements which may be the result of an identified problem. This is followed by specification of design solutions. The product is then developed from the design specification. It is implemented in a form that may be evaluated, for example a functional piece of software. The validation is in the form of trials of the product under realistic circumstances (Degoulet and Fieschi, 1996).

2.5.3 User-centred Design

It would be naïve of a designer to design a product for use by users with impairments and special needs without taking these needs into account. Cognitive and physical impairments are well documented in published literature. This may offer the designer an insight into disability and the effects of impairment, but does not provide the designer with an understanding of how the target audience relates to and interacts with a specific artefact or product. Design methods exist that utilise data gathered from the user during some or all phases of product development, for example user-centred design.

User-centred design (UCD) is a broad term that refers to product development in which the users and their representatives contribute to the design of a product. UCD places an "emphasis on making products usable and understandable" (Norman, 1988, p.188). UCD is a rational approach to design for this project because the involvement of patients and their representatives offers a method of directly gathering objective user performance data as well as subjective opinions, ideas and attitudes.

A definition of the term 'users' is provided here for clarification. Davis (1990) identifies primary users as those who interact directly with the computer and secondary users as those who interact indirectly with the computer. In the context of the thesis, stroke survivors are the primary users. The term user is employed throughout in reference to primary users unless otherwise indicated. OTs are considered to be secondary users.

2.5.4 International Standards for User-centred Design

Within the field of UCD there are recognised methods and international standards. The International Standards Organisation (ISO) has published benchmarks for the application of UCD in the form of ISO 13407 (ISO, 1999). The four key principles of ISO 13407 applied to UCD are to be found in table 2.1.

• Active involvement of users
• Appropriate allocation of function
• Iteration of design solutions
• A multidisciplinary design team

Table 2.1 Key principles of ISO 13407 (ISO, 1999).

'Active involvement of users' is subject to the design requirements and practicality. An intermediary or representative who speaks for the user is recommended by the standards if the users are unable to participate. This could be an issue with stroke survivors with a communication difficulty.

'Appropriate allocation of function' refers to recognising and acknowledging the skills and limitations of the user in order to distinguish between the tasks to be performed by the designed product and those to be performed by the user.

'Iteration of design solutions' enables small changes to be made and tested. Frequent evaluation aims to identify design flaws before they become serious.

The 'multidisciplinary design team' is necessary to optimise access to subject experts as consultants. This is of particular importance in a project that spans very different subject domains, such as this one, in which expertise in the fields of VR, stroke, software design, hardware design and human computer interaction are important.

Essential activities of the user centred design process are specified by ISO 13407 and are to be found below in table 2.2.

• Understand and specify the context of use • Specify the user and socio-cultural requirements • Produce designs solutions • Evaluate designs against requirements

Table 2.2 Essential activities of user centred design specified by ISO 13407.

'Understand and specify the context of use' is an activity in which the task is defined and users are observed performing existing tasks. The environment in which these tasks and future tasks are performed is studied and documented.

'Specifying user and socio-cultural requirements' is an activity in which the users and their needs are identified and made explicit. The activity, product or process is defined.

'Production of design solutions' is the activity in which the idea is developed into a working product that can be tested in the intended environment.

'Evaluating designs against requirements' compares performance data of users using the tool in the environment for which it was designed against the initial design requirements that were set at the beginning of the design process.

2.5.5 User-centred Design Approaches

UCD covers a range of activities in which users are involved in the design of a product. Various approaches to UCD have evolved to address different styles of working with clients. The context of use and the extent of user involvement in design are key drivers to choice of approach. Of the different UCD methods (for example contextual design, participatory design, empathic design, cooperative design), two approaches are introduced here in order to demonstrate the contrasting ways in which users may be involved in design.

Empathic Design typically involves observing the users as subjects performing familiar tasks in their own environment. The observer minimises contact in order not to disturb the natural patterns of working and through this remote observational method innovations and improvements to the work routines and production processes are developed.

Passively observing users in their own environment does not address the issues of what users themselves actually want. On the other hand users may be so accustomed to a procedure that they may not be able to consider improvements and new solutions to those procedures (Leonard and Rayport, 1997).

In contrast Participatory Design (PD) involves users of technology as partners or collaborators in the design process. PD embraces the philosophy that users are the best people to decide what they want from a product (Ehn, 1988; Blomberg and Henderson, 1990). The PD approach actively involves users in different stages of the design process, drawing on their experiences as well as acknowledging their capabilities and limitations.

Collaboration with users in the implementation of a technology also enables designers to understand how the technology will be used in the context of the work environment (Kensing and Blomberg, 1998).

PD is not without its problems. Cost and access to participants are potential barriers, and the working relationship between participants and those not involved may become strained because of the differences in ownership of the product. The collaboration on a specific project does not necessarily mean that the results will generalise (Ives and Olson, 1984).

2.5.6 The Structure of the Design Process

The design process for this project was based upon the activities defined by the international design standard ISO13407. These were presented in table 2.2.

The first activity of the project was to understand and specify the context of use which required the author to establish the kinds of tasks to simulate and to begin to understand both the intended environment and the user's requirements.

The second stage 'specify the user and socio-cultural requirements' involved consulting with stakeholders to identify the tasks and design features that they would find useful, and the issues of design that they are concerned about. The specific task was identified at this stage.

The development work for the project was divided into two stages: the VE and the TUI. The two activities of design 'produce designs solutions' and 'evaluate designs against requirements' were carried out for each component and merged to form the complete system. The designs were specified, constructed, tested with users and results fed back into the design process. This became a highly iterative process and is consistent with the Spiral Model (Boehm, 1988).

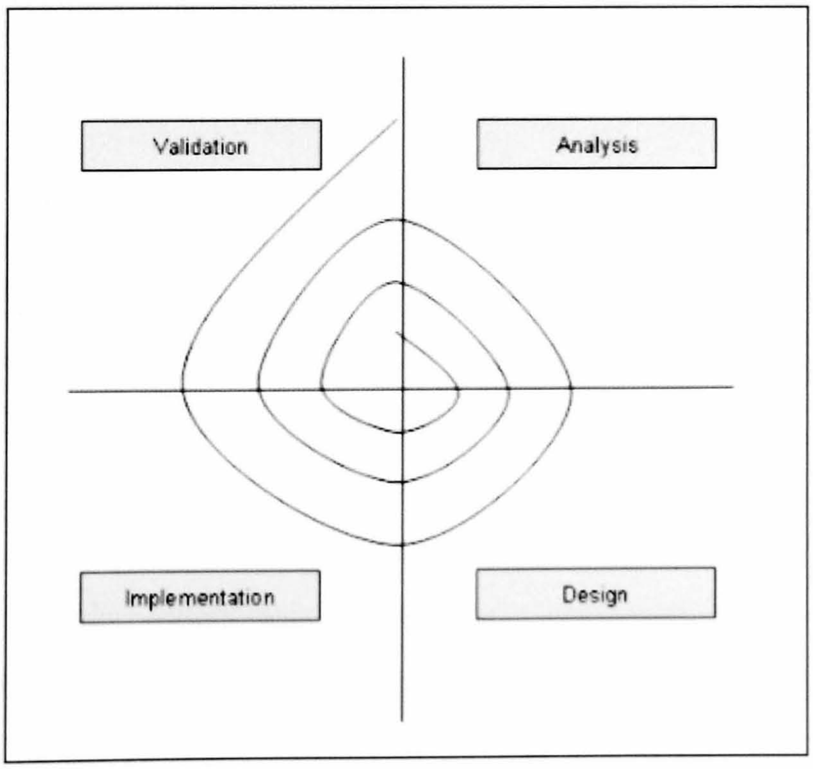

Figure 2.5 The Spiral Model (Boehm, 1988).

2.6 Summary of Chapter 2

The first part of the review considered the problems caused by stroke. Stroke causes impairments that affect cognitive and motor ability in ways that vary between individuals. These impairments have a detrimental effect on performance of every day activities.

Restorative rehabilitation aims to improve performance by treating the problem resulting from impairments. Useful and purposeful activities are recommended in a programme of rehabilitation as are learning motor and cognitive skills together in context.

A rehabilitation model was introduced as a reference for assisting in the choice of tasks to simulate. It was also used as a means of explaining why treatments that aim to restore function are better suited to disabilities that show promise of functional improvement, typical of many stroke survivors, and why others are better directed at adapting the environment, typical of progressive illnesses such as dementia.

Applications of VR have shown promise in rehabilitation and assessment strategies and these were discussed. Few studies involving VR in stroke rehabilitation have been conducted in the rehabilitation environment and few studies have been designed to include natural movement of the upper limb as an integral part of a simulation of an everyday activity.

The MR spectrum shows the gulf between activities conducted in the real world and activities conducted in a VE. A range of different technologies span the MR spectrum. Of these TUIs employ physical objects as controllers of digital data and address the problem of simulating and encouraging natural movement.

To investigate the needs of stroke patients as users of technology, a strategy to gather data directly from stakeholders was planned to complement the knowledge gained from the literature review. In order to design VR systems for stroke rehabilitation, an understanding of stroke patients' needs and barriers to participation is important. Of various design methods, UCD shows promise because it includes users in the design process. ISO13407 International Standard for UCD (ISO, 1999) identifies the process and activities that conform to good design. These formed the structure to the design process and identified the activities of design.

Studies were conducted in which patients, consultants and therapists were introduced to VR, including an application of a TUI. Their perspectives and opinions were gathered in order to feed back into the design process and this consultation phase of development is presented in the following chapter.

Chapter 3: The Consultation Phase

3.1 Introduction

The stroke rehabilitation literature recommended selecting tasks that are meaningful to the patient, enabling them to achieve an outcome that is purposeful and useful to everyday living. Following a review of literature the next stage of the design was a phase of consultation.

Three studies were carried out to introduce VR to therapists, consultants and stroke survivors. These also provided an opportunity to discuss the implications of using VR methods for stroke assessment and rehabilitation with different stakeholders.

Figure 3.1 shows the activities of design that were relevant to this particular phase of the process. The studies presented in this chapter show how the choice of activity for the simulation was made. They also demonstrate the different perspectives of stakeholders, and establish some attributes of VR that stakeholders considered to be important in the specification of the design.

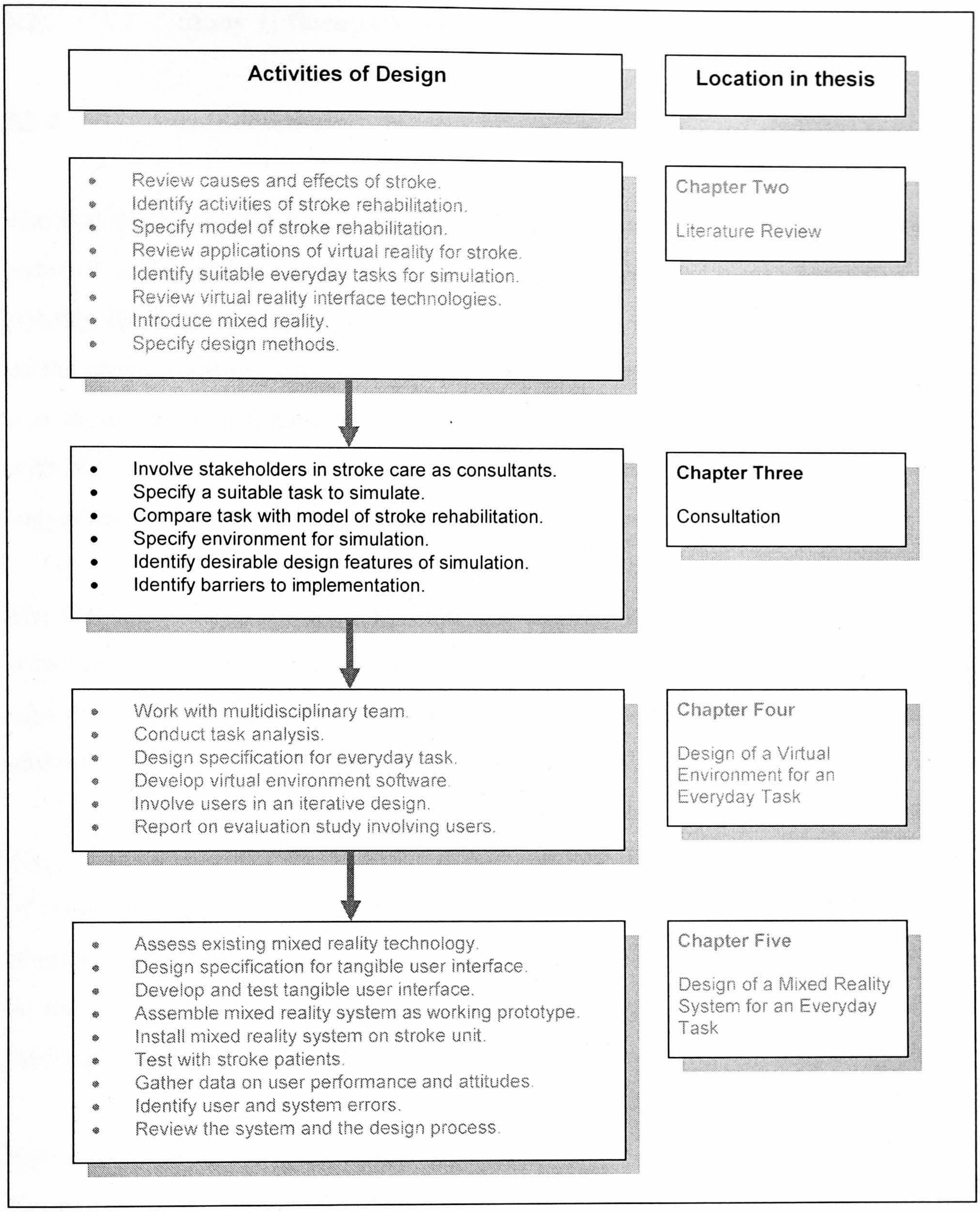

Figure 3.1 Activities of design presented in chapter three.

3.2 Study 1: Occupational Therapists

3.2.1 Introduction

The first step towards a dialogue with stroke carers was to make contact with a ward-sister of a Health Care of the Elderly (HCE) ward at the Queens Medical Centre (QMC), Nottingham, UK. The QMC is a large 1400 bed teaching hospital situated on the edge of Nottingham, a city with a population of over 200,000. The HCE ward was chosen because it includes stroke admissions. The concept of VR was discussed with the ward sister in the context of stroke rehabilitation and the ward sister suggested that this should be discussed further with a ward based OT.

The OT discussed assessment batteries and rehabilitation treatments currently used with stroke patients. Of concern to the OT was that any new strategies would not be permitted in the repertoire of current assessment and rehabilitation techniques without evidence of effectiveness and without direction from senior staff.

The OT expressed further concern that her opinions do not necessarily reflect those of other OTs and it was decided to hold a wider study in the form of a workshop event for OTs. The event took place in June 2000. The venue was a large classroom at the author's place of employment, the University of Nottingham School of Nursing, within the QMC.

Social Services provided a directory of OTs employed throughout the county of Nottinghamshire, which was targeted through consideration of convenience and accessibility to the venue. Of 166 OTs invited to the event, 22 people attended. Considering the workload of OTs this was considered to be good attendance. The aims of the workshop were:

- To introduce OTs involved in stroke rehabilitation to VR.
- To assess acceptability within the OT community of VR as a rehabilitation tool.
- To involve health professionals in discussions about user related issues and practical implementation of VR technology.

3.2.2 Method

A colleague gave a short presentation during which terminology and concepts used in VR and VEs were introduced and explained. Delegates were shown PowerPoint™ slides of four examples of VEs that were designed for different purposes. These are explained in more depth later.

Following the presentation, the actual VEs were made available on four computer workstations placed around the venue, which was a large classroom. The delegates were divided into four groups and members of each group were given the opportunity to experience each VE in turn. Participants were allocated a ten minute period to review the environments at each workstation. Staff from the Virtual Reality Applications Research Team (VIRART) at the University of Nottingham, UK, assisted with the workshops.

The four environments are shown below. The Virtual Factory (Figure 3.2) was a simulation of an industrial manufacturing environment that was designed specifically for the assessment of health and safety issues. The factory contained hazards that the user had to locate and identify by navigating the factory layout (Cobb and Brown, 1997).

The Virtual City was a collection of simulated daily activities (Figure 3.3). These included acquiring items on a shopping list, using a bus and navigating around streets. It was a dynamic city with moving traffic and people walking along the streets. It included shops and road crossings, and was designed for people with a learning disability to experience a simulation of real activities (Brown et al., 1999).

Virtual Lego (Figure 3.4) was a kit of simulated construction blocks that when assembled in the correct order build into a three-dimensional model of an off-road vehicle. It was demonstrated to show how spatial manipulation and sequential processing can be practised and assessed in a VE (D'Cruz, 1999).

A TUI was also demonstrated at this workshop. The TUI was a coffee making simulation in the form of a tactile device that was mounted above a standard computer keyboard (Figure 3.5). It employed real objects that were connected to actuators that operated a key-press when the objects were used. A coffee making simulation with VR model objects was displayed on the screen. Interacting with the physical objects caused activation of the virtual object in the VE. For example unscrewing the coffee jar lid caused the lid in the VE to unscrew. Interactions with physical objects in the real world were reflected as animations in the VE (Starmer, 2000).

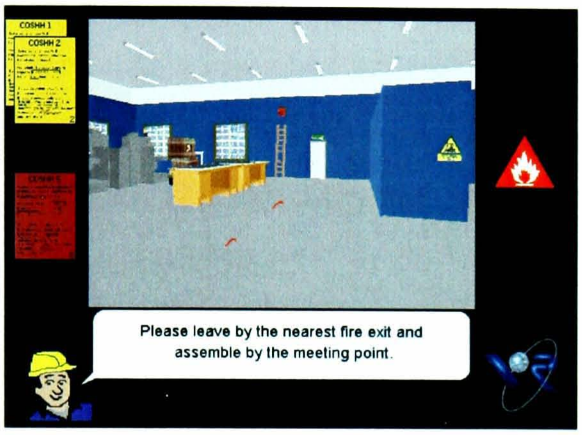

Figure 3.2 The virtual factory (Cobb and Brown, 1997).

Figure 3.3 The virtual supermarket (Brown et al., 1999).

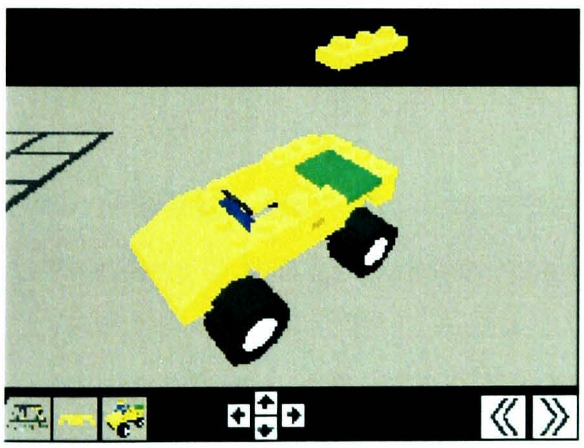

Figure 3.4 Virtual Lego™ (D'Cruz, 1999).

Figure 3.5 Tangible user interface to a hot drink making activity (Starmer, 2000).

Following the demonstrations and presentations a questionnaire was given out to all participants. Questionnaires were used for quickly gathering data because respondents were able to work at their own pace and work in parallel, improving the data gathering return time compared with interviewing.

Participants were asked to specify their role in stroke patient care. and work location (community or hospital). They were asked about their experiences of using VR then asked about their perspectives of VR for stroke rehabilitation. Scores were recorded using a five-point Likert scale, to rate twenty-five factors.

Three key questions were presented to the participants by a facilitator for discussion in the form of a focus group. The aim of a focus group was to gather information about the participants' "desires, experiences and priorities" (Kuniavsky, 2003, p.201). Observation notes were made and responses were recorded onto Mini DV tape to be transcribed after the event. The three questions posed to the group were:

- What should influence the design of VR systems for stroke assessment and rehabilitation?
- At what stage in the rehabilitation process would VR best be applied?
- What are the barriers to this (VR) technology being used routinely in stroke assessment and rehabilitation?

3.2.3 Results

3.2.3.1 Occupation Type and Location of Employment

The following data were acquired from the questionnaires. The distribution of respondents by occupation and location of employment is shown in table 3.1

Hospital based OT	11
Community based OT	5
Nurse / physiotherapist in HCE	3
Other	3
Total	22

Table 3.1 Participants occupation and work location.

Of 22 people attending only 16 were OTs, the remainder being healthcare professionals who were delegated to attend.

3.2.3.2 Prior Experience

Only two participants claimed to have had any experience of VR prior to the workshop. One participant reported an experience of VR in the context of online shopping, and the other in the context of three dimensional computer games. The nature of the online shopping experience was not made clear and it is not known whether this was actually an application of VR.

3.2.3.3 Using Virtual Reality with Stroke Survivors

This section of the questionnaire was divided into two parts. In the first part, participants were presented with a list of eight characteristics of patients and asked to give their opinion of the importance of each to the participation of patients in the use of VR as part of their treatment or assessment. Results are presented in table 3.2.

In the second part seventeen questions were presented that relate to the practical use of VR technology in stroke rehabilitation. Subjects were invited to give their opinion of the importance of these. Results are presented in table 3.3.

The scoring system used a five point Likert scale, polarised between very unimportant and very important. Low importance scored one point; a neutral answer scored three points and high importance scored five points.

Questionnaires from those participants who did not have direct involvement in stroke care were removed from the data set because it could not be presumed that they would possess the relevant experience to answer the questions.

Experience with stroke survivors was ascertained from a question that was posed at the beginning of the questionnaire. Within the sample some questions were not completed. The number of responses after exclusion is indicated below in the 'n' column.

Attribute	n	Low < Importance > High					Median	Range
		1	2	3	4	5		
Age of the Patient	12	1	1	2	3	5	4	4
Gender of Patient	12	5	6	1	0	0	2	2
Severity of Stroke	12	0	0	1	5	6	4.5	2
Patient Motivation	12	0	0	2	5	5	4	2
Patient's Prior Experience	12	0	4	4	3	1	3	3
Patient's Physical Mobility	12	1	6	3	1	1	2	4
Patient's Anxiety	12	0	1	4	5	2	4	3
Potential VR Side effects	12	0	0	2	5	5	4	2

Table 3.2 Therapists' perspectives of the importance of patients' attributes as criteria for participation in the use of VR.

Attribute	n	Low < Importance > High					Median	Range
		1	2	3	4	5		
Easy to use by the therapist	12	0	0	1	2	9	5	2
Intuitive Interface	8	0	0	3	2	3	4	2
Easy to control by patient	12	0	0	1	2	9	5	2
Simple Environment	12	0	1	4	3	4	4	3
Realistic Looking Environment	12	0	1	0	5	6	4.5	3
Objects Behave Realistically	10	0	0	0	3	7	5	1
(3D) Display	10	0	0	2	4	4	4	2
Provides Quantitative Data	11	0	0	3	5	3	4	2
Provides a Printout	12	0	0	7	3	2	3	2
Levels of Difficulty	12	0	0	1	2	9	5	2
Under Supervision Only	11	2	3	2	3	1	3	4
Time Limits	12	0	0	6	5	1	3.5	2
Inexpensive Equipment	12	0	0	2	6	4	4	2
Accessible via the Internet	12	0	1	3	4	4	4	3
Could be Used at Patient Home	12	0	0	3	4	5	4	2
Ability to Manipulate Objects	12	0	0	2	6	4	4	2
Touch (haptic) Feedback	11	0	4	1	3	3	4	3

Table 3.3 Therapists' perspectives of the importance of different design features.

Descriptive statistics presented are the median and the range of values in the format [median, range]. Higher median values correspond to higher perceived importance, greater ranges indicate lower consensus of opinion.

From table 3.2, severity of stroke was seen as important consideration in the use of VR as a rehabilitation tool [4.5, 2]. Patient's anxiety [4, 3], possible side effects [4, 2] and patient's motivation [4, 2] were also of concern. Patient's gender was considered to be of low importance [2, 2]. Patient's age [4, 4] and physical mobility [2, 4] provided the greatest variation in opinion.

Table 3.3 shows realism of object behaviour ranking highest of the design features [5, 1]. Ease of use by the therapist, ease of control by the patient, and the option to vary levels of difficulty were considered to be of equally high importance [5, 2]. A realistic environment was also considered to be important although there was low consensus on this [4.5, 3]. The ability to provide a printout was considered as a low priority [3, 2]. Working under supervision only attracted the greatest diversity of opinion [3, 4].

3.2.3.4 Therapist Focus Group

A summary of the notes and transcriptions of responses to the three discussion questions that were posed to the group is presented below:

1. 'What should influence the design of VR systems for stroke assessment and rehabilitation?'

The strength of VR technology according to the participants was the ability to produce realistic, safe and accessible, models of the physical world. The ability to create a realistic simulated environment in which the patient can perform purposeful tasks was considered to be important. The provision of graded levels of difficulty was a desirable attribute as was monitoring of performance and progress. Enabling the patient to work towards independence from the therapist was also identified as a desirable feature.

Interfacing with the environment raised some concern due to the differing physical abilities of these patients. It was suggested that a variety of input modes should be offered including touch screen, mouse, keyboard and other controls as appropriate. Versatility of input appears therefore to be a key issue.

2. 'At what stage in the rehabilitation process would VR best be applied?'

It was suggested that VR might be used to support initial assessment in hospital, but was perceived to have potential for application in both home and clinical environments. Attention shifted during the discussion towards the interface between hospital and community. The move towards more community-based care in the UK has increased the importance of assessing and promoting independence in everyday living skills.

Comments were made about the difficulties and reliability of safety assessment in performing tasks with an element of possible danger. For example patients would not be expected to handle boiled water in the hospital assessment setting. The potential of VR to provide a safe method of developing a patient's ability to perform hazardous tasks was considered a benefit of this technology.

3. 'What are the barriers to this technology being used routinely in stroke assessment and rehabilitation? '

The expense of VR equipment was identified early in the discussion as a concern. There was also an emphasis on the need to demonstrate clinical effectiveness through evidence-based practice, which requires that outcome measures must show the benefit of a given treatment. It was suggested that computer-based rehabilitation has not been widely accepted because of a lack of evidence of transfer of training.

3.2.4 Discussion

The seminar achieved the aim of introducing VR to OTs. The results of the questionnaire and the discussion held in the focus groups represent perceptions that are based upon a very limited prior experience of VR.

A suggestion that VEs might incorporate assessment strategies within the activities was made by the group. Benefits of VR technology were also discussed. The emphasis was placed upon the development of realistic environments in which meaningful activities can take place in safety.

Therapists were in a position to report on the pragmatic issues of introducing VR technology to the ward. Concerns were raised that in order for VR to be used routinely in a climate of evidence-based practice. trials of VR based tools would have to show a demonstrable improvement over current procedures.

Accountability was mentioned and the OT would not be expected to introduce new strategies without the consent of a consultant in authority. Following this first study a second study was organised in which consultants working in stroke care were invited to participate.

3.3 Study 2: Consultants

3.3.1 Introduction

In the previous study, therapists explained that decisions to implement new treatment strategies were not theirs to make but that these were authorised by stroke consultants in line with best practice and current research. The University of Nottingham has an active stroke research community and the logical way forward was to involve consultants in discussions about the design of VR for stroke care. The head of the Ageing and Disability Research Unit was first contacted, leading to the identification of potential participants. Letters were written to these people and four consultants agreed to attend a meeting.

3.3.2 Method

The meeting was held in the Mixed Reality Laboratory at the University of Nottingham Jubilee Campus, Nottingham. The four consultants in attendance were actively involved in stroke research and of these two had previously trained as OTs.

The four VEs described in the previous study were demonstrated to the consultants. There was an opportunity to discuss each of these in turn. The same three focus questions that were put to the therapist group were posed to the consultants. The conversation was recorded onto audio-tape and this was later transcribed.

3.3.3 Results

The consultant group suggested that embedding treatment strategies within realistic simulations of real world environments was preferential to replacing currently available abstract test batteries. The individual needs of the patients were considered to be important design issues. Both OTs present identified patient safety as important and reiterated the ability of VR to facilitate training in a safe and controllable environment.

There was a recommendation from the group that initial research in this area should take a case-based approach, working closely with a small number of patients rather than immediately attempting to identify generic techniques and solutions through randomised controlled trials.

3.3.4 Discussion

Discussions with the consultants reinforced the idea that VR could be useful for simulating environments for training that are safe for the user to practice in. The recommendation was not to use VEs to replace current assessment strategies but instead to use the VEs to assess cognitive and motor abilities that are not currently tested by assessment batteries.

Consultants proposed that although simple pen and paper tests do not quantify the extent of impairment, they have been shown to be reliable at assessing the presence of impairment. Replicating these on a monitor makes little sense and does not make use of the richness offered by a VE.

3.4 Study 3: Stroke Survivors in the Community

3.4.1 Introduction

In the third study former stroke patients were consulted to obtain the users' perspectives. Of particular interest at this stage were those stroke survivors who have returned to the community after a period of rehabilitation, because their personal experiences of care in hospital setting would be retrospective and they would be able to report on all stages of the rehabilitation process.

Community groups for stroke survivors were identified from a directory of self-help groups that was supplied by patient's reception at QMC. Following introductory letters that were sent to the secretaries of community based stroke clubs throughout Nottinghamshire, an invitation came from the co-ordinator of one group to discuss the project further with a view to holding a workshop with group members. The group was primarily a group for people with aphasia.

3.4.2 Method

The first meeting with stroke survivors was held in a community hall in Nottingham during a scheduled stroke club meeting in February 2001. Initially the number of club members attending was fifteen but this fluctuated during the proceedings. To maintain consistency with previous studies it was decided that the presentation would include the same four VEs that were demonstrated to the consultant and therapist groups at previous meetings.

The equipment was a Toshiba Tecra notebook computer connected to a Philips data projector. The environments were introduced and displayed to the group using data projection. The concept of VR as a means of creating a simulation of a real world scene was explained by the author and colleagues of the author.

Observation notes were taken and an audio tape was made of the proceedings. The small design team at this stage comprised the author and two supervisors. Following the presentation the chair of the group facilitated a discussion forum. It was felt inappropriate and unnecessary to invite a speech therapist to this meeting as the group operated normally under the leadership of the chairperson.

A group discussion was held that was based around the three focus questions that had been asked previously to the consultant and therapist groups. The dialogue was audio-taped and transcribed.

A follow up visit to the venue was made two months after the first demonstration. The purpose of the visit was to discuss any further thoughts that had not been expressed at the first meeting.

Ten participants attended the second event. Of these nine were stroke survivors and one was the wife (and carer) of one of those attending. All ten people had been present at the first demonstration. The follow up meeting took the form of a group discussion with the chairperson in attendance. The discussion was informal and was an invitation to those attending to add any further comments to those given at the first meeting with former patients.

3.4.3 Results

3.4.3.1 First meeting

Members present suggested that they could see the purpose of VR in rehabilitation. They added that having already returned to the community, this form of activity would be too late for them and the opportunity to practice tasks in the hospital setting was seen as a better place for VR.

The transition from hospital to community caused concern amongst participants. Concern was also expressed that despite attempts by shops and services to improve disabled access, the perception was that environments were not adapted to their needs.

Concern was also expressed that computer technology could be too difficult for elderly people to learn and simplicity of operation was requested.

3.4.3.2 Second Meeting

Those present described the assessments and treatment that had been administered by the OTs in hospital. Proficiency in these was seen as a means to returning home but comments were made about the limited opportunity to practice. Three members of the group (all male) identified making a hot drink as an activity that had been used as a component of their assessment of independence.

The group discussed the most appropriate timing and method of using VR technology in their rehabilitation. The opportunity to practice practical household skills was commented upon as something that would be well received.

Of importance in the consideration of designing VR technology was ease of use. Members of the group were mostly elderly and of those attending the second meeting only one person claimed to have any prior experience of using a computer. Ease of operation was therefore an important attribute of any new VR system as the users did not want to learn how to use a computer in addition to the task being practiced.

3.5 Selection of a Task to Simulate

The literature review in the previous chapter and the three studies presented in this chapter together give an insight into the problems that face the stroke survivor and the kinds of activities that would be appropriate for a rehabilitation setting.

The use of VR for simulating everyday activities and reducing risk of self harm by accidental injury was a recurring theme. The dangers of cooking and using hot liquids are eliminated in a computer simulation.

Preparing a hot drink is used routinely by OTs as an assessment of function in the stroke survivor. It has been used as the basis of previous VR studies for stroke assessment and rehabilitation because of its suitability (see chapter 2). It was concluded that a hot drink making task would be an appropriate focus for the simulation. Of the different hot drinks, a cup of instant coffee was initially chosen because it has fewer stages than making tea in a pot although the patient's preference of hot drink can influence the choice of assessment administered by the OT.

Practicing to make a hot drink is a purposeful and useful task that involves sequences of actions. It includes skills training (physical and cognitive) and goal setting. Administered as part of a rehabilitation therapy it could be used to offer encouragement. The activity is therefore consistent with the model of restorative rehabilitation presented in chapter 2 (Gladman et al., 2006).

3.6 Summary of Chapter 3

Therapists, consultants and former stroke patients were introduced to the concept of VR and to a range of different types of applications of VR. Their opinions and perspectives on VR were collected using a variety of data gathering techniques, including questionnaires and focus groups.

Importance was placed on designing applications that were realistic and that presented simulations of useful everyday tasks. Of particular interest was the possibility of simulating tasks that have an element of danger, such as handling hot liquids or using kitchen equipment.

A hot drink making task was chosen as the focus of the simulation because it was reported by stroke survivors that this was used as an assessment of independence and consequently an indicator of suitability for returning home. Having identified a task to model, the next stage was to develop a simulation of the task. This required a multidisciplinary team to address the diverse issues of developing technology for stroke survivors.

The following chapter presents the work of the team in developing the VE and the underlying software. The programming was carried out by the author and work presented here is the author's contribution to the project unless it is identified as being otherwise.

Chapter 4 Design of a Virtual Environment for an Everyday Task

4.1 Introduction

Following the consultation phase presented in chapter three, a coffee making task was chosen as the focus of the MR system. The rationale for the choice of task was that making coffee is a useful everyday activity but there are hazards because the task involves boiling water and the use of kitchen appliances.

The nature of the interaction with the VE was discussed in chapters two and three. The literature review revealed that appropriate physical movement in context of cognitive processes is considered to be important in rehabilitation of activities of daily living.

Studies involving stroke patients performing activities of daily living in VEs have focussed their attention upon cognitive processes and relearning sequences of actions. Few have required the participants to demonstrate dexterity in the fine physical hand and finger movements that the participant would require to complete the equivalent real world task.

Different input technologies were considered in chapter two and of these an MR system with a TUI was chosen as a design goal because the physical properties of the objects impose constraints on movement and handling that are difficult to achieve in a VE.

This chapter presents design activities that led to the development of the software and VE component of the MR system. It follows the formation of a multidisciplinary team and roles of its members, presents a task analysis, a design specification and the software development. The development and evaluation of the VE was a substantial project which was funded by the Stroke Association for a period of two years. The final section is a report of a study carried out to evaluate the VE, the majority of the field work being done by an OT who was a member of the design team.

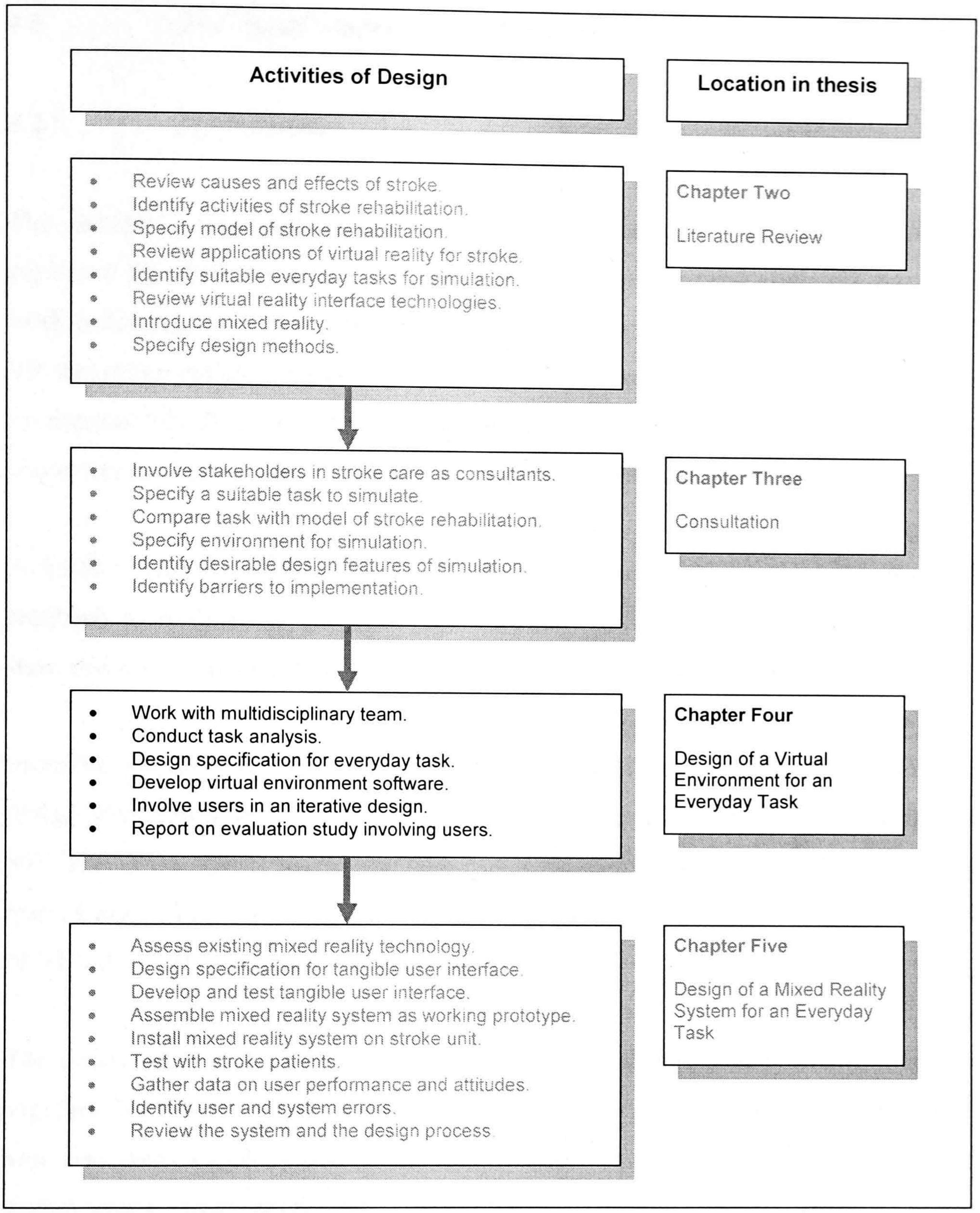

Figure 4.1 Activities of design presented in chapter four.

Figure 4.1 shows the activities of design that are presented in this chapter and how this phase of the design relates to other activities of the design process.

4.2 The Initial Stages of the VE Design

4.2.1 Introduction

The therapists who participated in the study reported in the previous chapter explained that they would not give direct instructions but would allow the patient to work independently, intervening only when necessary. Therapists were critical of VR that presented material in a rigidly sequential format. The coffee task constructed by Starmer (2000) that was demonstrated to stakeholders during the consultation phase was an example of a fixed sequence instructional training package.

A further criticism of the systems demonstrated was the absence of any recorded feedback or measure of patient's performance. Feedback and performance scores were considered to be useful design features by those therapists consulted.

From the consultations held with stakeholders the desirable attributes of any new VE design were emerging. The task was decided and the next stage was to develop the VE. The design process and the ISO 13407 standard required a multidisciplinary team. Consultants who participated in the previous studies were contacted. Members of VIRART were also invited to participate.

The design and production of the VE required a multidisciplinary effort, bringing together diverse knowledge from the fields of health and technology. A consultant who had participated in one of the earlier studies (see chapter three) chaired the design group. Individuals within the group had expertise in the fields of stroke research, computer science, hardware design and human factors. The team did not at this stage include an OT. The inclusion of an OT was considered to be important in order to have someone in the team who could work directly with the patients, having the skills to administer the simulation and to assess the patient.

The team received funding from the Stroke Association, enabling a full time OT to be employed on the project. Stroke Association Project 'TSA 13/02: Evaluation of a Virtual Environment for Stroke Rehabilitation' commenced in October 2003.

4.2.2 Multidisciplinary Team and Roles

The roles of the multidisciplinary team members were established. The author's role at this stage was the design and development of the VE. The role of the OT was to test the VEs with stroke patients, to identify and report problems encountered. and to feed the results back to the designer (author). The remaining members of the team formed a consultative committee steering the project and managing problems as they arose.

Bimonthly project team meetings were held to keep the project on track and to discuss alterations to any aspect of the research. Frequent interim meetings between the OT and author were held to discuss specific aspects of design and development.

4.2.3 Design Requirements

The initial activity of the team was to draw up a list of requirements for the VE based upon the findings of the previous consultation studies and personal expertise. The new VE should be was flexible in terms of movement of objects and task sequence. It should be easy to use. Objects should look and behave realistically. It should simulate a useful every day task. In addition the OT recommended that there should be a measure of task performance.

The OT was considered by the team to be a suitable candidate for the design of a scoring system because of her previous experience of developing and evaluating a stroke assessment index (Edmans and Webster, 1997).

For the VE to be useful, a comprehensive record of user activity was requested by the team in addition to a summary score. The consultation team identified the following data as necessary for the purposes of assessing the patient: the objects selected by the patient, whether the patient performs a task independently or requires assistance, whether the action taken was correct or incorrect, and the timing of each action.

Keeping track of performance and enabling freedom of choice in the task sequence (where appropriate) was seen as key to the design. Conveying the status of the task in the form of visible and audible feedback that was meaningful to the patient was also considered to be important by the team.

These design requirements and recommendations were summarized in the initial design specification (see table 4.1) which lists the desirable and essential attributes of the VE. At this stage it was not highly specific as the design was subject to change, but it provides a broad list of important features to be included in the VE.

Initial design specification for virtual environment
The task simulated in the VE must resemble a real coffee making task. The objects in the VE must resemble real objects. The objects must be freely mobile so that the therapist can place these as required. The workspace will also resemble the workspace used in a kitchen assessment. There will be no distracting or superfluous equipment.
The order or sequence in which the activities are performed is to be flexible. The constraint on sequence is that any sequences of events that are inappropriate or dangerous (if a real task) are not permitted.
Scores of performance are to be recorded. To be included are user identity, timing of activity, sequence of user input. A scoring system is to be devised and implemented, to score useful measures of task performance on a scale to be devised.
The system will intervene as necessary. The system will not instruct or direct the user unless there is failure to complete an action or an inappropriate action has been performed. The system will offer prompts, warnings and demonstrate correct actions as necessary.
Input will be versatile. The VE is to be developed and tested as a Stroke Association funded project but with the option of permitting a TUI to complete the MR project.
Delivery of the VE for the Stroke Association project is to be portable as equipment is to be recovered and locked away after every trial. For the MR system portability is to be considered. Storage on ward to be investigated as an alternative.

Table 4.1 The design specification for the VE.

4.2.4 Task Analysis

To enable the task to be simulated a description of the task was required. A task analysis is a design method that investigates how an activity is carried out in existing circumstances (Lindgaard, 1994). The result of the exercise is data that provides information about the task in a format that is appropriate for the purposes for which it was gathered. Kirwan and Ainsworth (1992) have categorized the different task analysis techniques into five categories.

- task data collection methods
- task description methods
- task simulation methods
- task behaviour assessment methods
- task requirements evaluation methods

'Task data collection methods' are techniques for gathering user performance data about an existing or proposed task. 'Task description methods' represent the task in the form of flowcharts or diagrams that describe the component actions that are involved in the task and the relationships between these actions. 'Task simulation methods' investigate the way people perform during an activity by using simulations of the activity and by expert walkthroughs. 'Task behaviour assessment methods' are used to identify safety problems that may arise in a system. 'Task requirements evaluation methods' are used to determine whether the equipment supports the user adequately in task performance (Lindgaard, 1994).

For this stage of development a task description was required. Hierarchical Task Analysis (HTA) was selected as a specific method because the result of a task analysis is a representation of the individual actions and the relationship between these actions. HTA has its origins in education and training. It is able to deconstruct a learning activity into its key learning objectives and to structure these components to allow the developer to identify strategic stages in the activity where assessment can take place.

In the context of this project the HTA was used to identify the components of the coffee making task and identify actions that are individually able to be assessed. The broad themes of a task are identified and each of these is divided into subordinate tasks or subtasks. Subtasks are further broken down until the task is described in terms of specific actions. The result is a flowchart that represents the connections and relationships between subtasks (Lindgaard, 1994; Kuniavsky, 2003).

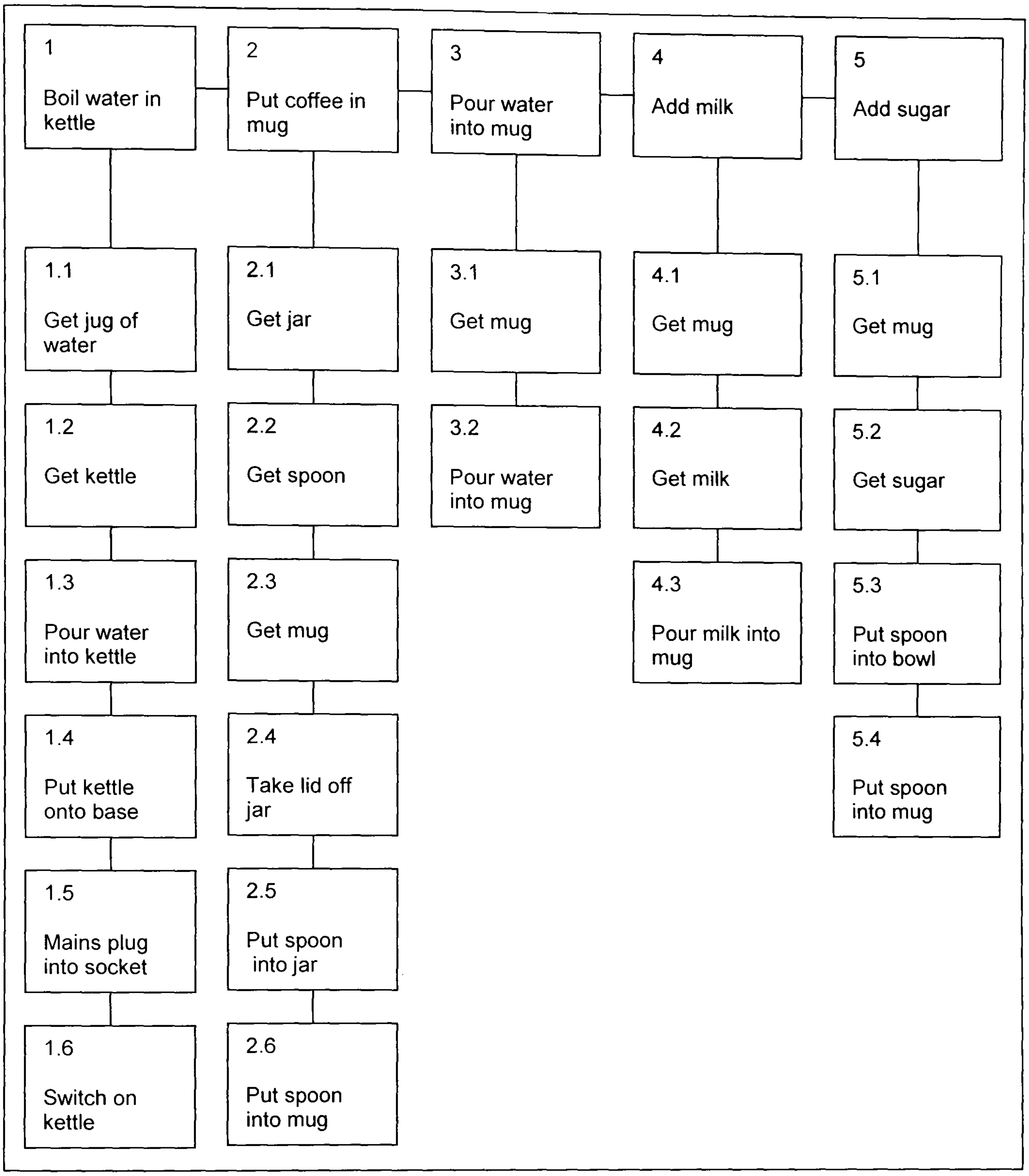

Figure 4.2 Task analysis for making instant coffee.

The task was defined as making a mug of instant coffee. Three compulsory components were specified: boiling water, spooning coffee (from a jar into a mug) and adding boiled water to the mug. Milk and sugar were offered as optional parts of the activity.

The OT explained that in the stroke rehabilitation setting that patients would not be expected to turn on a tap therefore the actions required to fill the kettle were adapted to comply with the procedure that would be followed on the stroke ward. This involved pouring water from a pre-filled jug. In the simulation water was boiled using an electrical kettle.

Certain top level tasks are not constrained to a fixed sequence, for example coffee can be put in the mug after boiled water has been added to the mug. The only mandatory and commonsense sequence is boiling the water prior to pouring it into the mug. The danger of damaging a kettle exists if the kettle is switched on whilst it is empty.

The five highest level tasks were subdivided into sequences of actions to complete the task. At this level there were certain subtasks that required the completion of prerequisite subtasks. For example, to boil water, there must be water in the kettle, the kettle must be plugged in and the kettle must be switched on.

HTA allows each of the subtasks to be divided further in order to describe specific movements however for the purposes of designing the VE the level of description shown in figure 4.2 was adequate: each subtask represents a discrete user action and this was considered to be at the appropriate level.

4.2.5 Description of the Virtual Environment as a System

A VE system plan was developed from the specification. Figure 4.3 shows an overview of the system. There were two distinct components of the system: one that facilitated the activity, monitoring the patients input and providing visible and audible feedback, the other in a supportive role, providing prompts, intervention and demonstrations as appropriate.

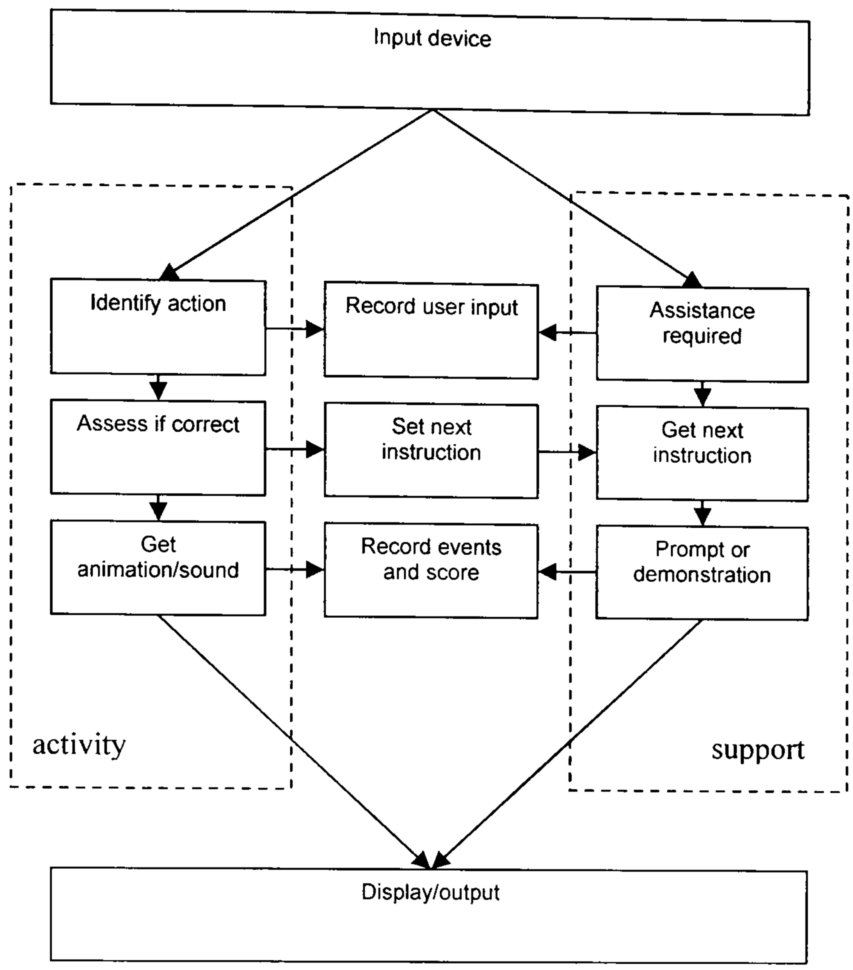

Figure 4.3 Structure of the VE system.

The system is explained in more depth below but an explanation of the diagram is presented here. The user performs an action by selecting, moving or acting upon an object. The system identifies the action by examining the objects and the context to assess whether the action is correct. The action is recorded in a file for the OT to examine after the session.

Feedback is given in the form of an audible and visible response. If the correct action is performed the VE responds by playing an appropriate prerecorded animation, for example water pouring into the kettle accompanied by a recorded sound clip of water being poured. The score for the action is calculated and the total score is updated.

If the user is unable to perform an appropriate action then the next instruction is identified and a verbal prompt is given. If the user completes the action then a score is recorded, however this is not the maximum score possible. The score is reduced following a prompt. This is explained in more depth later.

The user has a final opportunity to complete the action. Failing this the system presents a demonstration of the correct action and the system selects the next appropriate action which the use should attempt.

4.2.6 Defining the Stages of the Activity

The task analysis was used to define the actions and the objects required for each stage of the activity. This is presented in table 4.2 below.

Action
Get the jug
Get the kettle
Pour water into the kettle
Put kettle on the base
Plug the base into an electrical socket
Switch on the kettle
Get the coffee jar
Remove the jar lid
Get the spoon
Get the mug
Put the spoon into the coffee
Put the spoon into the mug
Get the milk
Pour milk into the mug
Get the sugar
Put spoon into sugar
Put the spoon in to the mug
Pour boiling water into the mug

Table 4.2 Actions for coffee making activity.

The objects that were required for this task were: jug, kettle, kettle base, socket, jar, spoon, mug, milk carton, sugar bowl. The colours were selected for reasons that are explained in more depth in the following chapter but in summary the objects were chosen to be individually of unique hue because the intention was that the VE software would be used for both the Stroke Association project TSA13/02 and for the MR project, for which the TUI used a computer vision system that used hue recognition.

Early into the project development, the OT requested that the task should be expanded to include making a cup of tea. This was debated by the design team. The OT's case was that patients may not drink coffee and that offering an alternative would enable these people to be included in trials of the VE. The case against is that it is a different task, requiring some additional objects in the environment. The design team decided that a tea making task was not sufficiently different to the coffee making task because the actions are very similar and most compulsory tasks are common to both. The design team concluded that the VE could include the option of a tea making task.

A teapot was added to the repertoire of objects. The tea making task was not intended to be part of the MR project however the modular approach to the software design enabled the tea task to be added fairly easily to the VE. Other objects retained their usual function.

4.2.7 Software Development Tools

The VEs that were demonstrated to therapists, former patients and consultants (see chapter three) were developed using a software tool called Superscape VRT™. The manufacturers of Superscape VRT™ discontinued production and support of the product, requiring an alternative for this project. A VR development tool called Virtools™ was chosen for its ability to enable rapid development and testing. This was readily available because it was the design tool in use by VIRART. Following some experimentation with Virtools™ it was decided by the author that it was an adequate tool for the task.

Virtools™ is not an object modelling tool but an environment modelling tool. The method of creating VEs recommended by the manufacturers is to create objects using an external 3D modelling tool (for example Lightwave™, 3D Studio Max™) and then to import these into Virtools™.

Objects imported into the Virtools™ development tool are given behaviours. The behaviours define how an object moves, how it responds to an interaction with other objects in the scene, and how the object is controlled. These may be sourced from a library of behaviours as part of the Virtools™ package or may be constructed by the designer. Multiple behaviours may be combined to produce complex behaviours and responses. Specific values (for example initial position, limits of movement, forces) are added by the designer as appropriate.

Virtual objects have associated behaviours that either respond to a change of the objects state or bring about a change in the objects state. This includes position, orientation and the proximity with other objects. The state of an object may be changed by one of the following three mechanisms:

- A change that is initiated by the user
- A change that is initiated by some internal mechanism
- A change caused by the interaction between two (or more) objects.

Pressing a switch is an example of an object state change that is initiated by the user. A temperature sensitive switch in a kettle that turns it off when the water has boiled is an example of an internal mechanism. Putting a spoon into a jar of coffee is an example of one object acting upon another object.

Figure 4.4 shows an image of the Virtools™ development screen. The VE development window is on the top left side. To the right is a library of behaviours that are dragged onto the scripting area, shown below the development stage. The scripts for objects are interconnected to form a flow chart allowing complex behaviours and interactions to be programmed. Scripts may be grouped together to improve readability and to reduce screen area.

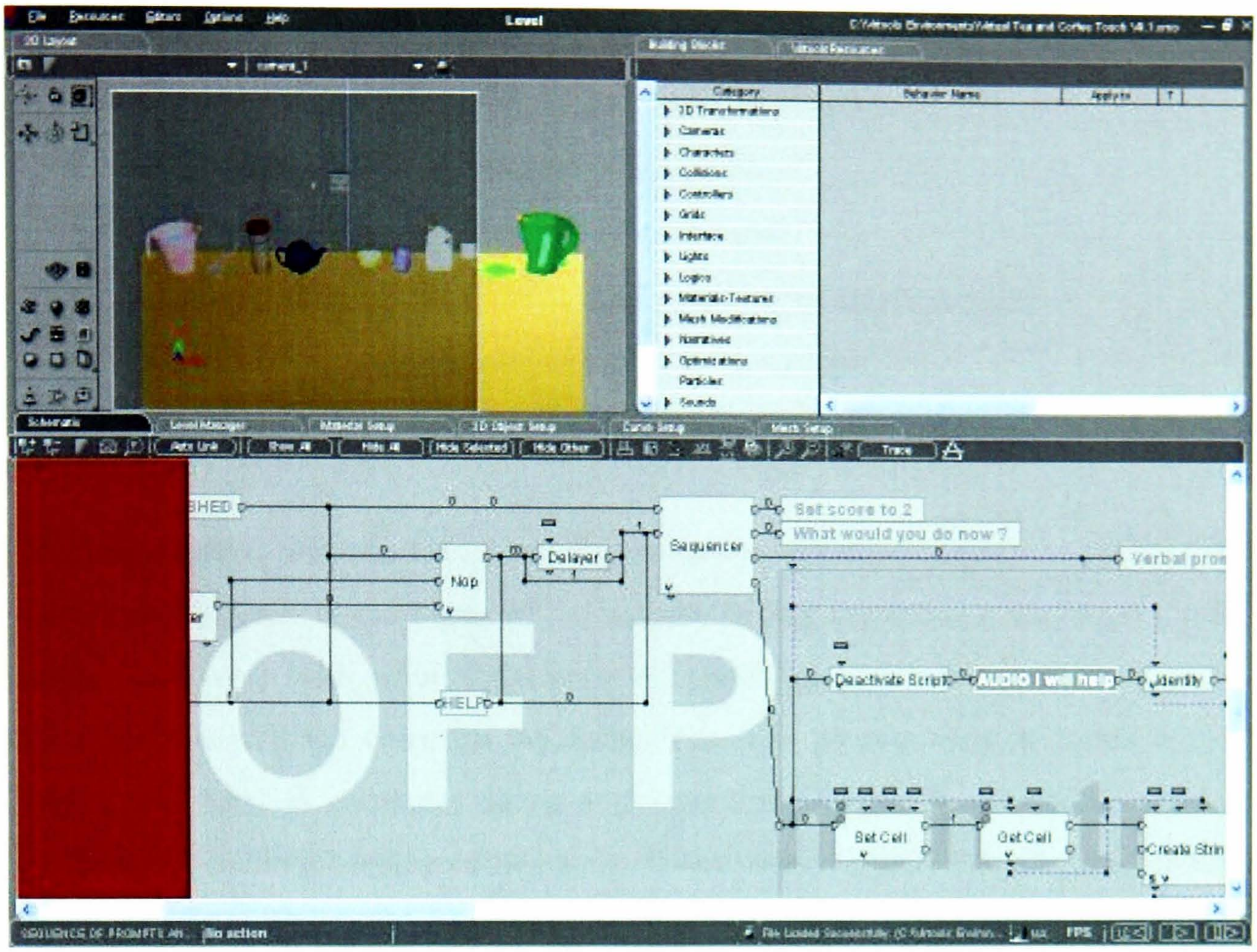

Figure 4.4 The Virtools™ development tool.

The screen shown above shows a small part of the system: in this instance part of the sequencer that initiates the responses as audio clips or visual demonstrations.

4.2.8 Audible Feedback and Instruction

A list of the subtasks identified in the task analysis was taken to a meeting of speech therapists who discussed the verbal prompts, responses and instructions that they would use when working with stroke survivors. They returned a list of phrases that they considered were appropriate for the coffee (and tea) making activity.

The OT independently provided a list of words and phrases that would be used during a hot drink making exercise. Comparison with the speech therapists list showed consistency and it emerged that the repertoire of prompts and instructions could be divided into themes as outlined below:

- A prompt asking the patient “what would they do” (not task specific).
- An instruction requiring the patient to perform a specific task.
- Information (feedback) about the task status.
- Confirmation if a correct action is performed.
- A warning if an incorrect or dangerous course of action is taken.
- Response if the subtask has already been completed.
- Response if a prior subtask must be completed first.

Working together with the OT, a list of phrases was compiled that would be used for the hot drink tasks. A colleague of the authors (a registered nurse who works with stroke survivors) with prior experience of recording commentary for e-learning materials provided the voice for the audio files. The phrases were recorded onto a Viglen PC desktop computer using a unidirectional dynamic microphone and a Goldwave™ audio recording editing suite. Other sounds effects (for example boiling water) were also recorded for the VE.

4.2.9 Task Performance Measurement Scores

A three level scoring system was devised by the OT. A score of 2 points was awarded to each subtask if the user performed a correct action unaided. If the user did not perform a correct action within a twenty second period, a verbal prompt was given. The twenty second delay was chosen by the OT because it was consistent with the period a therapist facilitating an activity with a stroke patient would wait before intervening. If the user responded to the prompt correctly then a score of 1 point was awarded.

If following a further twenty seconds the user did not perform a correct action a score of zero was awarded. The system then intervened, demonstrating the correct action in the VE and updating the next task variable appropriately.

4.2.10 Identifying the Next Action

An important part of the VE was the ability to demonstrate the action that a user should take in the event of a user error or period of inactivity. An algorithm was developed by the author, to predict the next action to be taken by the user based upon the current one.

Every action is allocated a unique numerical code enabling the actions identified in the task analysis to be represented in the software as variables in a numerical array. When a user interacts with the VE the objects are identified and if an appropriate combination of objects has been selected for an action the software identifies the numerical code for that action. For example if the user selects the jug and then the kettle the action of 'pouring water into the kettle' is identified as the action, and the numerical identifier (in this case 3) is stored as a variable called current_action.

The algorithm then locates the current_action value in the array. It identifies which top level sequence it belongs to, for example if the current action was 'pour water into the kettle' this would be part of the sequence of boiling water. It then examines all the other actions in the boiling water sequence, attempting to locate one that has not been completed.

When an action in the boiling water sequence has been identified that has not been completed, this is then set as the variable next_action.

There is also an over-ride facility. Some actions require a specific 'next action'. For example putting the spoon into the coffee jar must be followed by putting the spoon into the mug. A loaded spoon should not be put down as it would not be in the real world.

This section has introduced the task, the task description, and the development tools. The following section shows how these were used in the production of the VE.

4.3 Iterative Design of the Virtual Environment

4.3.1 Introduction

The design specification was used as basis for the development of the new VE. It broadly defined the major components of the VE, for example the task, the objects, flexibility in layout, and data to be recorded. Data gathered from stroke survivors in the community provided an overview of the general features of computer programs that they considered to be important (for example 'ease of use') and the kinds of tasks that they were assessed on in hospital (everyday living skills), but at this stage it was not known exactly what users wanted from this particular VE or how they would use it.

Because user's ideas and feedback were considered to be important in the design of the new VE a user-centred design approach was adopted as explained in chapter two. This followed the design activities identified in international standard ISO13407 (ISO, 1999) that were presented in table 2.2. Referring back to these, the first two activities are to 'understand and specify the context of use', and to 'specify the user and socio-cultural requirements'. These activities were the basis of the seminars, workshops and design specification that have been presented so far in this thesis.

The other two activities referred to in ISO 13407 are to produce designs solutions and to evaluate designs against requirements (ISO, 1999). The MR system required two separate designs, one for the VE software and one for the TUI hardware. The latter is the theme of the following chapter. The remainder of this chapter focuses on the development and testing of the VE and the associated software.

Stroke patients participated in studies in which measures of performance in the hot drink making task were recorded by the VE using the scoring system described above and using other observational and recording techniques described here. Studies were also conducted by the OT to investigate the errors made in the VE compared with those in the real world task.

4.3.2 Recruitment of Patients

A request for ethical approval to conduct studies with stroke patients was organized and submitted by the chair of the design team, and this was granted by the Ethics Committee at QMC, Nottingham. The design work for the VE commenced following approval and the process of recruiting patients to participate in the design and testing of the VE began.

Patients on the stroke unit were assessed by the OT for suitability to participate. Exclusion criteria were; dementia recorded in notes, a score of less than 8 on the Sheffield Aphasia Test and RMA gross motor function score of zero (the patient was unable to sit in a chair). Following the screening process in which 167 patients were invited to participate, a total of 50 patients were successfully recruited by the OT to take part in the study.

4.3.3 Equipment

The equipment used for the software development studies was a Toshiba Satellite Pro A10 notebook computer with the VE developed by the author running under Virtools™. To make the VE system portable and easy to use the OT chose to use a touch screen interface. To reduce the risk of damage to the screen the OT chose to use a rubber tipped wand to point to virtual objects in the VE rather than allowing the user to touch the screen directly. This decision was supported by the development team.

Patient activity was videotaped using a Sony miniDV camcorder mounted on a tripod. Patient interaction with the VE was recorded on a log-file generated by the VE software. The log-file recorded the user's code (names were not stored in the log-file), the chosen activity, the sequence and timing of detected events. The VE also produced a score sheet which included the user's performance score for each action and a summary score calculated as a percentage of the maximum score possible.

In addition real kitchen equipment was used by patients under supervision of either the OT or a research assistant, who was recruited to the project, in order to compare performance between real environments and VEs. Patients recruited to the study were expected to undertake both real and virtual tasks.

4.3.4 Method

The location of the studies was Ward F21 (a stroke ward) at QMC, Nottingham. Patients on this ward who were recruited successfully underwent a series of standardised assessments of cognitive and motor function before being assessed in the real world hot drink task (see Edmans et al., 2006). These were conducted by the OT.

Patients were offered the choice of making a cup of tea or coffee. Patients proceeded through the real task and their hand movements were recorded using the miniDV camcorder. An assessment protocol comprising 27 stages was used as a measure of performance, this being devised and scored by the OT. The protocol can be found in the appendices. Twelve stages were compulsory, the remaining 15 were optional. Video recordings were analysed by a competent trained assessor and from this assessment scores were generated.

Following the real task, patients were then invited to perform the hot drink task in the simulated environment. Patients were offered the same choice of tea or coffee to make in the VE.

Prior to performing the hot drink making task in the VE, patients were trained to use the touch screen by practicing a simple activity. This was a VE in which patients were required to pick up a postage stamp and place it on an envelope. The activity was constructed using Virtools™.

Participants were required to hold a pencil shaped wand with a rubber tip and touch it against the virtual object. To move the stamp to the envelope they touched the stamp, then the envelope. Initially the activity was devised in the form of both point and click operation or drag and drop, however the latter proved difficult for some patients and drag and drop mode was eventually removed from the task during the VE development.

Once participants had mastered the technique of using the wand and touch screen they were then given the hot drink task to attempt. As with the real task participants were offered the choice of tea or coffee and the same 27 stage assessment protocol was used. Video recordings were made of hand movements and scored independently by the assessor. User data was recorded as a measure of performance. The VE automatically recorded the timing of actions, objects selected, errors of repetition or wrong choice, prompts given and performance scores. This was used to identify discrepancies between observed and recorded activity.

The OT compiled reports in the form of tables of errors and problems that patients experienced during tests. Theses were compiled as text files in Word format and included recommendations for change made by both the OT and by patients.

Video recordings that were made by the OT were then used in conjunction with the error reports to troubleshoot technical problems and to observe how users made errors. The videotape recordings were inspected by the author and the OT. Errors and technical problems were discussed and these were used to guide the subsequent iteration of software.

The OT compiled a table of performance in both the real task and the VE task. An analysis of correlation was calculated by the OT.

Of the fifty patients video recordings made a sample of twenty patient's video recordings for both real and virtual tasks were analysed for user error analysis by the OT and the research assistant.

The OT identified and categorized the errors made by patients in both environments and the errors that were made in the real environment only and in the VE only. The numbers of errors made were compared between real, virtual and both environments.

4.3.5 Results 1: Modifications to the Design

The first part of the results section is a summary of the modifications to the design of the VE and a description of the final version. The VE was tested by the OT with a total of 50 stroke patients and the problems that were experienced during testing were fed back to the author in the form of summary reports. These reports were used to identify improvements and were discussed between the OT and the author.

Eight modifications were made to the initial design. The revisions presented in this section are accompanied by a summary of the OT report and recommendations for improvement. To assist with the development and to ensure that the latest revision was the one under test, each VE resulting from a modification was labeled as a new version (1 to 9). The results are presented sequentially following the development of each version.

For each version a summary of problems encountered is presented below and an explanation is given of what was changed and why it was changed. A discussion of how this affected the subsequent version is given where appropriate.

4.3.5.1 Version 1

Version 1 was built to test the drag and drop interaction. It was tested only by the OT and not tested with patients. In this version the virtual objects were initially positioned on a shelf located above the work surface. The user was required to drag objects down from the shelf onto the worktop by selecting the object on the touch screen and dragging the object down to the workspace using the rubber tipped wand.

The initial position of the objects was specified by the OT. The rationale for the position of objects was that those objects that are used as part of a compulsory action (kettle, spoon, mug, jug and jar) are to be found either side of a central line, as would be found in the real task. The OT explained that this is to encourage the patient with visual field impairment to attend to at least some of the objects within the scene.

Problems	Suggestions
Scoring system not fully implemented	Implement scoring system
No instruction to start	Add start prompt
Difficulty picking up spoon	Enlarge small objects
Difficulty with accuracy of dragging objects	Offer option of point and click
Needs better visible feedback (liquids in vessels, solids on spoon)	Improve visible feedback
Needs closure on task completion	Feedback on task completion
Need to be able to pause	Add pause so OT can stop the program and disable input

Table 4.3 Problems and suggestions for version 1.

Version 1 did not have a scoring system as this was designed to test proof of concept and as a means to investigate the interaction. The basic principle of operation was that an object was selected and this was dragged to a second object. When the first object was within a predetermined proximity of the second this triggered a response in the form of an animation and audible feedback. For example if the jug was dragged close to the kettle it would lift, tip and pour water into the kettle. This was presented to the user in the form of an animated sequence with the recorded sound of water pouring.

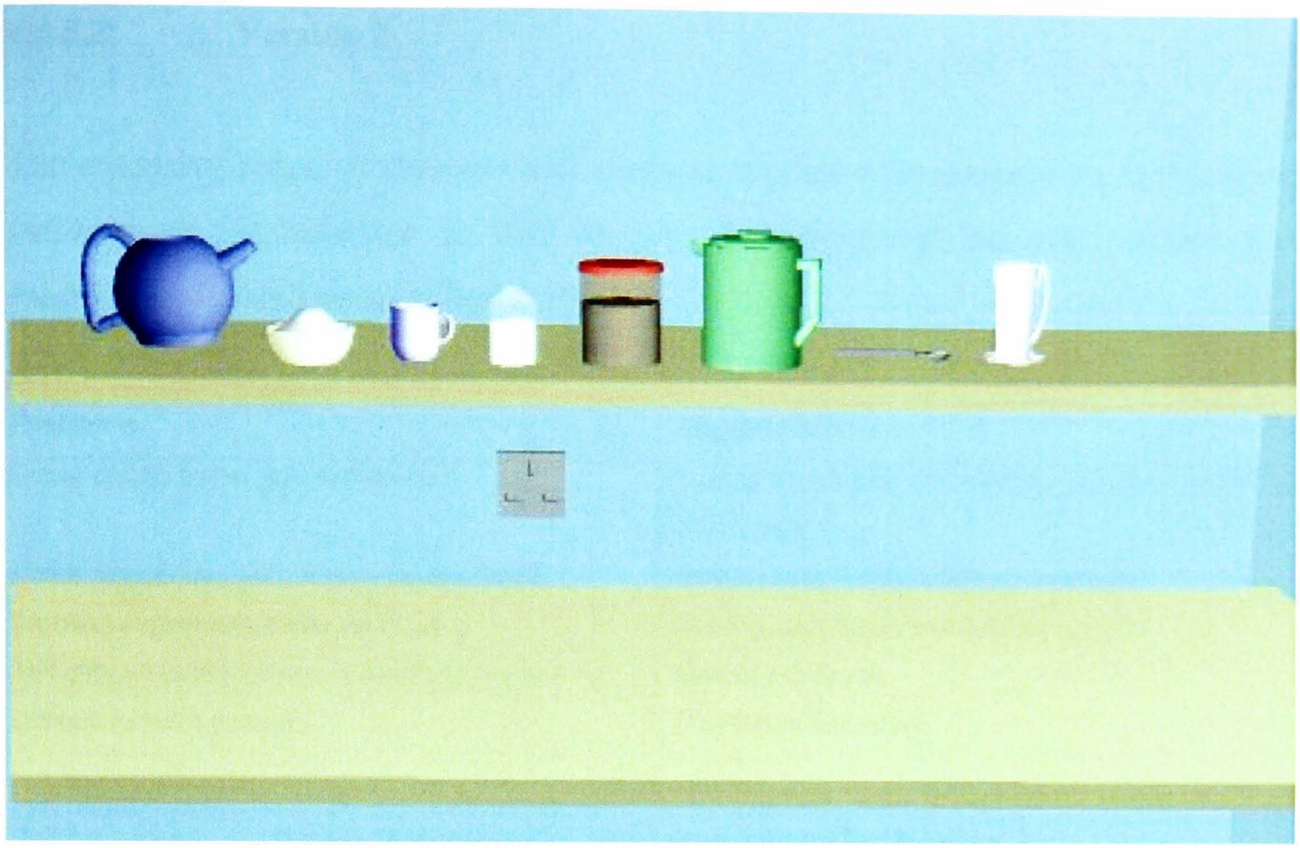

Figure 4.5 The initial VE.

A point and click mode of interaction was requested in addition to the drag and drop mode. The rationale was to give users a choice, because drag and drop requires the wand to be continually pressed against the touch screen to move objects and this was considered to be a possible issue of dexterity with some disabled users.

Other problems were identified. Small objects were found to be difficult to pick up and a solution to this was to place a selection zone around the object as explained in later.

4.3.5.2 Version 2

The extensive range of prompts and instructions that were devised by OT and the author were implemented in this version. An instruction for every action was recorded and added as described earlier.

Problems	Suggestions
Some erratic object pair behaviours	Create a task grid and check every permutation of object pair
Some sequences do not provide feedback	Identify and rectify feedback problem
Problem registering kettle on base	Identify and rectify kettle base problem
Still difficult to tell if there is anything in the mug	Visible feedback
Difficult to tell if paused	Feedback for pause

Table 4.4 Problems and suggestions for version 2.

The small objects were given a selection zone around them to make them easier to point at using the wand. A choice of dragging or clicking on objects to select them was offered.

A pause facility was added so that the OT could intervene if necessary. Although the aim was that the stroke patients should perform the activity without OT intervention by responding to prompts and feedback given by the VE, the option was necessary for those users who could not understand the prompts and for the OT to be able to discuss progress and problems with the patient.

Moving the kettle to the base caused a problem that was found to be associated with the selection zone. The kettle comprised different selectable component parts (switch, kettle body) and it was easy to select the kettle body when the intention was to select the kettle switch.

4.3.5.3 Version 3

In order to test the system a task grid was constructed with every object shown across and down a matrix. Every permutation of pairs of objects was tested, taking into account the different states that objects could be in. A simple matrix of objects is not sufficient because this only tests an object in one state against another object in one state. For example a spoon could have one of three states (empty, sugar, coffee) and the response that is given depends upon the context of the action as well as the object acted upon.

Problems	Suggestions
No feedback given for moving or replacing lids	Give feedback to show lids moved
Prompts do not identify objects required for a task	Make objects flash after second prompt
Conflict with timing between demonstration and input results in scoring incorrect	Disable input whilst prompts and demonstrations are given

Table 4.5 Problems and suggestions for version 3.

When a lid was moved to the jar no feedback was given to show that it was in the correct position. This was resolved by the creation of a simple animation in the following version.

The OT suggested that when the verbal prompts were offered they could be accompanied by the objects blinking to attract the attention of the user, and to reduce confusion of object identification.

There was a timing issue if the user performed an action during a demonstration. This was resolved by simply disabling user input during prompts and demonstrations by the VE.

4.3.5.4 Version 4

In this version the input was disabled during verbal prompts and demonstrations to eliminate the conflict that occurred causing and error in the scoring.

When a verbal prompt was given to perform an action those objects that were required for the stated action were programmed to flash intermittently for approximately five seconds in order to attract the user's attention and guide the user to the correct equipment.

Problems	Suggestions
Patients have problems with lids, mistakenly selecting nearby objects	Identify current object with pointer, make lids easier to select without selecting nearby objects

Table 4.6 Problems and suggestions for version 4.

The OT reported that users selected the jar when the intention was to select the jar lid. This was scored as a user error. The OT requested that some form of visible feedback was necessary, to inform the user when an object was selected and which object was selected. Making the objects flash could cause confusion with the prompting system so another technique was devised. A yellow pointer was created which identified the object that was selected.

4.3.5.5 Version 5

Patients found it difficult to keep the wand pressed against the screen. Dragging was therefore found to be difficult to achieve but the option to use it was retained by request of the development team for this version. Patients adopted a brush stroke style hand movement using many small strokes to move objects. This made the movement of objects quite laborious and required the user to repeatedly select the same object.

Problems	Suggestions
Dragging appeared to be harder than point to point (for interaction)	Remove drag and drop as an option
Difficulty selecting objects that are occluded by other objects	Remove possibility of occluding objects by ensuring that objects are always positioned so that they are visible
Kettle can boil if removed from base once sequence started	Reset kettle state to "off" if removed from base
Unsure if liquid poured.	Make liquid levels more obvious

Table 4.7 Problems and suggestions for version 5.

Other problems were identified. When the kettle boiling sequence was activated the animation continued for some time concluding with a steam effect and the sound of boiling water. Once the animation had started it continued until it had completed and this became a problem if users took the kettle off the base. This had not been an issue previously because users had not removed the kettle whilst it was boiling. A mechanism for halting the animation was required.

Liquid levels were not very clear so these were amended for the next version. Occluded objects were also a problem. If a large object was moved directly in front of a smaller object then the smaller object became hidden and unusable.

4.3.5.6 Version 6

Problems	Suggestions
Small object (switch) still difficult to select	Increase size of selection zone
Colour of drink confusing, black coffee should be dark	Improve colour range in feedback. Allow for a range of options: milk, water, black coffee, white coffee
Waiting for next instruction/prompt not always necessary	Remove "what would you do now" prompt and use a push button as an alternative means of assistance

Table 4.8 Problems and suggestions for version 6.

The problems experienced were mainly concerned with techniques of selection and feedback. The kettle switch was found to be difficult to select despite adding a selection zone. The variety of feedback for the colour of the drink was confusing to patients because it only showed a brown drink when coffee and water were present but did not change to a paler brown colour if milk was added. All possible permutations of content and colours were listed for inclusion in the next version.

For the next version the OT suggested that a help button facility would enable users to request assistance with the next stage without waiting twenty seconds. This would be particularly useful if the user knew they had to do something but were unsure what this was.

4.3.5.7 Version 7

The kettle switch was still too small so an increased active zone was created around it which improved ability to select it.

A help button was constructed. If the user required assistance with a stage, pressing a large red button delivered a prompt or demonstration as appropriate. This was an additional method of triggering the verbal prompts and demonstrations in addition to the time limit of twenty seconds.

Problems	Suggestions
Time delay between switching kettle on and feedback	Investigate feedback delay for kettle switch
Drink colour changes too slowly therefore confusing	Investigate why liquid colour change is slow
Increased versatility of boiling water sequence requested by OT	Investigate feasibility, implement if versatility of boiling water sequence is desirable

Table 4.9 Problems and suggestions for version 7.

4.3.5.8 Version 8

Drink colour is subject to permutations of milk (white), water (transparent), black coffee (or tea) and white coffee (or tea) being present in the mug. A software routine was devised using Virtools™ to present the correct colour.

Problems	Suggestions
Feedback from final action is interrupted at finish	Investigate timing of last action and task completion

Table 4.10 Problems and suggestions for version 8.

The problem identified in the table was due to timing. When the user performed the last action to complete the task, the audible and visible feedback was interrupted as the program stopped. This was solved by delaying the completion sequence (scoring and feedback to inform user that they had completed) until the last animation had finished.

4.3.5.9 Version 9: Summary of the Final Version

A stage was reached when the design team decided that subsequent changes would be of little value. The result was a VE comprising a worktop upon which nine objects were placed. The starting position was in line towards the back of the worktop. The positioning was consistent with the layout of a real practical kitchen task assessment.

At the centre of the scene was a single power socket. The bench surface was not given any texture pattern in order to reduce possible distraction or confusion. The final version is shown in figure 4.6.

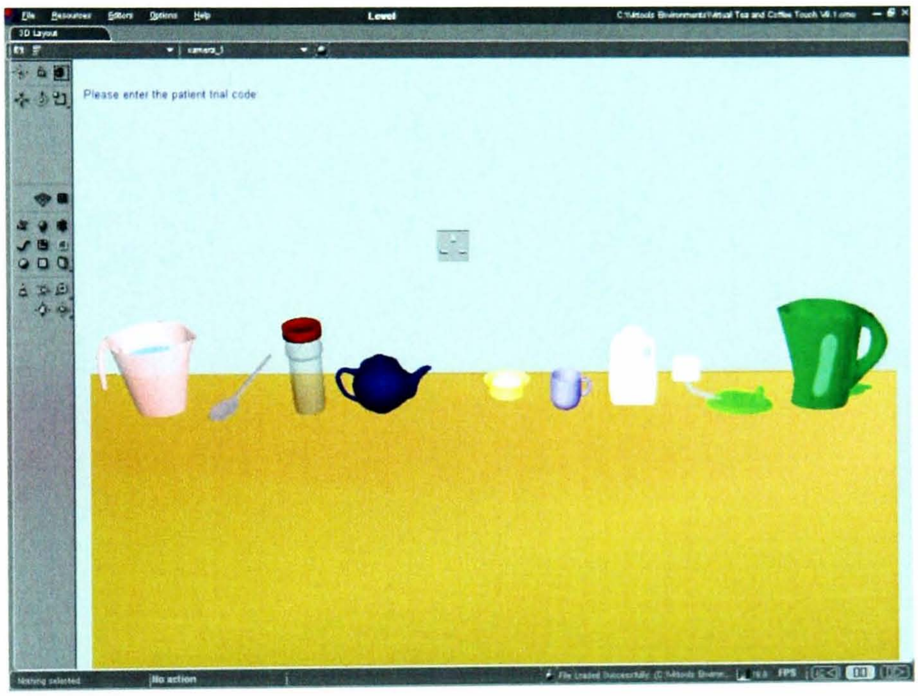

Figure 4.6 The final VE.

Objects were selected by pointing at them using the wand. To perform an action involving two objects, both were selected in the correct order. This triggered an animation in which the first object moved to the second and performed the appropriate action. Whilst animations were underway input was disabled to avoid confusion with the position of objects.

Support was provided by a verbal prompt followed by a demonstration of the correct action in the VE. Assistance was gained by inactivity for a period of twenty seconds or by pressing a large red help button.

The system recorded every action and intervention by both user and computer. Scores were calculated and displayed when the user had completed the task but not during the task.

An electronic version of the OT assessment sheet was automatically completed by the software. These were saved as user files in printable format. An OT task sheet is included in the appendices.

4.3.6 Results 2: Evaluation Study

A study conducted by the OT compared task performance results of fifty stroke patients using the VE against scores in the real task. The assessment scores were compared between real and VEs and these are presented below.

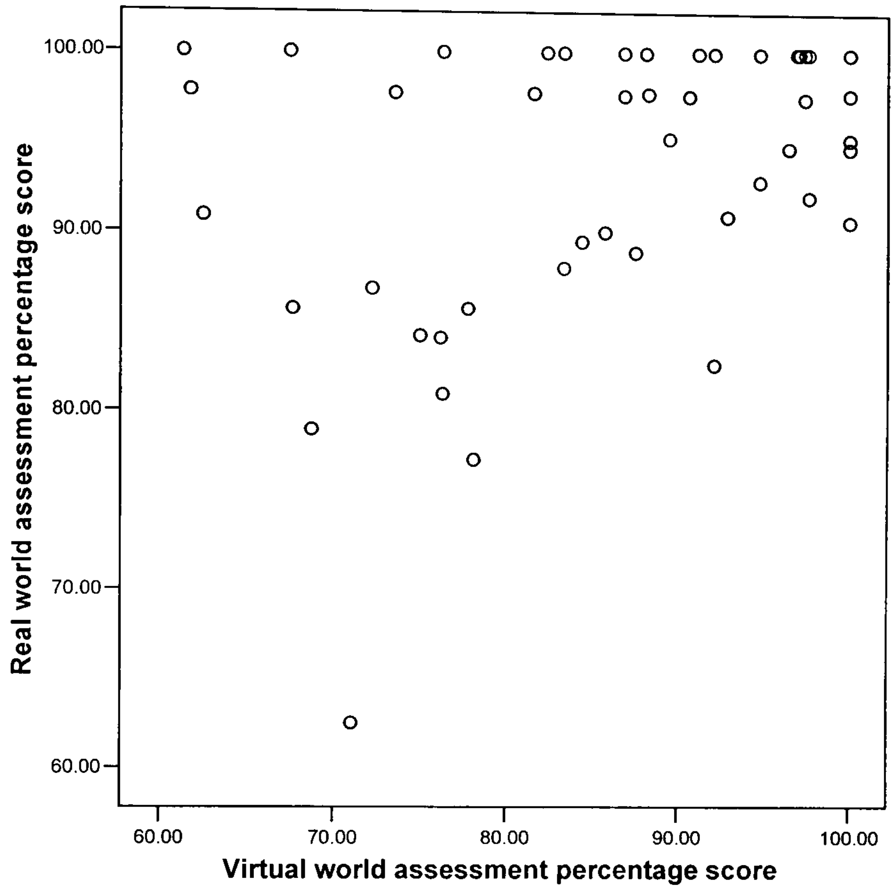

Figure 4.7 A comparison of real and VE assessment scores (%) (Edmans et al., 2006).

Real world scores of 100% are not uncommon however fewer patients scored 100% in the VE. Spearman's Rho was calculated ($\rho=0.3$, $p<0.05$). Real and VE scores were not strongly correlated.

Errors made in both real and VE tasks are presented below. Both tables were compiled by the OT for Stroke Association Project TSA 13/02 but are included because they have implications for the MR project. These tables are based upon a sample of twenty patients from the fifty stroke patients recruited (Edmans et al., 2006).

Error type	Error in both real-world assessment and virtual environment	Error in real-world assessment only	Error in virtual environment only
Initiation	3	0	8
Attention	0	3	2
Neglect	0	1	1
Addition	0	1	0
Sequence omission	5	0	9
Perseveration	0	1	1
Selection	0	1	9
Object use	0	0	0
Problem solving	2	0	6
Dexterity	2	0	8
Quantity	0	6	0
Spatial	0	1	0

Table 4.11 Comparison of error types during real world and VE task performance (n=20) (Edmans et al., 2006).

The table above shows that errors are made in both real environments and VEs. The error pattern was not as expected. Errors were made by subjects in both environments, but errors were more common in the VE.

A Wilcoxon Signed Rank Test performed (by the OT) on errors scored z = 2.14 ($p<0.05$) showing significant difference between error types in virtual and real environments. This suggests that the two tasks are different and although the VE may enable users to proceed through the task, it does not fully represent the real world task.

4.4 Discussion of results

Following an iterative design process involving stroke patients as participants in the design of a VE for making a hot drink, a final version was constructed that enabled the users to proceed through the task. The system was portable and practical, being easily carried to the patient's bedside if required and easy for the OT to initialise.

The VE presented the hot drink making task as a safe and controlled simulation, recording user performance scores and user activity as well as identifying selection and sequencing errors.

The evaluation of the completed VE showed that the VE did not completely represent the real world task. Two factors that showed high error rate in the VE compared to the real world were dexterity and selection. Initiation, problem solving and selection errors are also more common in the VE (Edmans et al., 2006).

The VE task was more difficult than the real world task and although errors were made in both types of activity, these varied between the two environments. Patients showed greater proficiency in dexterity, selection and problem solving in the real task compared with the VE. The VE presents different problems that are not present when using real objects.

Selecting an object in the VE was achieved by pressing gently against a touch screen using a wand that resembles a pencil, clearly different to the real world action of holding and grasping objects. Some patients who were able to perform the task in the real world showed dexterity errors in the VE.

Although the research in this section was carried out by the OT in consultation with the design team it does show that the VE presents new problems. The fact that the VE scores and real world scores were not strongly correlated suggests that the skills required to make a hot drink in the VE do not equate exactly with those required to make a hot drink in the real world.

4.5 Summary of Chapter 4

A research and development team was formed and a design specification was developed. A task analysis was conducted for the coffee making task. A VE was designed through a collaborative effort by a multidisciplinary design team.

Stroke patients were involved in the testing of versions of the VE and the OT fed back any problems they experienced through summary reports. These influenced the design of a VE through several modifications until a version was produced that was considered by the team require little further revision.

The final version was able to record user activity and act in a supporting role, offering prompts and animations to demonstrate the correct action to take. It was controlled using a touch screen which originally used a 'drag and drop' interaction. This was found to be difficult and a 'point to point' interaction was included.

A study undertaken by the OT compared the VE and real task. It was shown that these were different. Errors were more common in the VE task compared with the real task. In particular errors of dexterity and selection were more common in the VE.

The VE was devised for the Stroke Association studies but also formed part of the MR system. The following chapter explains how the TUI was developed and how it was connected to the VE to form the MR system.

Chapter 5: Design of a Mixed Reality Simulation for an Everyday Task

5.1 Introduction

The previous chapter followed the development of the VE and the underlying software. This was used and evaluated by the OT as a discrete system using a touch screen interface but was also designed to be used as a component of the MR system. The other component of the MR system was the TUI.

The touch screen did not encourage naturalistic movement of the hand or upper limb to complete the task, the only physical component of the task required was the ability to point a pencil shaped wand. A more realistic and naturalistic user interface was developed as the method of controlling the simulation. The rationale was explained in chapter two; in summary, activities of everyday living comprise a mixture of cognitive and physical processes, and the stroke rehabilitation literature proposed that it is beneficial to the patient if these processes are trained together in the context of a useful task.

Although various input devices exist there are benefits and drawbacks that were discussed in chapter two. A TUI was developed to permit unencumbered movement and to exploit the physical and designed properties of real objects in order to enhance the realism of the experience.

The process of developing the interface and completing the MR system is shown in figure 5.1. An assessment of an existing system was carried out with participation by former stroke patients who were resident in the community and by OTs in the hospital. Chronologically the interface and VE software were being developed concurrently. The first two studies involving an MR presented in sections 5.2 and 5.3 of this chapter were conducted prior to the formation of the multidisciplinary team. Following the formation of the design team a new design was constructed and installed on a stroke unit. Fourteen patients tested the system. Issues of practical implementation were identified and these are discussed at the end of this chapter.

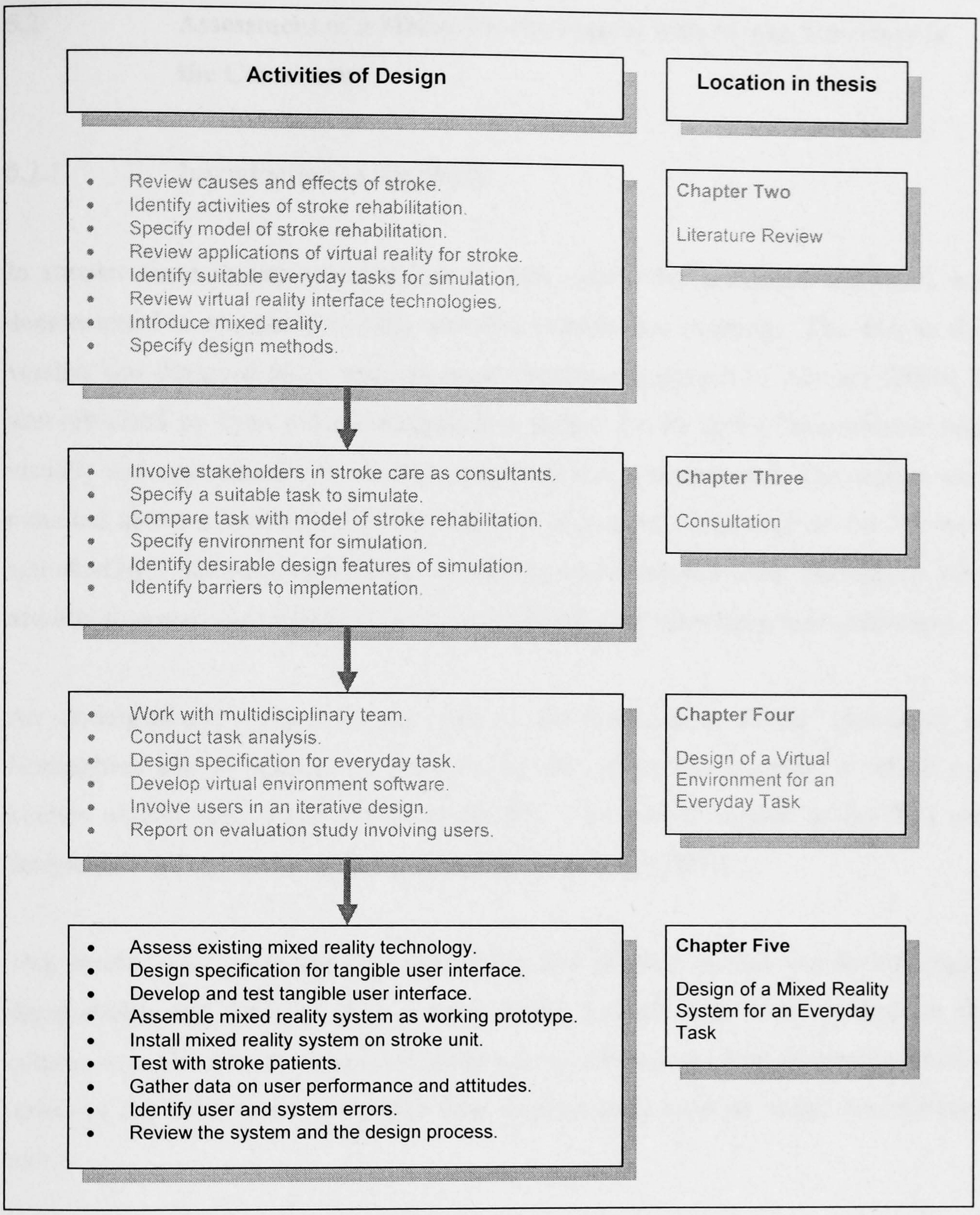

Figure 5.1 Activities of design presented in chapter five.

5.2 Assessment of a Mixed Reality System with Stroke Survivors in the Community

5.2.1 Introduction to the Study

In chapter three it was reported that an MR system for making a hot drink was demonstrated to stakeholders who attended consultation meetings. The TUI in this version was designed as an undergraduate engineering project by Starmer (2000). It was criticised by those who participated in studies for its lack of resemblance both visually and operationally to the real equipment that it represented. The objects were mounted above a keyboard and the different sequences of the task in the VE were activated by a mechanism whereby the objects operated a keypress. The objects were actually toys and were smaller than the real objects they were intended to represent.

An undergraduate project in the School of Engineering at the University of Nottingham saw a redesign of the TUI for the coffee making task in which real kitchen objects were used to control the VE. This second version of the TUI was designed for adults with a learning disability by Tymms (2001).

Two studies were proposed. The aim of the first of these studies was to investigate acceptability and usability with former stroke patients who were resident in the community. The aim of the second study was to investigate practical implementation issues of the MR system with OTs who worked on a hospital stroke rehabilitation unit.

Previously, in the consultation phase, the VEs were employed as a means of introducing and demonstrating the concept of VR (and MR) as a potential treatment tool for stroke rehabilitation. Now the systems were being evaluated in terms of measurable outcomes of performance (time taken, errors made and technical problems) which would be used to inform the design specification.

5.2.2 Description of the Mixed Reality System

The MR system described previously used real objects that were fixed to a device mounted above a computer keyboard. When each object was used, an alphanumeric character was generated and this was used to control the VE. The second version described here used real objects with a variety of different electrical switches embedded within them, as explained below (Tymms, 2001). These switches were connected in parallel with the key switches of an IBM desktop PC keyboard. Activation of these switches emulated an appropriate key press. The hardware and a screenshot of the VE are shown in figure 5.2.

The task for the second version of the TUI was an instant coffee making exercise. It had a fixed sequence programmed into the software that controlled the VE. The equipment consisted of a kettle, a base, a tap, a mug, a jar, a spoon, a milk carton and an assistive tilting device. Objects were mounted on a base board 60cm by 40cm made of 1cm thick wooden board.

The kettle, milk bottle and spoon could be moved freely. The mug, coffee jar, tap, kettle base and tilting device were fixed to the base board. The tilting device was a mechanism in the form of a hinged frame that holds a kettle and allows it to be rotated in a vertical axis.

The first stage required the user to fill the kettle from the tap by placing the kettle underneath the tap and by pressing down on it. This was followed by the simulation of boiling water by placing the kettle onto the kettle base and operating the electrical switch on the kettle. The third stage was to put coffee into a mug by using a spoon to press down onto a micro-switch mounted inside the mug. Pouring water into the mug from the kettle was simulated by placing the kettle onto the assistive tilting device and tipping this towards the mug, activating a micro-switch fixed near to the tilting device's hinge.

The final stage was to add milk by tipping a milk carton towards the mug. The carton contained a magnet near the lip and the mug contained a magnetically operated rhodium-plated reed switch which was activated when the magnet was within an operational proximity. The proximity was measured at 2.5cm by moving the magnet towards the switch and measuring the distance between the magnet and the switch when the reed switch made a connection.

No stages were optional. Sugar was not included. The spoken instructions that were given by the computer and the intended user response to the instruction are presented below in table 5.1.

Instruction	**User Response**
Place the kettle under the tap	Pick up kettle Place on worktop underneath the tap
Switch on the tap	Press down on the tap
Put the kettle onto the base and switch on the kettle	Pick the kettle up and place on the base Press the switch on the kettle Wait for kettle to boil
Take the lid off the coffee jar	Unscrew lid of the jar
Spoon coffee out of the jar	Pick up the spoon Push down lightly into the coffee jar
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 kettle on the tilting device Tip the kettle towards the mug
Pour milk into the cup	Pick up milk carton Tip the spout when above mug

Table 5.1 Instruction and user response.

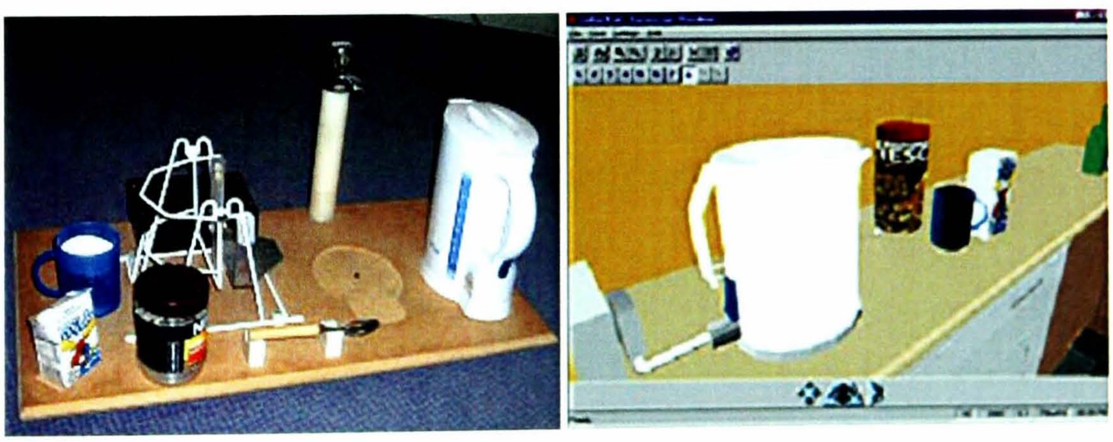

Figure 5.2 The TUI hardware and VE for the coffee making activity.

5.2.3 Method

Following the first phase of studies involving former stroke patients, contact was made with a second community based self help group through a person who had attended both group meetings. This person was a stroke survivor and the leader of a self-help stroke group based in Mansfield, Nottinghamshire. Membership of this group was aimed at those people who had experienced a stroke and acquired communication difficulties.

A series of visits were made to this group by the author and colleagues following invitation from the group's chairperson. The first visit was held during a scheduled meeting to present an introduction of VR to the group. The four environments described in chapter three were presented to the group using a Toshiba Tecra portable notebook computer and a Philips data projector. The basic principle of MR was introduced to the group and at the group-leaders invitation an observational study of group members using the MR system was organised.

The observational study took place during a scheduled group meeting. Of those present, seven people (all stroke survivors) consented to participate. Written consent was obtained from all participants and countersigned by a carer. Two speech therapists were present. They had previously agreed to attend in order to ensure that the verbal instructions and activities involved in the task were appropriate for the participants. They were also available to assist if communication difficulties arose.

The equipment was set up at a community hall in Mansfield, Nottinghamshire, where scheduled meetings of the group regularly took place. The author explained and demonstrated the procedure to the group. Following this, individuals were invited to work through the activity.

The proceedings were videotaped using a Panasonic VHS camcorder, which was mounted on a tripod and positioned vertically above subjects in order to focus only on hand movements. Observation notes were taken throughout the event.

Of the seven stroke survivors who took part in the study, five were male. All subjects were living in the community where they lived either alone or with support from a carer. Six participants had negligible or no use of their right arm. All participants chose to stand up to make the drink.

5.2.4 Results

All participants completed the task by following the verbal instructions that were given by the computer. All participants completed the activity within four minutes, with a mean time of 2 minutes 38 seconds.

Errors made and the problems encountered are presented in table 5.2. These are based upon results from all participants on their first attempt.

Instruction	Error and Problems Encountered	Instances
Place the kettle under the tap	Problem with weight of kettle	1
Switch on the tap	User did not respond to instruction	2
Put the kettle onto the base and switch on the kettle	Users placed kettle onto the tilting device instead of the base	4
Put the kettle onto the base and switch on the kettle	Problem operating kettle switch	1
Take the lid off the coffee jar	Poured water before instruction given	3
Spoon coffee out of the jar	Ineffective user response	4
Spoon coffee out of the jar	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
Replace the lid on the coffee jar	Difficulty replacing lid	1
Pour water into the cup	Inappropriate action to pour water	2
Pour milk into the cup	Ineffective user response	5

Table 5.2 Errors and problems encountered.

5.2.5 Discussion

The TUI appeared to serve as a focal point and also a physical boundary to the activity. The kettle was situated close to the right side boundary of the worktop. The only subject who had sufficient use of his right hand to grasp objects tended to use his right hand to pick up the kettle. The six participants without use of their right arm did not position themselves to align their left hand with the kettle. They reached across the worktop to the right in order to pick up the kettle with their left hand.

Discussing this with the therapists, it was suggested that versatility in locating and placing items was considered of importance. Therapists said that it was necessary for them to be able to position objects to suit the patient at commencement of the exercise and for the patient to be able to move these freely.

All seven participants responded to the verbal instructions that were generated by the computer although some difficulty was found with instructions that contained more than one command. The third instruction asked the user to place the kettle onto the base and then to switch the kettle on. One participant placed the kettle on the base correctly but required the second part of the instruction to be repeated. The speech therapists suggested that the system should deliver simple and clear instructions using familiar terminology and only describing single discrete actions.

Timing was also important in the delivery of the instruction. A sound effect was used to inform the user that the virtual kettle had boiled. Three participants immediately responded by tilting the kettle (simulating pouring water) anticipating the action required before the appropriate instruction to do so was given.

The instruction to place the kettle on the base and switch on the kettle caused problems. One of the reasons appeared to be of understanding the terminology. In four instances the kettle base was confused with the assistive tilting device.

The kettle was too heavy for one person to lift even though it was empty, demonstrating that consideration of the patients physical ability is important. This patient may have been able to complete a simulation of the task in the touch screen operated VE in which strength is not an issue but would not be competent in making a real hot drink.

In ten instances activation and recording of an event did not occur due to inappropriate action by the user. It was apparent from video analysis that object recognition was not an issue in these circumstances. The appropriate utensils were used, and the actions matched the instruction however for those actions that relied on proximity detection, the sensors were not operated effectively. Pouring milk required the magnet inside the lip of the milk carton to come into close proximity with the reed switch placed inside the mug. This frequently did not happen. A more sensitive yet robust and discriminating method of sensing when actions were performed was required.

In order to minimise the number of objects in view the software program automatically changed the field of vision to focus on the current event. Camera angles were preset by the software. Comments received from participants and the therapists indicated that this could be confusing. From certain angles objects were partially obscured. For example in one scene the coffee cup obscured the coffee jar. Participants made further suggestions for improvement. Increasing performance feedback was suggested by showing the liquid levels in the kettle that correspond to user input.

This study has engaged stroke survivors in a coffee making activity using an MR system that employs real objects as part of a TUI. The participants contributed to design of future versions by identifying usability problems and practical issues of implementation. This study established features of an MR system that are desirable and those that are not desirable.

Flexibility in the movement and positioning of objects is desirable. This may be of particular importance for those patients with a visual field deficit. Reliable mechanisms for sensing user activity are also important.

5.3 Studies of a Mixed Reality System in use on a Stroke Unit

5.3.1 Introduction

A study was organised with OTs in order to begin to investigate the practical issues of using an MR system in the hospital setting. The study was an opportunity to identify design improvements to future versions by discussing ideas for change with the therapists. It was also an opportunity for the author as a designer to work with OTs in the task environment and to discuss how an MR system might be used in practice by stroke patients.

The MR system described in the previous study was taken to a ward that admits stroke patients. Two OTs who worked on the ward agreed to work through the simulated coffee making task and to provide feedback.

5.3.2 Method

The TUI to the coffee making activity described in the previous section was set up in a rehabilitation room on a health care of the elderly ward at the QMC, Nottingham with permission from the ward sister. The VE was run using a Superscape VRT™ environment and presented on a Toshiba Tecra portable notebook computer.

Staff on the ward had been written to concerning the study and two OTs had consented to participate. The equipment was set up on the unit and a demonstration of the coffee making task was given by the author. Following this the therapists worked through the activity independently.

Observation notes were made throughout. After completing the task the OTs were invited to offer their opinions and suggestions for improvement. A questionnaire was given to the OTs to complete, inviting them to offer criticism and constructive feedback for future designs.

5.3.3 Results

A 'hands off' approach to instruction was recommended. The OTs agreed that they do not usually give direct instruction as the MR system did. They reported that the role of the OT in assessment and treatment tends to be as a facilitator, intervening if the patient performs a dangerous action, if the patient perseverates or is clearly unable to continue.

The major criticism made by both the OTs was the lack of freedom of movement of the objects. Positioning objects to suit the user was considered to be of importance. A further criticism raised by both OTs was the inflexibility of the task. This particular application was designed to teach people a specific sequence to complete the activity. It was designed for people with a learning disability but not specifically for people with stroke. The OTs suggested offering users free choice in the sequence to complete the activity.

5.3.4 Discussion

The feedback from OTs in this study was consistent with the findings from the previous studies. Free movement of objects was considered to be an important design feature. Other drawbacks identified by the OTs were that the task sequence was too rigid. Both OTs in this study suggested flexibility in the task order as a desirable attribute. Verbal instruction was not considered to be essential to the activity, and the OTs suggested that it should only to be used as a prompt when the user is unable to continue or is unable to perform an action correctly.

A positive aspect of the MR system is that the interface encourages the user to perform tasks using naturalistic upper limb movement and the OTs suggested that the concept had potential as a training tool. One OT explained that the system was not suitable in its present form as a treatment tool because it was not designed for stroke rehabilitation. Concern was expressed that a redesign may not be fit for purpose without the collaboration with a qualified stroke therapist.

5.4 A Tangible User Interface to the Coffee Making Task

5.4.1 Introduction

The discussion of TUIs held in the consultation phase (see chapter three) and assessments of TUIs presented above demonstrated that the existing systems were not suitable for the purposes of stroke rehabilitation, a recurring criticism being the inflexibility in the positioning of objects. A new and more versatile interface was required.

The development of a TUI to the VE commenced with a review of the task description. The optional components (milk and sugar) allow for variation between users in the overall task and the actions are replicated in other sequences (pouring boiling water, spooning coffee). These add complexity to the design of the TUI which was intended as a demonstration of a prototype. Following a discussion with the OT the compulsory components of the task were retained and the optional components were removed. The task was now broadly defined as making a cup of coffee by boiling water, spooning coffee into the mug and adding hot water.

By referring to the task analysis (presented in chapter four), the actions to be monitored by the TUI were identified and these were approved by the OT. Boiling water consisted of the following three stages; pour water from the jug into the kettle, put the kettle on the base and switch the kettle on. Stroke patients would not be expected to plug the kettle in when performing the task on a hospital ward therefore the OT advised that this should be omitted from the MR system.

Spooning coffee from the jar into the mug required the user to get the spoon, jar and mug, put the spoon in to the jar then in to the mug. The inclusion of a lid on the coffee jar was considered by the OT to be desirable but not an absolutely necessary part of the task. For the prototype, following discussion between the author and the OT, it was agreed that in order to demonstrate the concept of the TUI to stroke patients the lid could be removed from the task.

Acquisition of objects was also considered by the OT to be part of the task and this was therefore included in the assessment strategy. The OT suggested that patients should be given credit for acknowledging the objects that were involved in the task, even if the objects were not subsequently used by the patients.

The task for the MR system was defined by eleven stages shown in table 5.3.

Get the jug of water
Get the kettle
Pour water into the kettle
Place the kettle on the base
Switch the kettle on
Get the mug
Get the jar
Get the spoon
Put the spoon into the jar
Put the spoon into the mug
Pour boiled water from the kettle to the mug

Table 5.3 Actions for the MR system.

5.4.2 Detecting User Action

A mechanism for detecting each of the actions in table 5.3 action was required. It was not sufficient just to detect when correct actions occurred but also to include the facility to detect and identify incorrect actions for feedback to the user and for recording user performance. Characteristics of the proposed input device were defined. Broadly, the requirements of the TUI were that it must:

- Detect and identify an object that is being used
- Detect when two objects are within proximity of each other
- Detect when an action has been performed by or on an object

For each of the actions identified in table 5.3 a description of the user activity necessary to perform that action was written. This is presented in table 5.4.

Action	Description
Get the jug of water	Jug moved into workspace
Get the kettle	Kettle moved into workspace
Pour water into the kettle	Jug moved into proximity of kettle then tilted
Place the kettle on the base	Kettle placed onto base
Switch the kettle on	Electric switch on side of kettle pressed
Get the mug	Mug moved into workspace
Get the jar	Jar moved into workspace
Get the spoon	Spoon moved into workspace
Put the spoon into the jar	Spoon put into jar
Put the spoon into the mug	Spoon put into mug
Pour boiled water from the kettle to the mug	Kettle moved into proximity of mug then tilted

Table 5.4 Action and description.

Mechanisms were required to detect when the activity was taking place. By examining the descriptions, the types of technology required to detect the activity could be considered. These were discussed at team meetings and it was evident that the TUI would require a hybrid of several different kinds of sensing mechanism.

For detecting the spatial location of objects a computer vision system was suggested. For detecting when vessels were being poured a tilt switch was suggested and for detecting when an object was in contact with another a pressure sensing mechanism was suggested.

Entity relationship diagrams were used as means of representing the objects and the actions being performed. Entity relationship diagrams show objects (entities) in boxes and these are connected by lines, labelled to show the relationship between the entities (Preece, 1994). Here the entities were real kitchen objects and the relationships were the actions performed on the objects.

Entity relationship diagrams were adapted by the author by adding a third box to each relationship, which included the proposed mechanisms for detecting the actions. These adapted entity relationships are shown in figure 5.3. The various sensing mechanisms are explained in more depth in the following sections.

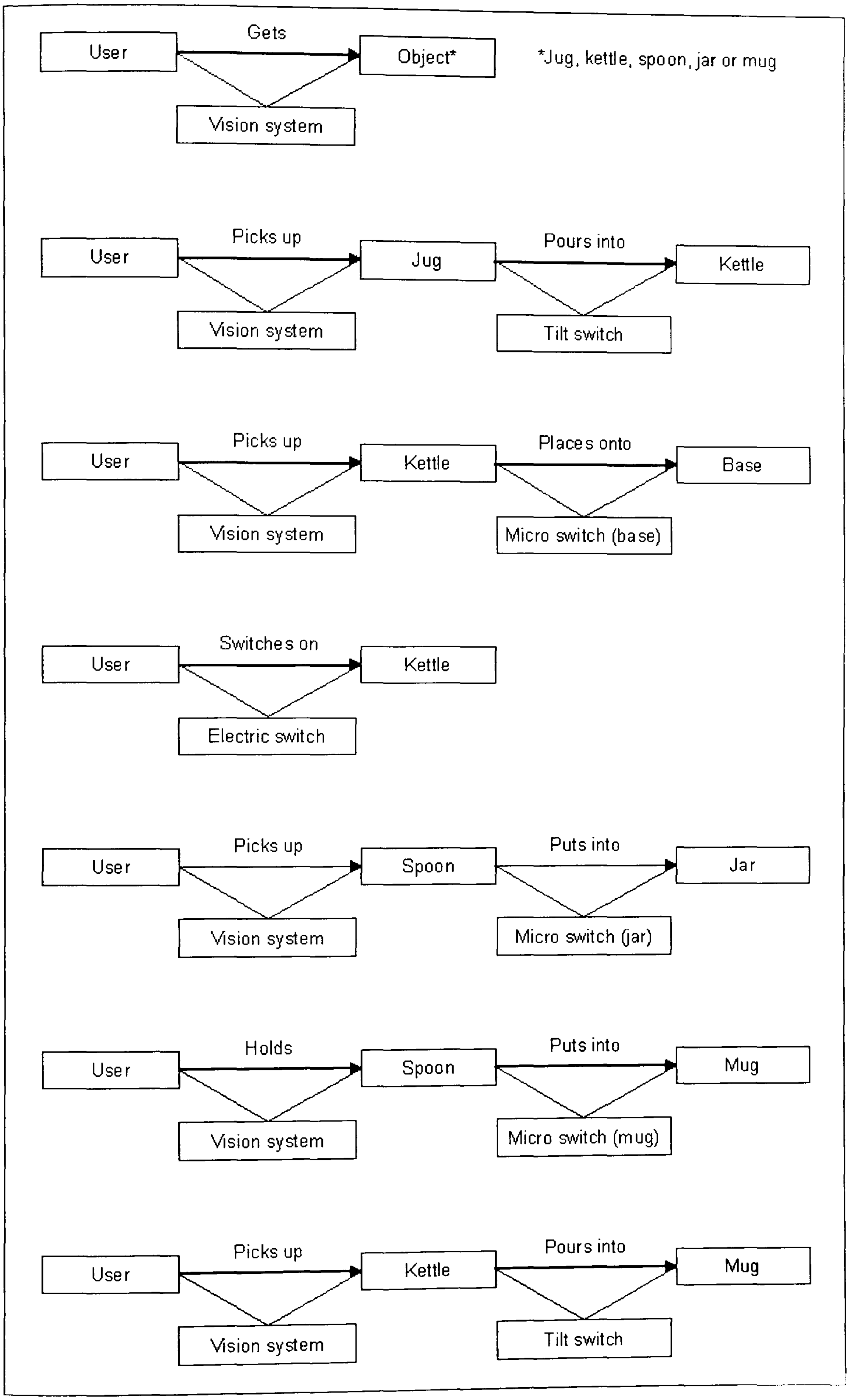

Figure 5.3 Entity relationship diagram for coffee making activity.

5.4.3 Tracking objects

Tracking technology was employed to identify and locate objects in the physical workspace. Tracking technologies can be categorized as either 'active' or 'passive'.

Active tracking requires a source signal emitted by the object (for example infra red, ultrasound) that is located by remote sensors. The position of the signal source and hence the location of the associated device is triangulated by comparing the timings of received signals at different receivers (Harrison and Jaques, 1996).

Unlike active tracking, passive tracking does not require the object to emit a source signal. Passive sensing mechanisms are used to locate and identify objects. Digital cameras are commonly used. The object to be tracked is placed in the field of view of the digital camera. The digital image generated by the camera is processed by software that identifies any objects located in the workspace by matching the physical properties of the image (usually colour) with a stored model of the object (Harrison and Jaques, 1996).

In the TUI proposed for this project, multiple objects coexist in the workspace. A technology was required with the capability to differentiate between several objects simultaneously. Active tracking of multiple objects poses problems of signal interference, confusing the triangulation and location of an individual object. Infra-red and ultrasound tracking require an unbroken line of sight between the source and receivers.

Another form of active tracking system, mechanical tracking, involves linkages between objects. This was rejected because this would encumber the user and would be in conflict with purpose of developing a freely moveable TUI.

A passive tracking system was chosen because it is not subject to the constraints of active systems described above. Computer vision technology was available at the School of Computer Science at the University of Nottingham. This used colour matching and had demonstrated adequate performance in distinguishing between multiple objects in the field of vision of a digital camera (Ghali et al., 2003).

5.4.4 A Computer Vision System

The computer vision system used in this project employed a Logitech™ web-cam positioned to point vertically downwards onto a workspace using a Kodak tripod. The workspace was constructed from a matt-black (i.e. non-reflective) plywood board 100cm X 60cm. The web-cam was connected to a Toshiba Satellite Pro notebook computer running the vision system software coded in C++ by colleagues at the School of Computer Science at the University of Nottingham.

A robust technique for visual recognition of coloured objects and spatial location within the field of view of a video camera has been developed by Swain and Ballard (1991). Their technique compares red, green and blue (RGB) attributes of objects placed within the field of view of a digital camera with the colour histograms of previously trained objects or models. In their technique, the RGB components of an image captured by the camera are compared with those of the model and the resulting match is calculated as a confidence value.

Red, green and blue colour (RGB) component segmentation is susceptible to light intensity. Inconsistent or low level lighting produces unreliable results. Instead of using RGB components the Hue, Saturation and Light (HSL) components were measured.

The light intensity component (L) was ignored so that the system was not susceptible to light intensity variations. The saturation component of colour (S) refers to the amount of white light or noise that is included in the colour. High saturation gives purer colour and has a low noise component. The saturation was therefore set to the maximum level for optimum colour. The hue (H) component was the remaining variable and this was used to identify objects in the field of view.

A model of each object was generated. Each object was placed in the field of view of the camera in turn and a frame was grabbed. The frame was a snapshot of the entire field of view and the part of the image that would become the model was extracted from the background. The model was separated from the background using Paintshop

Pro™ and the resulting image was saved as a portable network graphics (PNG) file. This was repeated until a model was stored for every object to be identified.

To measure the confidence of a match between a captured image of an object and its model, objects were placed in the field of view of the camera and the images were compared with pre-recorded models of all the objects. The confidence of a match between image and model was calculated by the vision system software in the following way.

When an object was moved into the field of vision of the camera, an 8*8*8 bin hue histogram of the captured image was compared with the hue histograms of every model that were stored as PNG files. Hue values were compared.

If $N_I(i)$ is defined as the value calculated for the i^{th} bin of image I (1)

Then $N_M(i)$ is the value calculated for the i^{th} bin of model M (2)

The difference between (1) and (2) is calculated for all bins and the minimum of the result and zero is registered for each operation. This is repeated for all 8*8*8 colour bins. The summation of each operation results in a value between $-N_M$ and 0. A negative value represents low correspondence of colour matching. A score of zero represents a positive colour match.

The confidence that a model matches an image is defined as C(M,I) (3)

Pridmore et al. (2004) present an expression to calculate C(M,I) based upon the work of Swain and Ballard (1991) as:

$$C(M,I) = \left[1 + \frac{\sum_{i=1}^{i=511} \min\left(N_I(i) - N_M(i), 0\right)}{N_M} \right]$$

Low intersection between a model and the image will result in a summation approaching $-N_M$ thus:

$$C(M,I) \text{ will be approaching } 1 + (-N_M/N_M) = 0 \quad (4)$$

High intersection between the model and the image will result in a summation approaching 0, thus:

$$C(M,I) \text{ will be approaching } 1 + (-0/N_M) = 1 \quad (5)$$

A threshold value is predefined within the configuration file prior to sampling. Values computed in excess of this minimal value are considered to indicate a positive match between image and model.

The spatial location of the object is calculated in two stages. First the average location of pixels in a given bin is calculated. The proportion of pixels in a given bin that match the model is calculated. This is used as a weighting in which high values correspond to a confident match. Using these weightings the coordinates that correspond to a good match are aggregated, the result being x and y coordinates that approximate to the centre of the matched object.

The author developed a technique for passing object identity and coordinate data from the vision system to the Virtools™ VE. When operational, the vision system constantly updates a data file that contains the object identity and its spatial coordinates relative to the camera origin. This was repeatedly accessed by the VE software. The identity and coordinates of a positive matched object were then used to control a simulation of the object in the VE. This process was repeated at a frequency set in a configuration file. The value was set at 8Hz for this project, a value that was considered as a compromise between processing demand on the software against the reliability of tracking a moving object.

5.4.5 Testing the Vision System.

To test the vision system an experiment was set up to measure the confidence that the system would correctly identify an object over repeated trials. The Logitech™ camera was mounted on the tripod with the lens pointing towards the work surface and was connected to the Toshiba Satellite Pro notebook computer.

Five small pencil marks were made at five different positions on the work surface. Four marks were equally spaced to form a 50cm square with a fifth mark at the centre of the square. With the vision system software running the jug was placed on one of the markers. The data file recorded the confidence of a match between the model and the image of the object.

This was repeated for each of the four remaining markers. Five measures of confidence for the jug were recorded from which the mean and standard deviation were calculated.

This exercise was repeated for each of five objects that were to be used in the TUI in turn and the results are presented in table 5.5.

	JUG	KETTLE	JAR	MUG	SPOON
Confidence	0.975075	0.836774	0.900000	0.999051	0.991753
	1.000000	0.824477	0.881818	0.919355	0.938144
	0.790739	0.820378	0.853846	0.846300	0.804124
	0.829262	0.791685	0.806993	0.907970	0.940206
	0.997757	0.797980	0.813906	0.999051	0.824742
Max	1.000000	0.836774	0.900000	0.999051	0.991753
Min	0.790739	0.791685	0.806993	0.846300	0.804124
Mean	0.919897	0.814259	0.851313	0.934345	0.899793
S.D.	0.098419	0.018863	0.040838	0.065280	0.081157

Table 5.5 Confidence values and descriptive statistics for five samples of each object.

Confusion of recognition between objects was of concern. Kitchen items are commonly made of metal or glass with reflective surfaces. These cause a variation in the detected hue making identification of the object erratic. Similarly electrical appliances are commonly white or metallic. Objects were selected by the author and by the OT for their unique hues. Metal and glass objects were rejected. The objects that were used in the TUI were: a pink water jug, a green plastic electric kettle. a red coffee jar, a blue mug and a yellow spoon.

Following the calculation of the confidence of a match between an object and its model a second study was conducted to calculate the ability of the system to differentiate between objects.

Each object was placed individually under the camera in turn. The vision system calculated the confidence of a match between the object and every stored model. This was repeated for each object in turn and the results are presented below in table 5.6.

To ensure that the identification of the object is reliable the confidence of an object matched to its model must be substantially higher than the value calculated for the objects compared with other models, and should be approaching C=1. Table 5.6 shows that each object and its corresponding model (on the diagonal) show higher confidence values than other combinations.

MODEL	OBJECT				
	JUG	KETTLE	JAR	MUG	SPOON
JUG	**0.920738**	0.040692	0.450350	0.441176	0.352577
KETTLE	0.031157	**0.818182**	0.224476	0.040797	0.280412
JAR	0.100698	0.045821	**0.859441**	0.748577	0.354639
MUG	0.050100	0.009076	0.504196	**0.794118**	0.111340
SPOON	0.010219	0.013175	0.167133	0.113852	**0.977320**

Table 5.6 Confusion matrix for each object matched against each model.

The mug and jar show confidence values that are not too dissimilar. Similar values between two objects could cause errors in identification of these objects. Setting the minimum level at which the confidence value is considered to give a true match is therefore critical. A threshold value higher than 0.748577 (see object 'mug' compared with model 'jar') is required and a value lower than 0.794118 (see object 'mug' compared with model 'mug') is required. A value of 0.77 is reasonable. In practice the confidence values were improved by re-sampling the objects and creating new models by removing parts of the model that could cause a reduction in the confidence value, for example darker areas caused by shadows.

The importance of sourcing of objects of a single hue is demonstrated below in figure 5.4. This shows the hue distribution chart of the green kettle compared with that of a user's hand. The chart on the left is of the kettle, showing a very narrow range of hue values. The chart on the right is of a white Caucasian person's hand, showing a wide spectrum of hue values.

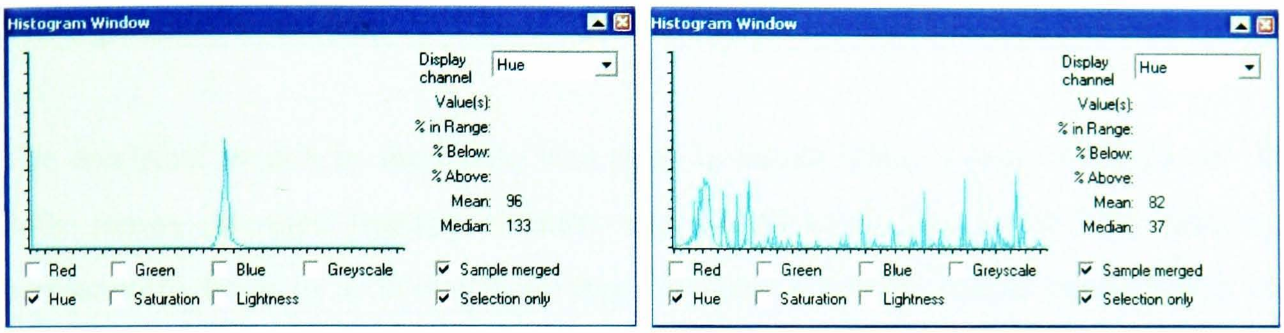

Figure 5.4 Comparison of hue distribution of kettle (left) with hue distribution of hand (right).

5.4.6 Sensors for Event detection

Although the identities and positions of objects in the scene may be computed by the vision system, this is not sufficient to confirm that an action has been carried out. For example detecting that the spoon is in close proximity to the jar is not the same as detecting that the spoon has been put into the jar. Using proximities as confirmation of action is clearly not adequate, and a robust method of detecting the intended actions was required.

A solution was sought using sensor technology. Electrical switches that detect a measurable change (tilt, pressure, continuity) were identified as a method of detecting actions and devices incorporating these sensors were constructed by the author as explained below.

Pressure sensors used type 6451 PCB mounted sub-miniature micro-switches. These incorporate a small lever which when pressed makes an electrical connection. Being small, the levers alone provided an inadequate target area for patients to push down on. Rigid boards of slightly smaller diameter than the object were attached to the micro-switches and mounted inside the objects forming a plate or diaphragm against which the user could press a utensil.

Tilt sensors used non-mercury tilt switches type CM1300 with a maximum make angle of 10° below horizontal and break angle of 10° above the horizontal. These were mounted inside objects that were normally tilted (poured) for which detection of a tilting action is required.

The electrical switch in the kettle was used to detect when it was switched on. The 240v mains operated heating element was deactivated. The kettle base plug was permanently fixed to a three pin surface mounted electrical mains outlet which was wired to a keyboard[1] encoder. When the kettle was placed on the base and switched on this completed a circuit across the keyboard encoder, emulating a key press.

5.4.7 Radio Frequency Switching

Radio controlled switches allow unencumbered freedom of movement that wired sensors do not offer. A radio frequency (RF) system to connect the sensors to the VE was sought. Of concern was the radio frequency band which must be carefully chosen to ensure that interference with hospital communication and medical equipment does not occur. Technical staff at the both the Medical Physics Department, QMC, and the Medical Equipment Service Unit (MESU), QMC were consulted. A system operating at 433 MHz, an all purpose license free bandwidth that is used for remote car locking systems was recommended.

Radio frequency switches were constructed. The transmitters were type AM-RT4-433[2] powered by 1.5 volt lithium cells and these were activated by either tilt switches or sensitive micro-switches. The circuits were constructed by the author, and were small enough to fit inside the kitchen equipment (the circuits were approximately 3cm x 2cm). An AM-HRR3-433 receiver was used to detect event triggers from the objects. The transmitter and receiver decoder circuits are to be found in the appendices, with permission from the manufacturers.

[1] available from Audon electronics
[2] available from RFSolutions Ltd: see appendix

The reliability of the tilt switches and micro-switches to operate the RF transmitter consistently over a fixed distance was measured. Each transmitter was placed in turn at a measured distance of two metres from the receiver. The receiver was connected to the USB port of a Toshiba Satellite-Pro notebook computer. The receiver was designed so that when an incoming signal was received, it operated a 500Ω relay. The relay contacts closed across two pins of the keyboard encoder, generating an alphanumeric character. Incoming strings of characters could be monitored using a simple text editor, confirming the receipt of a transmitted signal.

To test the sensors, each switch was operated repeatedly. Micro switches were repeatedly pressed down. Tilt switches were repeatedly tilted to an angle of 20° above horizontal and returned to an angle of 20° below the horizontal. The sensors were required to complete 100 consecutive switching events successfully before they were used.

5.4.8 Combining Sensors and the Vision System

The RF sensors were designed to detect when an action took place but not the context of the action. The vision system was used to identify those objects that were involved in the action and their location in the workspace but not to detect when an action had taken place. These two sources of data were complementary and together provided the necessary data to identify the context and event of an action.

A combination of the vision system and the sensors formed the basis of the TUI. This was connected to the input of the notebook computer to form the interface part of the MR system.

5.4.9 The Mixed Reality System

The TUI and the VE together formed the MR system. The VE was designed to monitor patient performance and to support the activity by providing prompts and demonstrations. The TUI was the input component of the MR system. The basic principles of its function were devised from the studies with similar input devices, flexibility of positioning of objects and realism of object function being desirable attributes.

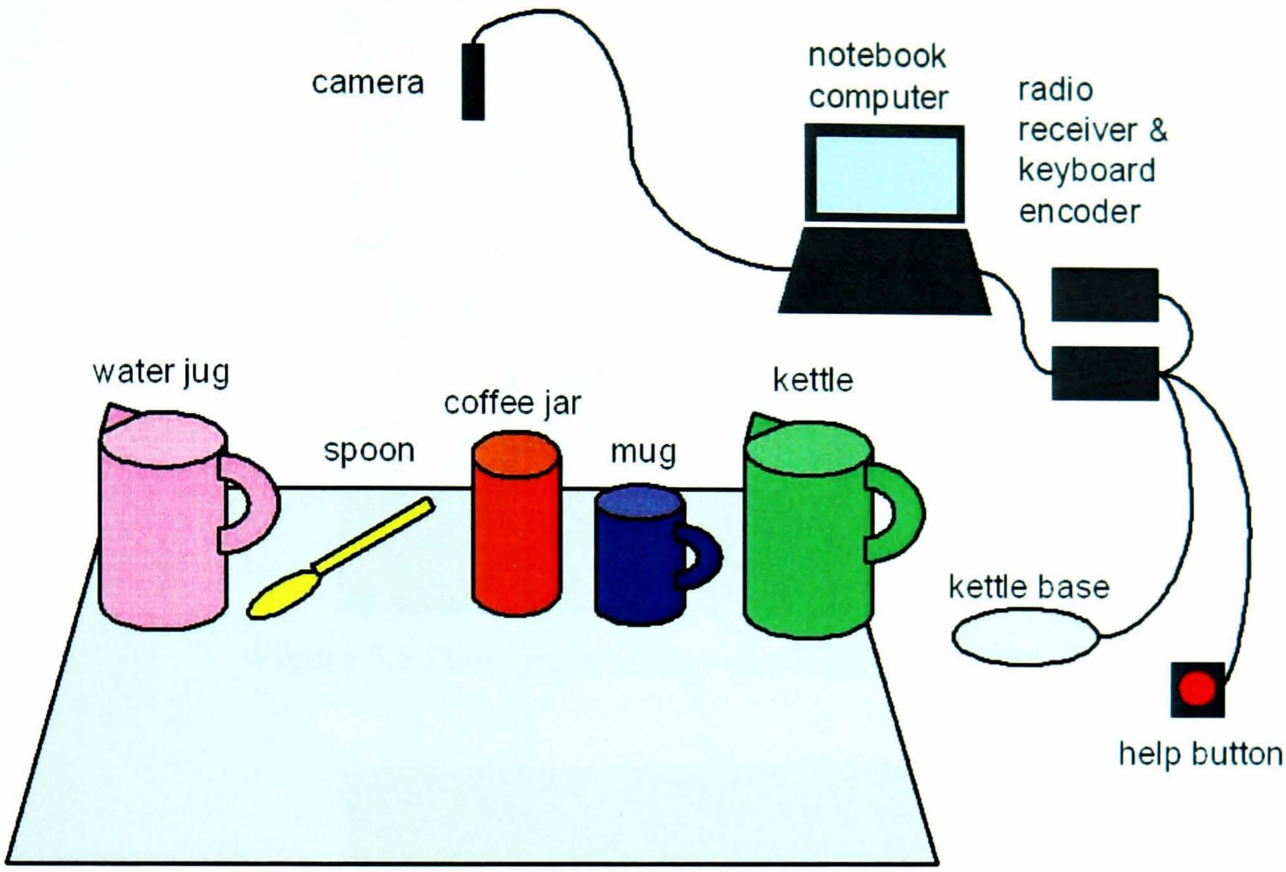

Figure 5.5 The complete MR system.

The resulting hardware was a kitchen workspace with real objects as controllers of the VE, with a camera detecting objects and their position, and sensors detecting events.

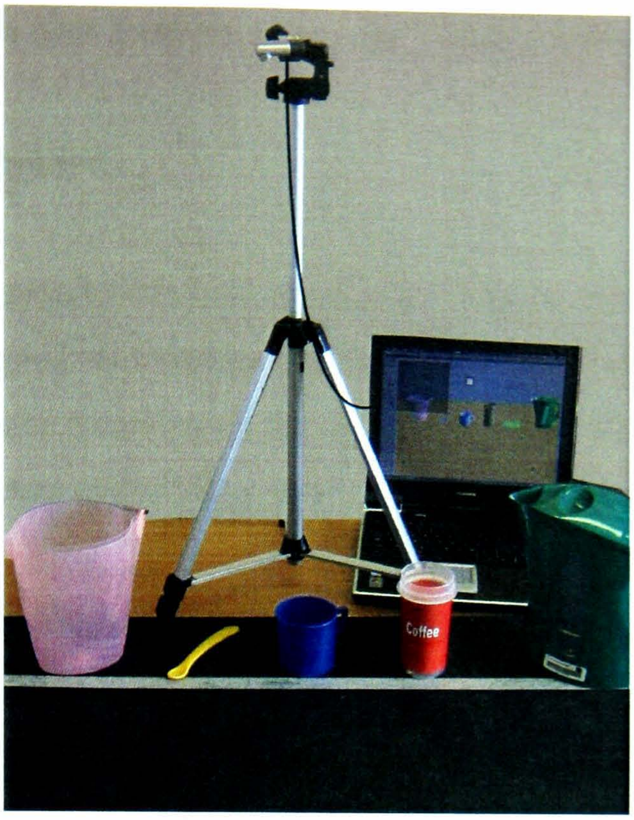

Figure 5.6 Photograph of the completed MR system.

Figure 5.7 The equipment in use.

Figure 5.6 shows a photograph of the apparatus, including the notebook computer in the background which can be seen displaying the VE. Figure 5.7 shows the equipment being used.

5.5 Studies with Patients Using the Mixed Reality System

5.5.1 Introduction

In this study, the MR system was used in the rehabilitation setting by stroke survivors. This study was designed to investigate the practicality of the system and through collaboration with stroke survivors on the stroke unit, to iteratively develop the layout and specific requirements of the MR system. The aims of the study were:

- to study the feasibility of implementing an MR system on a stroke unit
- to investigate the implications of using an MR system on the stroke unit
- to find out whether stroke survivors could understand and use the system
- to identify errors, both technical and user, to feed back into the design
- to identify improvements in the system

5.5.2 Equipment

The equipment for the MR interface evaluation consisted of the following:

Technical:

- Toshiba Satellite-Pro notebook computer
- VE of the coffee making task programmed in Virtools™
- Creative Labs web-cam mounted vertically on a Kodak tripod and connected to a USB port of the notebook computer
- Audon Electronics keyboard encoder connected to a USB port
- 433MHz Radio Frequency Receiver connected to keyboard encoder
- A red help button

For observation:

- Sony MiniDV digital video camcorder with tripod
- Notepad and pen
- Questionnaire (computer attitude survey and MR system feedback)

Kitchen equipment:

- Kettle with tilt switch and RF transmitter
- Kettle base wired to keyboard encoder
- Jug with tilt switch and RF transmitter
- Mug with micro-switch and RF transmitter
- Plastic spoon
- Coffee jar with micro-switch and RF transmitter

5.5.3 Method

From August 2005 for a period of three months stroke survivors who were admitted to the Stroke Unit at QMC, Nottingham, were assessed for suitability to participate in the study. Patients were initially included if they were diagnosed with a stroke and were undergoing rehabilitation with good prospect of returning home. As with the previous study they were excluded if they presented with or had a recorded history of dementia, susceptibility to screen triggered epilepsy, psychiatric illness, inability to speak English, hearing impairment, no upper limb function or were enrolled on another study. Suitability to participate was assessed by the OT who had access to patient's notes.

Patients who fulfilled the selection criteria above were invited to participate. Those who expressed an interest in the study were given a patient information sheet. The sheet was read out to the subjects and they were then asked whether they would like to continue to participate. Patients were informed that at any stage they may refuse to continue. Verbal consent was gained in compliance with ethical requirements. The OT was in attendance at every session.

The equipment was set up in the day room of the stroke unit with the utensils and other kitchen hardware positioned towards the back of the work surface. Users were required to bring objects into the field of view of the camera for them to become active components of the activity.

Patients were seated in front of the work space. Initially the computer was positioned to the right of the workspace for ease of access and visibility. The VE software program was run and the patients were allocated a unique identifier code (of the format MR.n where n is between 1 and 14). The patient's name was not recorded for reasons of anonymity.

The computer issued a verbal prompt to start the task and the patients followed the cue to commence the coffee making activity. Written observation notes were made throughout including unusual occurrences, errors made and problems with the equipment.

Each session was videotaped using a Sony miniDV camcorder mounted upon a Kodak tripod and directed towards the working area. Only the patient's upper-limb movements were recorded onto miniDV tape for analysis. The patient's face was not recorded, also for reasons of anonymity.

The computer recorded every action in the sequence that was detected by the vision system and the RF sensors. It recorded whether a verbal prompt was necessary and whether a visual demonstration was given. It also recorded whether the session was manually paused and when it was resumed. The time of each event was added to the sequence record so that events recorded by the computer could be matched against events that were captured by the camcorder.

Following the completion of the activity the subjects were interviewed by the author with the OT in attendance. The interview comprised a computer attitude survey and further questions about the user's experience of using the MR system.

A Computer Attitude Scale (CAS) devised by Lloyd and Gressard (1984) was used for the attitude assessment. The CAS comprised questions associated with themes of anxiety, confidence, usefulness and liking. The CAS used for this study comprised eight questions, four of which were positively worded, the remainder being negatively worded. The responses were scored on a five point Likert scale.

For the four positively worded questions five points were allocated to "strongly agree" responses. One point was allocated to "strongly disagree" responses and neutral responses ("don't know") scored three points.

For negative worded questions the reverse is true. Five points were allocated to a "strongly disagree" and one point for a "strongly agree" response. Questions were paired so that for each negative worded question there was a positive counterpart, one pair for each of the four themes. The statements are presented in table 5.7.

CAS statement
1. Computers do not scare me at all
2. I am sure I could use computers for learning
3. I will do as little work with computers as possible
4. Learning to use computers is a waste of time
5. Computers make me feel uncomfortable
6. I think using a computer would be very hard for me
7. I think working with computers would be enjoyable and stimulating
8. I am sure I could use computers for work or learning

Table 5.7 CAS statements, comprising four themes of paired questions (Lloyd and Gressard, 1984).

A further five statements about participants' experiences of the session were rated using a five point scale. Finally and an open ended question was presented, offering the opportunity to suggest improvements.

When the observations and questions had been completed the OT led the patient back to the ward. After each trial all results, recorded media and notes were held securely in a locked metal filing cabinet away from the ward.

Mini DV tape recordings of patient progress were recorded onto DVD. Microsoft Windows™ Movie Maker V6.1 was then used to analyse the DVD contents. As both the VE and Windows™ Movie Maker V6.1 include time stamping it was possible to compare the events that the computer registered with those that the DV camcorder recorded in the field.

For each trial, the video recording was inspected and actions were noted with the time of the event from the start of the activity recorded. Two tables were generated for each participant; one showing the actual events interpreted from the video recording. the other showing events recorded by the computer. Theses tables of results are to be found in the appendices.

The two sets of data were compared. Corresponding events in both tables indicate actual events that were also recorded electronically. Discrepancies between these two sets of data were identified and categorised as either user error or technical error. These errors were then analysed in order to make improvements to the MR system as appropriate.

5.5.4 Results of Study One: Patients MR1 to MR4

5.5.4.1 Results for MR1

Patient MR 1 was a 77 year old male who was admitted to the stroke unit following a second stroke. He was unable to move his left arm but was normally right handed. He was able to talk and to respond to spoken language.

MR 1 commenced the task by explaining what he required for the task and repeated this for each stage of the task. He quickly grabbed each piece of equipment and moved it into the workspace so that he had accumulated all the apparatus and utensils before using them. MR1 put the spoon into the jar then into the mug. He then picked up the kettle and tilted it towards the mug. He did not fill the kettle or switch it on before pouring the kettle. He completed the activity by making a stirring action in the mug with the spoon. The session was stopped at 1m 1s.

USER ERROR	SYSTEM ERROR
Poured kettle to mug without filling or boiling.	Recorded get jug when jug not picked up. Did not register spoon

Table 5.8 User and system errors (MR1).

MR 1 clearly understood that this was a simulation of a coffee making activity, following the correct sequence of spooning coffee into a mug however he failed to carry out the process of boiling water, tilting the kettle to the mug without performing the boiling water sequence.

The jug was registered in error. Conversely the spoon was not registered when present. The confidence values of each object was measured and it was found that the spoon was below the threshold that had been set to C(M,I)=0.8 , whilst the jug was consistently above this value when in the cameras field of vision. Images of the jug and spoon were captured and new models were made. Confidence levels were re-measured and the spoon was reliably registered.

Question		Participant's Response	Score
Prior Experience: I use computers		Never	6
Q1	Computers do not scare me at all	Strongly disagree	1
Q2	I could use computers for learning	Strongly disagree	1
Q3	I will do as little work with computers as possible	Strongly agree	1
Q4	Learning to use computers is a waste of time	Slightly disagree	4
Q5	Computers make me feel uncomfortable	Slightly agree	2
Q6	I think using a computer would be very hard for me	Strongly agree	1
Q7	I think working with computers would be enjoyable and stimulating	Slightly agree	4
Q8	I am sure I could use computers for work or learning	Slightly disagree	2
Q9	When the computer gave instructions, I could hear them clearly	Strongly agree	5
Q10	When the computer gave instructions, I could understand what was being asked	Strongly agree	5
Q11	I knew what I had to do to carry out the instruction	Strongly agree	5
Q12	The device enabled me to do what was asked of me	Strongly agree	5
Q13	The screen was useful as it showed me what I had done	Not sure	3
Q14	If I could make changes to this, it would be:	Make sure the actions are as real as possible. Could include lid on jar.	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		3
Confidence	(Q2 + Q6)		2
Liking	(Q3 + Q7)		5
Usefulness	(Q4 + Q8)		6
Total			16

Table 5.9 Questionnaire responses (MR1).

5.5.4.2 Results for MR2

Patient MR2 was a male aged 89 years, normally right handed. He reported that this was his second stroke and it was ten weeks since he had been admitted. The OT reported that he had some dysphasia but was able to communicate and was therefore included.

MR2 was not always certain what to do next. He observed the screen and appeared to be waiting for prompts. After obtaining the jug he poured the jug towards the kettle without first bringing the kettle into the scene. He then pressed the switch on the kettle.

After a period of inactivity MR2 was asked by the OT to get the kettle which he did. After a further period of inactivity MR2 pressed the help button which triggered the computer to offer the advice to "get the kettle base". Although this was an appropriate instruction MR2 did not respond to the instruction.

After a further period of inactivity by the user, the OT advised MR2 to pour the jug of water into the kettle which he did. MR2 gathered the mug, spoon and jar. He put the spoon into the mug then correctly put the spoon into the jar and back to the mug repeatedly.

After a further period MR2 was asked by the OT to put the kettle on the base. In error he placed the mug on the base but with assistance from the OT placed the kettle correctly. He remained inactive for a further period until the OT asked "what is the next stage?" He picked up the jug and poured it towards the kettle, something that he had already done in the task.

Finally, he poured the kettle towards the mug then put the spoon into the mug. The session was stopped at 10min 22 sec.

USER ERROR	SYSTEM ERROR
Poured jug to kettle without bringing kettle into scene. Empty spoon to mug Put mug on base Attempted to boil water without placing kettle on base	

Table 5.10 User and system errors (MR2).

Following the technical problems from the previous patient study, all objects were registered when placed in the cameras field of vision. As with MR 1, patient MR 2 appeared to comprehend the concept of the MR system. MR 2 appeared to be confused by the kettle base, placing the mug on it but not the kettle. MR 2 placed an empty spoon in the mug prior to putting it in the jar.

The OT intervened frequently during this patient study. The patient was not able to complete the task relying on the computer generated prompts and demonstrations.

Question		Participant's Response	Score
Prior Experience: I use computers		Less frequently than once a month	5
Q1	Computers do not scare me at all	Slightly disagree	2
Q2	I could use computers for learning	Slightly agree	4
Q3	I will do as little work with computers as possible	Slightly agree	2
Q4	Learning to use computers is a waste of time	Slightly disagree	4
Q5	Computers make me feel uncomfortable	Slightly agree	2
Q6	I think using a computer would be very hard for me	Strongly disagree	5
Q7	I think working with computers would be enjoyable and stimulating	Slightly disagree	2
Q8	I am sure I could use computers for work or learning	Slightly agree	4
Q9	When the computer gave instructions, I could hear them clearly	Strongly disagree	1
Q10	When the computer gave instructions, I could understand what was being asked	Strongly disagree	1
Q11	I knew what I had to do to carry out the instruction	Slightly agree	4
Q12	The device enabled me to do what was asked of me	Slightly agree	4
Q13	The screen was useful as it showed me what I had done	Slightly disagree	2
Q14	If I could make changes to this, it would be:	No improvements	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		4
Confidence	(Q2 + Q6)		9
Liking	(Q3 + Q7)		4
Usefulness	(Q4 + Q8)		8
Total			25

Table 5.11 Questionnaire responses (MR2).

5.5.4.3 Results for MR3

Patient MR3 was a male aged 57 years who was normally right handed and had suffered a stroke that resulted in loss of use of the left upper limb some 21 days previously. He had an unfortunate tendency to vomit if any sudden or unusual body movements were made although the actual cause of this was not known at the time.

MR3 had limited mobility and was seated in a wheelchair for the duration of the trial. He progressed through the activity at a steady and continuous pace until he completed the activity.

MR3 correctly picked up the kettle and jug then poured the jug to the kettle. He then correctly placed the kettle on to the base. A prompt by the computer warned that there was no water in the kettle.

The mug, spoon and jar were picked up together. The spoon was put into the jar then into the mug actions that are correct. A prompt by the computer requested that the coffee should be spooned into the mug.

MR3 complied with a prompt to switch the kettle on and following the simulated boiling of water he poured the kettle towards the mug.

Finally he replaced the kettle onto the base and received a warning that he had already switched the kettle on, due to the kettle switch remaining in the on position. He completed the task at 6m 45s.

USER ERROR	SYSTEM ERROR
	Failed to register jug poured to kettle. Repeated error message: Already switched kettle on

Table 5.12 User and system errors (MR3).

The patient performed the correct actions in the correct order. The first problem was that the jug to kettle action had not been recorded. The OT intervened to demonstrate that the jug had to be tilted (to activate the tilt switch). On a second attempt the patient successfully performed the correct action.

Question		Participant's Response	Score
Prior Experience: I use computers		Never	6
Q1	**Computers do not scare me at all**	Strongly agree	5
Q2	**I could use computers for learning**	Strongly agree	5
Q3	**I will do as little work with computers as possible**	Slightly agree	2
Q4	**Learning to use computers is a waste of time**	Strongly disagree	5
Q5	**Computers make me feel uncomfortable**	Strongly disagree	5
Q6	**I think using a computer would be very hard for me**	Strongly agree	1
Q7	**I think working with computers would be enjoyable and stimulating**	Strongly agree	5
Q8	**I am sure I could use computers for work or learning**	Strongly agree	5
Q9	**When the computer gave instructions, I could hear them clearly**	Strongly agree	5
Q10	**When the computer gave instructions, I could understand what was being asked**	Strongly agree	5
Q11	**I knew what I had to do to carry out the instruction**	Strongly agree	5
Q12	**The device enabled me to do what was asked of me**	Not sure	3
Q13	**The screen was useful as it showed me what I had done**	Strongly agree	5
Q14	**If I could make changes to this, it would be:**	None. Don't normally make coffee.	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		10
Confidence	(Q2 + Q6)		6
Liking	(Q3 + Q7)		7
Usefulness	(Q4 + Q8)		10
Total			**33**

Table 5.13 Questionnaire responses (MR3).

5.5.4.4 Results for MR4

A male aged 50 years old, MR4 was normally right handed and suffered his first stroke 18 weeks prior to the trials. His left upper limb was affected and he was emotionally affected by the stroke. He was accompanied by his carer who observed the proceedings without interrupting.

MR4 performed the task steadily and slowly, considering each stage carefully before performing an action. He acquired the jug and poured it towards the kettle before placing the kettle on the base. This sequence is correct. As with MR 3 assistance was necessary due to the system in not recording the water pouring.

MR4 had difficulty placing the kettle on the base. He acquired the spoon and put it into the jar but had not brought the jar into the scene. This was demonstrated by the author and MR4 repeated the action, retrieving the jar. He made the action of spooning coffee from jar to mug, repeating this. Finally he poured the kettle to the mug, also repeating this. The task was completed at 2m 45s.

USER ERROR	SYSTEM ERROR
Difficulty putting kettle on base, following demonstration, user correctly places kettle.	Failed to recognise jug poured to kettle

Table 5.14 User and system errors (MR4).

MR 4 comprehended the purpose of the MR system and correctly performed the task. As with MR 3 the jug was not tilted and the action was not recorded by the computer. The OT intervened to demonstrate the pouring action.

MR 4 had some difficulty locating the kettle onto the base due to misalignment. The base is flat with a spigot that locates into the base of the kettle to make an electrical connection. The kettle was not correctly aligned to allow this and a demonstration by the OT was necessary, following which the patient correctly placed the kettle.

Question		Participant's Response	Score
Prior Experience: I use computers		Less frequently than once a month	5
Q1	**Computers do not scare me at all**	Strongly agree	5
Q2	**I could use computers for learning**	Strongly agree	5
Q3	**I will do as little work with computers as possible**	Strongly disagree	5
Q4	**Learning to use computers is a waste of time**	Strongly disagree	5
Q5	**Computers make me feel uncomfortable**	Strongly disagree	5
Q6	**I think using a computer would be very hard for me**	Strongly disagree	5
Q7	**I think working with computers would be enjoyable and stimulating**	Strongly agree	5
Q8	**I am sure I could use computers for work or learning**	Strongly agree	5
Q9	**When the computer gave instructions, I could hear them clearly**	Strongly agree	5
Q10	**When the computer gave instructions, I could understand what was being asked**	Strongly agree	5
Q11	**I knew what I had to do to carry out the instruction**	Strongly agree	5
Q12	**The device enabled me to do what was asked of me**	Strongly agree	5
Q13	**The screen was useful as it showed me what I had done**	Slightly agree	4
Q14	**If I could make changes to this, it would be:**	Stroke affects memory and this is useful. I didn't use the screen much.	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		10
Confidence	(Q2 + Q6)		10
Liking	(Q3 + Q7)		10
Usefulness	(Q4 + Q8)		10
Total			**40**

Table 5.15 Questionnaire responses (MR4).

5.5.4.5 Summary of Changes Made Following Study One

During the trial with MR3 an error message was repeatedly given that the kettle was already switched on when it was placed on the base. This was not an error but was it registered as one by the computer as an action that had already been completed. The kettle may be removed from the base and replaced repeatedly with the switch in the 'on' position. This is acceptable providing there is water present. The kettle switch in the TUI latched on when operated and this only allowed for one attempt. This was corrected in the VE to allow the kettle to be replaced on the base with the switch on by ensuring that if the kettle was removed from the base the "kettle to base" status variable was reset.

During the first study with patient MR1 to MR4 the notebook computer was positioned to the right hand side of the workspace. For MR5 onwards, following advice from the OT, the notebook computer was relocated to a central position, in order to reduce unusual head and neck movements that patients would have to make in order to turn away from the workspace to view the screen.

5.5.5 Results of Study Two: Patients MR5 and MR6

5.5.5.1 Results for MR5

MR5 was a 52 year old male who was normally right handed and had experienced a stroke four weeks previously that had affected his left side particularly his left upper limb. No speech impairment was evident.

He correctly acquired the jug and poured it towards the kettle which was not in the scene. The OT asked him to bring the kettle into the scene which he did. MR5 placed the kettle on the base and switched it on. He was prompted by the computer to "do something else first". The action to fill the kettle had not been recognised as the kettle was out of view.

The sequence of filling the kettle and placing it on the base was repeated twice by MR5. The kettle was switched on and the simulation of water boiling was displayed on the computer.

MR5 correctly acquired the mug, spoon and jar. He placed the spoon into the jar then into the mug. MR5 poured the kettle towards the mug and placed the kettle back on the base. He completed the task in 5m 21s.

USER ERROR	SYSTEM ERROR
Poured jug to kettle: kettle not in scene, responded to instruction to do so	Spoon not recognised hence actions involving spoon not registered

Table 5.16 User and system errors (MR5).

Placing objects in the field of view of a camera is not a natural part of making a cup of coffee hence it was not always performed. Objects were initially placed to the rear of the workspace out of the cameras view and subjects were expected to bring objects onto the workspace in order that the objects are registered (and scored) as having been 'got' by the patient. The patient did not move the kettle onto the workspace, therefore did not get the kettle. In a real assessment on a stroke unit, the OT explained that the patient would be required to show that they had acquired the kettle by bringing forward. This is therefore not a system error but a patient omission.

Question		Participant's Response	Score
Prior Experience: I use computers		Every day	1
Q1	**Computers do not scare me at all**	Strongly agree	5
Q2	**I could use computers for learning**	Strongly agree	5
Q3	**I will do as little work with computers as possible**	Strongly disagree	5
Q4	**Learning to use computers is a waste of time**	Strongly disagree	5
Q5	**Computers make me feel uncomfortable**	Strongly disagree	5
Q6	**I think using a computer would be very hard for me**	Strongly disagree	5
Q7	**I think working with computers would be enjoyable and stimulating**	Slightly agree	4
Q8	**I am sure I could use computers for work or learning**	Strongly agree	5
Q9	**When the computer gave instructions, I could hear them clearly**	Strongly agree	5
Q10	**When the computer gave instructions, I could understand what was being asked**	Strongly agree	5
Q11	**I knew what I had to do to carry out the instruction**	Strongly agree	5
Q12	**The device enabled me to do what was asked of me**	Strongly agree	5
Q13	**The screen was useful as it showed me what I had done**	Not sure	3
Q14	**If I could make changes to this, it would be:**	Possibly a lid on the coffee. The switch was hard with one hand.	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		10
Confidence	(Q2 + Q6)		10
Liking	(Q3 + Q7)		9
Usefulness	(Q4 + Q8)		10
Total			**39**

Table 5.17 Questionnaire responses (MR5).

5.5.5.2 Results for MR6

MR6 was a female aged 75 years who had experienced three strokes although this latest episode was not yet confirmed. She had an affected left side and was normally right handed. She was able to communicate effectively.

MR6 commenced the activity by acquiring the spoon, jar and mug. She correctly placed the spoon into the jar then the mug. When prompted to "press the red button" she complied and the computer issued the instruction "get the kettle" which she did.

MR6 then poured the kettle towards the mug, without filling with water or boiling water. She complied with a further prompt to press the red button and the instruction was to get the base. MR6 did not identify the base and this had to be demonstrated by the OT. She placed the kettle onto the base but incorrectly. Again the OT demonstrated the correct action.

Following a prompt to pour water into the kettle MR6 complied by picking up the jug but not tilting it sufficiently close to the kettle for the action to register. The experimenter demonstrated the action and MR6 complied.

Following a prompt to push the button the instruction was given by the computer to switch the kettle on. MR6 attempted this experiencing some difficulty with the kettle switch but eventually managed to complete this and the water boiling simulation was activated.

The prompt to push the red button was followed by the instruction to spoon coffee into the mug. MR6 acquired the mug, jar and spoon and placed the spoon in the jar then the mug. She did not press sufficiently onto the sensor for it to register so the instruction was repeated. The session was stopped at 7m 01s.

USER ERROR	SYSTEM ERROR
Did not get the base without demonstration by OT Rocked kettle on base	Get jug of water not registered. Spoon to jar not registered Repeatedly registers error for unloaded spoon to mug Kettle to mug registered in error

Table 5.18 User and system errors (MR6).

The concept of the MR system appeared to be understood, as MR 6 performed the correct actions of spooning coffee into the mug. MR 6 responded appropriately to the computer prompts.

As with previous studies the tilting action was not performed correctly and had to be demonstrated. MR 6 did not put the spoon into the jar sufficiently to activate the micro-switch and the action was not registered, hence an error of putting an empty spoon into the mug was recorded.

MR 6 repeatedly rocked the kettle whilst on the base, causing a repetition of the message "you have already done that". As with MR 3 this is an error that is difficult to resolve. If the patient perseverates (repeating an action) then the system must be able to identify this, offer a prompt and prevent the patient from continuing with the repeated action. If, as in this case, the patient removes the kettle from the base before it has completed the boiling sequence, replacing the kettle must permit the sequence to continue.

Question		Participant's Response	Score
Prior Experience: I use computers		Never	6
Q1	Computers do not scare me at all	Strongly agree	5
Q2	I could use computers for learning	Strongly agree	5
Q3	I will do as little work with computers as possible	Slightly disagree	4
Q4	Learning to use computers is a waste of time	Strongly disagree	5
Q5	Computers make me feel uncomfortable	Slightly agree	2
Q6	I think using a computer would be very hard for me	Slightly agree	2
Q7	I think working with computers would be enjoyable and stimulating	Slightly agree	4
Q8	I am sure I could use computers for work or learning	Slightly agree	4
Q9	When the computer gave instructions, I could hear them clearly	Strongly agree	5
Q10	When the computer gave instructions, I could understand what was being asked	Strongly agree	5
Q11	I knew what I had to do to carry out the instruction	Strongly agree	5
Q12	The device enabled me to do what was asked of me	Strongly agree	5
Q13	The screen was useful as it showed me what I had done	Slightly agree	4
Q14	If I could make changes to this, it would be:	Clear and straightforward. I watched the screen to see if I was doing it right.	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		7
Confidence	(Q2 + Q6)		7
Liking	(Q3 + Q7)		8
Usefulness	(Q4 + Q8)		9
Total			31

Table 5.19 Questionnaire responses (MR6).

5.5.5.3 Summary of Changes Made Following Study Two

The failure of the system to recognise the spoon is a system error that occurred with patient MR 1. When placed flat the spoon is clearly recognised however if the spoon is held with the narrow side towards the camera, the image presented is very much diminished and insufficient to match the model. To correct the error the spoon model a new model of the spoon was sampled and the confidence value measured before the third study took place.

5.5.6 Results of Study Three: Patients MR7 to MR10

5.5.6.1 Results for MR7

A male aged 75 years with an affected left side and some dysphasia but able to communicate, MR7 was normally right handed. He was able to walk but was seated for the trial.

He progressed steadily through the task but there were instances when he was not able to decide what to do to continue the activity. He started the activity by placing the kettle onto the base and switching it on, without first adding water to the kettle.

MR7 acquired the mug, jar and spoon together and correctly placed the spoon into the jar then into the mug. He stated that the water has boiled and poured the kettle towards the mug. The sequence to boil water had not been completed as he had not filled the kettle initially.

MR7 followed prompts and after a demonstration by the OT correctly filled the kettle, placed it on the base and switched it on. During the boiling water simulation MR7 repeatedly poured the jug towards the kettle. Following the boiling water simulation MR7 correctly poured the kettle towards the mug. The session was stopped at 4m 30s.

USER ERROR	SYSTEM ERROR
Put spoon to jar then spoon to mug but not operating micro-switches hence not registered Switched kettle on when empty Patient unsure how to pour water, assisted by OT Patient repeatedly poured water from jug to kettle	

Table 5.20 User and system errors (MR7).

No technical problems were identified in this session. The system did identify the error of putting an empty kettle on the base and switching it on. It offered the appropriate prompts to which the patient responded. The OT intervened to demonstrate how to tilt the jug. This was a recurring problem, as users frequently did not tilt the jug towards the kettle as one would expect.

Question		Participant's Response	Score
Prior Experience: I use computers		Every day	1
Q1	Computers do not scare me at all	Strongly agree	5
Q2	I could use computers for learning	Strongly agree	5
Q3	I will do as little work with computers as possible	Strongly disagree	5
Q4	Learning to use computers is a waste of time	Strongly disagree	5
Q5	Computers make me feel uncomfortable	Slightly agree	2
Q6	I think using a computer would be very hard for me	Slightly agree	2
Q7	I think working with computers would be enjoyable and stimulating	Strongly agree	5
Q8	I am sure I could use computers for work or learning	Strongly agree	5
Q9	When the computer gave instructions, I could hear them clearly	Strongly agree	5
Q10	When the computer gave instructions, I could understand what was being asked	Strongly agree	5
Q11	I knew what I had to do to carry out the instruction	Strongly agree	5
Q12	The device enabled me to do what was asked of me	Strongly agree	5
Q13	The screen was useful as it showed me what I had done	Strongly agree	5
Q14	If I could make changes to this, it would be:	No changes	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		7
Confidence	(Q2 + Q6)		7
Liking	(Q3 + Q7)		10
Usefulness	(Q4 + Q8)		10
Total			**34**

Table 5.21 Questionnaire responses (MR7).

5.5.6.2 Results for MR8

A female of 83 years, MR8 was normally right handed with an affected left side. MR8 was able to understand what was expected and progressed steadily through the task. She correctly completed the sequence for boiling water, pouring water from jug to kettle, placing the kettle on the base and switching on the kettle.

MR8 acquired the mug and the jar but was unsure what to do next. The OT pointed out that there was a spoon. She picked up the spoon and placed it into the jar. Initially the spoon did not register. MR 8 then placed the spoon on the surface.

MR8 poured the kettle to the mug. She pressed the help button for assistance and was prompted by the computer to place the spoon in the mug which she complied with, completing the activity. The session finished at 8m 39s.

USER ERROR	SYSTEM ERROR
Kettle rocked causing repeated error message.	Spoon not registered, held sideways

Table 5.22 User and system errors (MR8).

MR 8 completed the activity but during the session performed the two frequent errors: rocking the kettle and holding the spoon sideways. The former generated a repeated error message that the action had been performed which is correct and this cannot be attributed to a system error. The spoon was not registered because an insufficient image was captured to match the model.

Question		Participant's Response	Score
Prior Experience: I use computers		Never	6
Q1	Computers do not scare me at all	Slightly agree	4
Q2	I could use computers for learning	Strongly disagree	1
Q3	I will do as little work with computers as possible	Strongly agree	1
Q4	Learning to use computers is a waste of time	Strongly agree	1
Q5	Computers make me feel uncomfortable	Slightly disagree	4
Q6	I think using a computer would be very hard for me	Strongly agree	1
Q7	I think working with computers would be enjoyable and stimulating	Strongly disagree	1
Q8	I am sure I could use computers for work or learning	Strongly disagree	1
Q9	When the computer gave instructions, I could hear them clearly	Strongly agree	5
Q10	When the computer gave instructions, I could understand what was being asked	Strongly agree	5
Q11	I knew what I had to do to carry out the instruction	Strongly agree	5
Q12	The device enabled me to do what was asked of me	Strongly agree	5
Q13	The screen was useful as it showed me what I had done	Strongly disagree	1
Q14	If I could make changes to this, it would be:	Could be useful. Only change to make the spoon work better otherwise none.	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		8
Confidence	(Q2 + Q6)		2
Liking	(Q3 + Q7)		2
Usefulness	(Q4 + Q8)		2
Total			**14**

Table 5.23 Questionnaire responses (MR8).

5.5.6.4 Results for MR9

Patient MR9 was a male aged 64 years, normally right handed. Four weeks previously he suffered a stroke that affected his left side. He was unable to move without a wheelchair and was seated in this throughout the trial.

MR9 acquired the jug, poured it to the kettle and switched on the kettle. He put the spoon in the jar then the mug. These actions were performed in the correct order however MR9 did not bring objects into the field of view of the camera and therefore the actions were not registered by the system. The kettle was repeatedly registered as being present when it was not present.

MR9 stopped the task at 3m 59s.

USER ERROR	SYSTEM ERROR
Mug not in scene therefore sequence not registered	Spoon not registered Poured water not registered Kettle registered when not present

Table 5.24 User and system errors (MR9).

MR9 wore a green shirt with long sleeves. During the session the kettle repeatedly appeared in the VE when it was not in the work space. This was confirmed by the computer record of activity. By viewing the video and comparing it with the registered actions it was apparent that the problem was that the vision system confused MR9's green sleeve with the green kettle.

Question		Participant's Response	Score
Prior Experience: I use computers		Never	6
Q1	**Computers do not scare me at all**	Strongly agree	5
Q2	**I could use computers for learning**	Slightly agree	4
Q3	**I will do as little work with computers as possible**	Strongly agree	1
Q4	**Learning to use computers is a waste of time**	Strongly disagree	5
Q5	**Computers make me feel uncomfortable**	Strongly disagree	5
Q6	**I think using a computer would be very hard for me**	Slightly agree	2
Q7	**I think working with computers would be enjoyable and stimulating**	Slightly disagree	2
Q8	**I am sure I could use computers for work or learning**	Slightly agree	4
Q9	**When the computer gave instructions, I could hear them clearly**	Strongly agree	5
Q10	**When the computer gave instructions, I could understand what was being asked**	Strongly agree	5
Q11	**I knew what I had to do to carry out the instruction**	Strongly agree	5
Q12	**The device enabled me to do what was asked of me**	Strongly agree	5
Q13	**The screen was useful as it showed me what I had done**	Strongly agree	5
Q14	**If I could make changes to this, it would be:**	Its straightforward. There was no milk.	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		10
Confidence	(Q2 + Q6)		6
Liking	(Q3 + Q7)		3
Usefulness	(Q4 + Q8)		9
Total			**28**

Table 5.25 Questionnaire responses (MR9).

5.5.6.5 Results for MR10

MR10 was a 59 year old male who was able to walk unaided. He was normally right handed and suffered a stroke just under 21weeks previously.

Following an accident thirty years previously MR10 had lost both hands and used a prosthetic device to pick objects up.

During the trials MR10 had problems picking up the equipment, dropping the jug at one point. He also had problems holding the kettle and operating the switch. MR10 used a strategy of holding the spoon in his mouth but did not actually use the spoon for its intended purpose, pouring coffee directly from the jar into the mug.

MR10 stopped at 3m 11s.

USER ERROR	SYSTEM ERROR
Dropped jug	Spoon not registered first time
Knocked jar over	Spoon to jar registered as spoon to mug
Repeatedly replacing kettle	

Table 5.26 User and system errors (MR10).

This patient performed actions that would have been dangerous if the activity had been real. He was clearly unable to hold the objects appropriately.

There were stages at which the patient had problems knowing what to do next. He used the help button but pressed twice each time, causing the system to play the verbal prompt and the visual demonstration in close succession. MR 10 followed the demonstrations with appropriate actions although his disability was a barrier to the successful execution of these.

Question		Participant's Response	Score
Prior Experience: I use computers		Never	6
Q1	**Computers do not scare me at all**	Slightly disagree	2
Q2	**I could use computers for learning**	Not sure	3
Q3	**I will do as little work with computers as possible**	Strongly agree	1
Q4	**Learning to use computers is a waste of time**	Slightly agree	2
Q5	**Computers make me feel uncomfortable**	Slightly disagree	4
Q6	**I think using a computer would be very hard for me**	Strongly agree	1
Q7	**I think working with computers would be enjoyable and stimulating**	Slightly agree	4
Q8	**I am sure I could use computers for work or learning**	Not sure	3
Q9	**When the computer gave instructions, I could hear them clearly**	Strongly agree	5
Q10	**When the computer gave instructions, I could understand what was being asked**	Strongly agree	5
Q11	**I knew what I had to do to carry out the instruction**	Strongly agree	5
Q12	**The device enabled me to do what was asked of me**	Strongly agree	5
Q13	**The screen was useful as it showed me what I had done**	Slightly disagree	2
Q14	**If I could make changes to this, it would be:**	Different people use different hands. The help button was a good idea	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		6
Confidence	(Q2 + Q6)		4
Liking	(Q3 + Q7)		5
Usefulness	(Q4 + Q8)		5
Total			**20**

Table 5.27 Questionnaire responses (MR10).

5.5.6.5 Summary of Changes Made Following Study Three

In this study in one instance the green kettle was matched with the green hue of a participant's sleeve. From this study it was learned that the user must not wear a coloured long sleeved shirt because this could confuse the vision system.

The spoon caused persistent problems due to its small size and difficulty registering. A new model was made and tested before the next study.

5.5.7 Results of Study Four: Patients MR11 to MR14

5.5.7.1 Results for MR11

A male aged 81 years, MR11 was normally right handed and suffered his stroke 7 weeks and 3 days prior to the trials. He had an affected right side, with no movement in the right arm. MR11 required a wheel-chair to move. He was able to communicate clearly and to comprehend spoken words.

MR11 proceeded by acquiring the mug, jar and spoon. He correctly placed the spoon into the jar then into the mug, simulating putting coffee into the mug, repeating this. MR11 picked up the water jug and poured this towards the mug, which is incorrect. He was advised by the experimenter that there is a kettle but no action was taken and the session was stopped at 1m 28s.

USER ERROR	SYSTEM ERROR
Poured water from jug to mug without using kettle	

Table 5.28 User and system errors (MR11).

This patient could clearly perform the action of acquiring the objects and spooning coffee from the jar into the mug, however the sequence of boiling water was not carried out.

He did not use the kettle but poured water from the jug to the mug without following the procedure for boiling water. MR11 did not request assistance and even when prompted to get the kettle he did not. The session was stopped before the task was completed. It is possible that he considered that by pouring water from the jug to the mug he had actually completed part of the exercise.

Question		Participant's Response	Score
Prior Experience: I use computers		Never	6
Q1	Computers do not scare me at all	Not sure	3
Q2	I could use computers for learning	Slightly agree	4
Q3	I will do as little work with computers as possible	Slightly disagree	4
Q4	Learning to use computers is a waste of time	Strongly disagree	5
Q5	Computers make me feel uncomfortable	Not sure	3
Q6	I think using a computer would be very hard for me	Slightly disagree	4
Q7	I think working with computers would be enjoyable and stimulating	Strongly agree	5
Q8	I am sure I could use computers for work or learning	Slightly agree	4
Q9	When the computer gave instructions, I could hear them clearly	Slightly agree	4
Q10	When the computer gave instructions, I could understand what was being asked	Strongly agree	5
Q11	I knew what I had to do to carry out the instruction	Not sure	3
Q12	The device enabled me to do what was asked of me	Slightly agree	4
Q13	The screen was useful as it showed me what I had done	Slightly agree	4
Q14	If I could make changes to this, it would be:	Don't know what to change	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		6
Confidence	(Q2 + Q6)		8
Liking	(Q3 + Q7)		9
Usefulness	(Q4 + Q8)		9
Total			32

Table 5.29 Questionnaire responses (MR11).

5.5.7.2 Results for MR12

An 81 year old female, MR12 was a normally right handed person who suffered a stroke 7 weeks and 5 days previously. She walked with assistance of a walking frame. MR12 was able to converse and comprehend spoken words.

When the computer program was started it asked "what would you do to make a cup of coffee?" MR12 responded by saying "water, coffee, milk, sugar if you have it" then started the activity. MR12 touched the jug and moved her hand, simulating holding and pouring the jug. The author advised that the objects are for picking up, and the patient replied that she "can't reach them".

MR12 placed the spoon in the jar then brought the jar forward. With assistance from the OT the kettle was brought into the scene. MR12 acquired the jug and poured it towards the kettle after lifting the kettle lid.

Some confusion appeared to follow. MR12 placed the spoon in the jar, poured the kettle towards the jar repeatedly, and stirred the spoon in the jar, apparently mistaking the jar for a mug. The session was stopped at 3m 23s.

USER ERROR	SYSTEM ERROR
Patient does not pick objects up initially: patient states unable to reach OT assisted get kettle Repeatedly poured kettle to jar	

Table 5.30 User and system errors (MR12).

MR12 appeared to understand what was asked of her as she verbally listed appropriate components of the activity. The coffee jar appeared to be confused with the mug. MR12 did not always use appropriate actions, appearing to distinguish the activity from a real task. She placed objects in proximity but did not always perform the correct action to activate the sensor.

Question		Participant's Response	Score
Prior Experience: I use computers		Never	6
Q1	Computers do not scare me at all	Strongly disagree	1
Q2	I could use computers for learning	Strongly disagree	1
Q3	I will do as little work with computers as possible	Strongly agree	1
Q4	Learning to use computers is a waste of time	Slightly agree	2
Q5	Computers make me feel uncomfortable	Strongly disagree	5
Q6	I think using a computer would be very hard for me	Not sure	3
Q7	I think working with computers would be enjoyable and stimulating	Strongly agree	5
Q8	I am sure I could use computers for work or learning	Strongly agree	5
Q9	When the computer gave instructions, I could hear them clearly	Strongly agree	5
Q10	When the computer gave instructions, I could understand what was being asked	Strongly agree	5
Q11	I knew what I had to do to carry out the instruction	Strongly agree	5
Q12	The device enabled me to do what was asked of me	Strongly agree	5
Q13	The screen was useful as it showed me what I had done	Slightly agree	4
Q14	If I could make changes to this, it would be:	Once or twice I used the screen when I was stuck	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		6
Confidence	(Q2 + Q6)		4
Liking	(Q3 + Q7)		6
Usefulness	(Q4 + Q8)		7
Total			23

Table 5.31 Questionnaire responses (MR12).

5.5.7.3 Results for MR13

MR13 was a male aged 74 years, 2 weeks post stroke. He was normally right handed with his left side predominately affected but had limited use of both hands. He walked with the assistance of a walking frame. MR13 was able to communicate clearly and understand the spoken word.

MR13 correctly proceeded by acquiring the jug, mug, jar and spoon. He correctly placed the spoon into the jar then into the mug. He repeated this. MR13 then poured the jug towards the mug and then poured the kettle towards the mug. The session stopped at 1m 52s.

USER ERROR	SYSTEM ERROR
Poured water directly from jug to mug	Spoon to jar not registered
Poured kettle to mug with no water inside	Kettle registered when not in scene

Table 5.32 User and system errors (MR13).

MR 13 displayed similar actions to those of MR 11, pouring water directly from jug to mug without boiling water in the kettle. The 'spoon to jar' action was insufficiently performed and did not trigger the micro-switch, hence the following action (spoon to mug) was registered as an error. This was recorded as placing an empty spoon into the mug. The above demonstrates how important it is that the computer's image of the activity matches the real (user) activity. A single mistake made by the system in registering the user's actions will cause the system to offer an incorrect message or prompt because it is thrown out of synchronisation with the real world task.

Question		Participant's Response	Score
Prior Experience: I use computers		Every day	1
Q1	**Computers do not scare me at all**	Strongly agree	5
Q2	**I could use computers for learning**	Strongly agree	5
Q3	**I will do as little work with computers as possible**	Slightly disagree	4
Q4	**Learning to use computers is a waste of time**	Strongly disagree	5
Q5	**Computers make me feel uncomfortable**	Strongly disagree	5
Q6	**I think using a computer would be very hard for me**	Strongly disagree	5
Q7	**I think working with computers would be enjoyable and stimulating**	Strongly agree	5
Q8	**I am sure I could use computers for work or learning**	Strongly agree	5
Q9	**When the computer gave instructions, I could hear them clearly**	Strongly agree	5
Q10	**When the computer gave instructions, I could understand what was being asked**	Strongly agree	5
Q11	**I knew what I had to do to carry out the instruction**	Strongly agree	5
Q12	**The device enabled me to do what was asked of me**	Strongly agree	5
Q13	**The screen was useful as it showed me what I had done**	Slightly agree	4
Q14	**If I could make changes to this, it would be:**	Not sure if I used the screen	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		10
Confidence	(Q2 + Q6)		10
Liking	(Q3 + Q7)		9
Usefulness	(Q4 + Q8)		10
Total			**39**

Table 5.33 Questionnaire responses (MR13).

5.5.7.4 Results for MR14

A female aged 68 years, MR14 was normally right handed and suffered a stroke four weeks previously that affected both her right hand and right leg. She was transported by wheelchair and sat in this during the study. MR14 was able to communicate and understand spoken words.

MR14 correctly acquired the jug and kettle. She poured the jug towards the kettle and attempted to place the kettle on the base. Some difficulty was experienced placing the kettle correctly on the base and eventually the OT had to intervene. MR14 did not switch on the kettle.

MR 14 correctly placed the spoon into the jar then into the mug but these were outside the cameras field of vision and were therefore not registered. The session stopped at 1m 14s.

USER ERROR	SYSTEM ERROR
Difficulty placing kettle Objects not registered because they were not brought into the field of view.	

Table 5.34 User and system errors (MR14).

MR 14 understood the procedure but demonstrated difficulty in placing the kettle on the base correctly. This demonstrates an action that causes a problem as part of the MR system and is an impediment to completing the activity correctly. In a VE only this person may have been able to select appropriate objects but the difficulty in manipulating them correctly may not have been identified.

Question		Participant's Response	Score
Prior Experience: I use computers		Never	6
Q1	Computers do not scare me at all	Strongly agree	5
Q2	I could use computers for learning	Strongly agree	5
Q3	I will do as little work with computers as possible	Not sure	3
Q4	Learning to use computers is a waste of time	Strongly disagree	5
Q5	Computers make me feel uncomfortable	Strongly disagree	5
Q6	I think using a computer would be very hard for me	Slightly agree	2
Q7	I think working with computers would be enjoyable and stimulating	Strongly agree	5
Q8	I am sure I could use computers for work or learning	Not sure	3
Q9	When the computer gave instructions, I could hear them clearly	Strongly agree	5
Q10	When the computer gave instructions, I could understand what was being asked	Strongly agree	5
Q11	I knew what I had to do to carry out the instruction	Strongly agree	5
Q12	The device enabled me to do what was asked of me	Strongly agree	5
Q13	The screen was useful as it showed me what I had done	Slightly agree	4
Q14	If I could make changes to this, it would be:	No changes	
Summary of CAS scores:			
Anxiety	(Q1 + Q5)		10
Confidence	(Q2 + Q6)		7
Liking	(Q3 + Q7)		8
Usefulness	(Q4 + Q8)		8
Total			33

Table 5.35 Questionnaire responses (MR14).

5.5.7.5 Summary of Changes Made Following Study Four

Following the final study the system errors recorded were infrequent and no changes were made to the system at this point.

5.5.8 Data from Computer Attitude Survey

The mean age of participants was 70.35 years old, with a standard deviation of 12.21. The range of ages was between 50 and 89 years old. Experience was scored on an ordinal scale in which 1 reflects daily use prior to the stroke and a score of 6 reflects no prior use (see appendices). Three (21.4%) participants had used computers daily prior to their stroke and 9 (64.3%) had never used a computer. Table 5.36 shows patient, gender, age, CAS score and experience. CAS scores varied with a minimum of 14, maximum of 40 and a median of 31.5.

Code	Gender	Age	CAS score	Experience score
Mr1	M	77	16	6
Mr2	M	89	25	5
Mr3	M	57	33	6
Mr4	M	50	40	5
Mr5	M	52	39	1
Mr6	F	75	31	6
Mr7	M	75	34	1
Mr8	F	83	14	6
Mr9	M	64	28	6
Mr10	M	59	20	6
Mr11	M	81	32	6
Mr12	F	81	23	6
Mr13	M	74	39	1
Mr14	F	68	33	6

Table 5.36 Gender, age, attitude scores and experience scores.

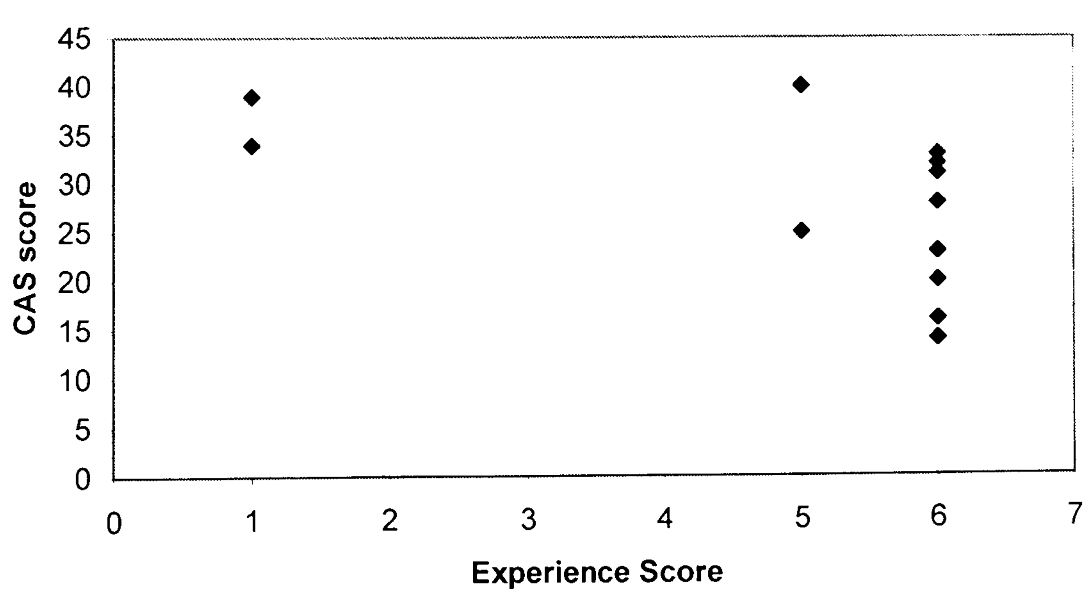

Figure 5.8 CAS score V experience score.

Figure 5.8 shows the CAS scores plotted against experience. Spearman's Rho was calculated (because the 'experience' scale is ordinal) and the values (ρ=-0.672, p=0.008) show this is significant at the 0.01 (1%) level and therefore moderately negatively correlated. Participants who used computers daily showed a positive attitude towards computers with two scores of 39 (out of a possible 40) and one score of 34. Infrequent users of computers varied. One of two participants who used computers less than monthly scored a maximum of 40, the other scored 25. Those with no prior experience show a wide range of attitude scores (14 – 33).

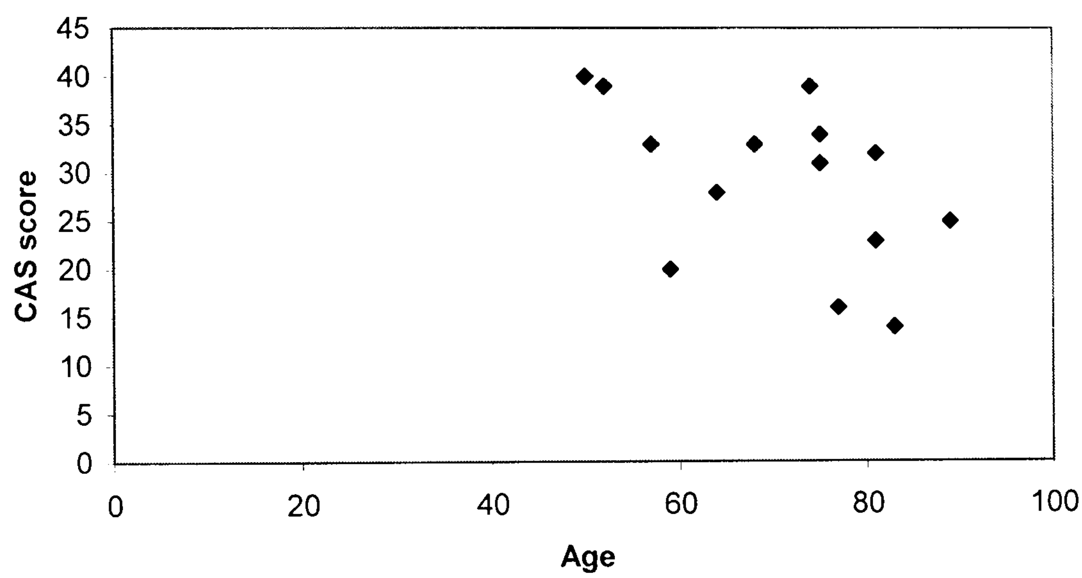

Figure 5.9 CAS score V participant's age.

Figure 5.9 shows the CAS scores plotted against patients' age. Pearsons r was calculated (r=-0.506, p=0.065). In this study age does not correlate strongly with attitude to using computers.

5.5.9 Summary of Data from User Experience Survey

A further five questions were asked about the patients experience of using this system. A five point Likert scale was used with positively worded questions, 1 being strongly disagree through to 5 being strongly agree. Descriptive statistics of results are presented in table 5.37.

Statement	Median	Range
When the computer gave instructions, I could hear them clearly	5	4
When the computer gave instructions, I could understand what was being asked	5	4
I knew what I had to do to carry out the instruction	5	2
The device enabled me to do what was asked of me	5	2
The screen was useful as it showed me what I had done	4	4

Table 5.37 Patients responses to questions about the MR environment.

The MR system enabled users to perform the task and users knew what to do to perform the task. Comprehension and clarity of instructions were an issue. Participants were asked whether they would make changes, and if so what would they be. Comments received by the participants are summarised below.

Patient	Comments
MR1	Make sure the actions are as real as possible. Could include lid on jar.
MR2	No improvements.
MR3	None [changes]. Don't normally make coffee.
MR4	Stroke affects memory and this is useful. I didn't use the screen much.
MR5	Possibly a lid on the coffee. The switch was hard with one hand.
MR6	Clear and straightforward. I watched the screen to see if I was doing it right.
MR7	No changes.
MR8	Could be useful. Only change to make the spoon work better otherwise none.
MR9	Its straightforward. There was no milk.
MR10	Different people use different hands. The help button was a good idea.
MR11	Don't know what to change.
MR12	Once or twice I used the screen when I was stuck.
MR13	Not sure if I used the screen.
MR14	No changes.

Table 5.38 Patients' comments about changes to the MR system.

5.5.10 Discussion of results

Table 5.39 shows a summary of errors. Errors were divided into two kinds: user errors and system errors. User errors were identified by the OT and by the author, with support from video analysis. These included errors in selection and inappropriate use or mishandling of equipment.

Inappropriate use can be defined as not using the objects for their designated purpose. Insufficient action is defined as the user not performing the action to the extent that it would be in the real world, for example not tilting the jug sufficiently for this to activate the tilt switch.

System errors were those in which actions were not recognised and recorded by the software or those for which inappropriate responses were made by the software. Errors are discussed below.

User error: inappropriate action	
Kettle to mug: no water	2
Kettle not placed on base	1
Kettle poured into jar	1
Kettle switched on when empty	1
Poured jug directly to mug	2
Repetition of action	1
Difficulty placing kettle on base	5
Placing mug on base	1
Empty spoon to mug	1
User error: insufficient action	
Spoon to jar not registered	3
Jug to kettle	2
System error: object or action not recorded	
Spoon not recorded	6
Kettle not recorded	2
Jug not recorded	1
System error: object or action recorded in error	
Kettle not in scene	2

Table 5.39 Summary of user and system errors (all users).

Frequently users did not bring objects into the field-of-view of the camera. Objects were therefore not recognised by the vision system in these cases and consequently the VE was unable to reliably register user action. In the real assessment of ability to perform the hot drink task an object would be recorded as being "got" by the patient even if it was acquired but not used. This influenced the design of the MR system so that only objects moved into the workspace were recorded as being selected in compliance with the real task.

A seemingly simple improvement would be to register objects as being "got" when they are moved by the patient, as opposed to when they are brought into the field of view of the camera. This brings a further problem however, as an object can be registered as being acquired even if it is not moved, providing it is used within an action. For example if a patient tilted a jug towards a kettle the patient would be given a score reflecting the acquisition of both objects.

A physical problem of placing the kettle correctly on the base was repeated on two occasions. This brings a conflict in the design. Should a kettle that is easier to use be employed or should the users be penalised for improper use of equipment? In the VE controlled by the touch screen, users could score points for placing the kettle on the base by selecting the kettle then selecting the base using the wand.

Dexterity in handling the kettle is not measured or required for the touch screen system other than ability to point to objects on the screen. The MR system is more realistic in simulating the actual hand movements required to achieve the actions. Patients who satisfactorily completed the VE based task using the touch screen have demonstrated ability to proceed through sequences of actions but this does not mean that they are proficient at the real task.

Activation of the pressure sensors was an issue with a TUI described in the initial studies (Tymms, 2001) and was occasionally an issue with the later systems designed by the author and design team. Although sensitive micro-switches were used that required only light pressure, the problem was that users sometimes did not make contact with switches at all. For example a frequently recorded error was to simulate pouring coffee from the spoon into the mug by tipping the spoon. The action used by the patient was acceptable and appropriate. This reiterates the importance of ensuring the actions used to interact with TUIs for stroke faithfully correspond to the real equivalent.

On six events the spoon did not register when the video camera clearly identified it present within the workspace. This is not a user error in the sense that the user has not actually made a mistake of object selection or handling. Users frequently held the spoon so that it was occluded by the hand or held sideways so that insufficient pixels were available to the camera for colour matching.

System errors were detectable when objects that were registered as being present by the software were not present in the video recording. In one trial the kettle was repeatedly registered by the vision system when it was clearly absent from video analysis. Studying the actions showed that this was most likely due to the green colour of the patients sleeve forming a colour match with the kettle model. This demonstrates the importance of reducing or removing intrusive colour to the workspace beneath the vision system camera. The colours of sleeves and other objects (watches, jewelry) are registered by the vision system and can affect model-image matching.

Computers are common in the home and the workplace, and people who are currently employed in a full time occupation are also those who will be at risk of stroke in decades to come. It is possible that the use of technology in rehabilitation will become increasingly accepted as stroke patients are more commonly experienced computer users.

5.6 Summary of Chapter 5

The VE was coupled to the TUI to complete the MR system. This was installed in the day room of a stroke unit in a hospital. Stroke patients were invited to participate in studies using the MR system and a total of fourteen patients were recruited. Four studies took place on separate occasions, enabling improvements to be made at each step of the iteration.

The patients recruited to the studies were mainly inexperienced in using computers. Those with experience of using computers were positive about using them. Those with little or no experience showed a wide range in attitudes towards computers.

As patients performed the coffee making task using the MR system, the computer recorded user interaction and a video recording was made as a record of actual events. Video analysis identified user errors and technical errors. Users frequently did not bring objects into the field of view and these were not registered. Small objects (for example the spoon) caused registration problems when occluded or held so that only a small part of the object was exposed to the camera.

The design of an MR system for an everyday task and the issues of implementing this on a rehabilitation unit in the hospital environment are discussed further in the following chapter.

Chapter 6: Discussion

6.1 Introduction

The first part of this chapter includes a brief summary of the work that was carried out towards this thesis and is presented here as part of a review of the process of designing and implementing an MR system for stroke rehabilitation.

In the early phase of the project, consultants, therapists and stroke survivors were invited to meetings to view examples of VR and to discuss VR as a tool for stroke rehabilitation. Ideas generated by participants during this phase led to the choice of a coffee making task. This was shown to be acceptable to consultant groups and was consistent with a widely accepted model of stroke rehabilitation (Gladman, 2006).

Following a user-centred design approach, a multidisciplinary team worked together to produce a VE that was evaluated as part of a Stroke Association funded project.

An assessment of existing MR technology led to the identification of flexibility in positioning of objects and sequencing of the actions as desirable design attributes for training everyday tasks. A TUI was constructed and this was connected to the VE to complete the MR system. The MR system was installed on a stroke ward. Feasibility and practical issues of implementing the MR system on the ward were investigated by means of a series of studies with stroke patients.

The research questions were presented in chapter one and these are discussed in this chapter in context of the work presented in this thesis. The questions were: 'what are the practical implications of implementing the MR system on a ward as part of a plan of stroke care?' and 'what are the issues of designing an MR system for use by stroke survivors to practice an everyday task?' Note that the questions have been reversed from the original order for the purposes of this discussion because the system was implemented before the design could be evaluated.

The benefits and barriers to the use of VR in stroke rehabilitation are considered, followed by a discussion of the activities of design, including design features, task selection and the multidisciplinary team. The design of an MR system for an everyday task is discussed, and practical implementation and usability issues are considered in the context of using MR on the hospital ward.

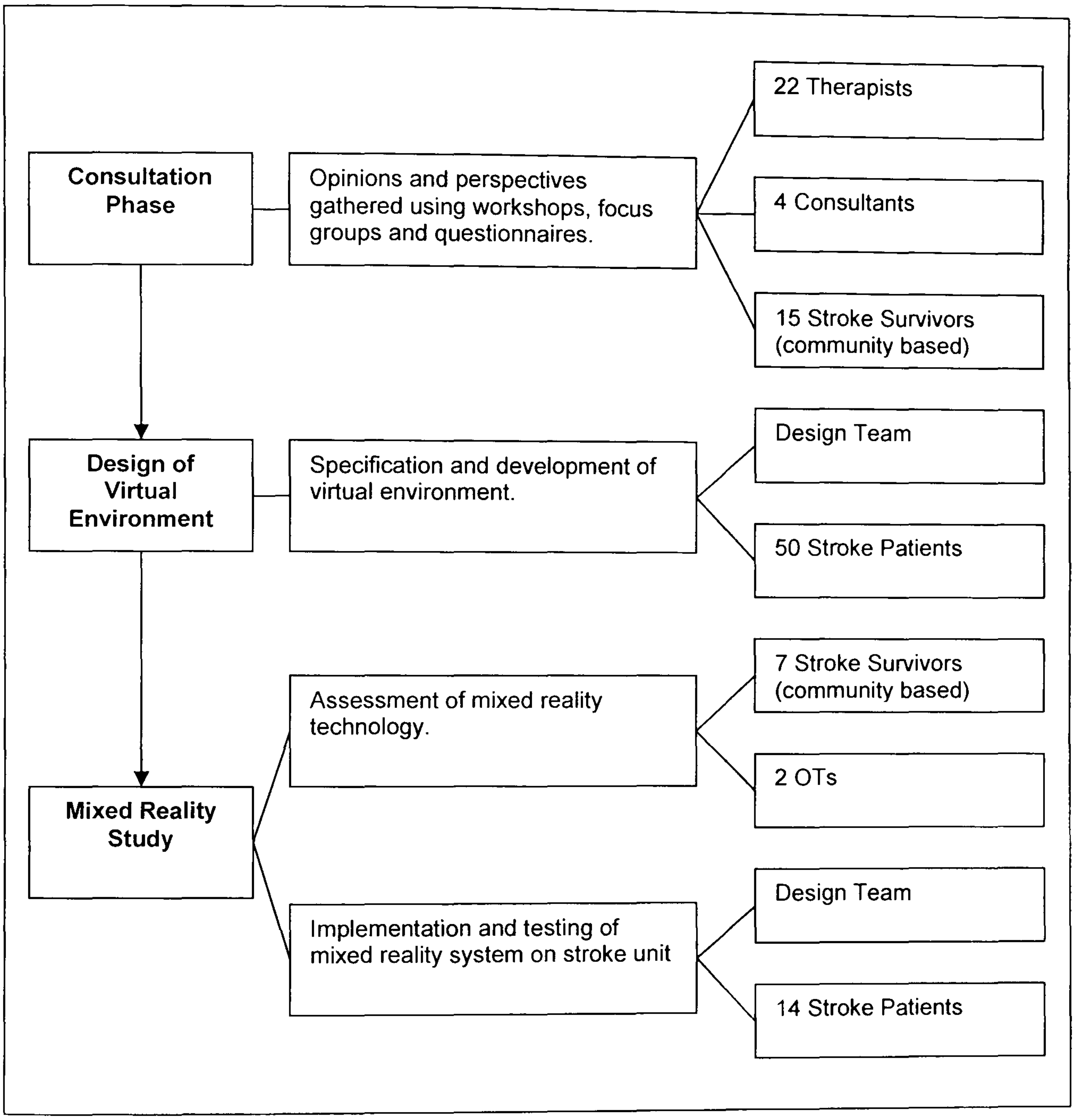

Figure 6.1 Summary of work and people who were involved.

A summary of the design activities and the different stakeholders who were involved at each stage of development is shown in figure 6.1.

6.2 Benefits of VR for Stroke Rehabilitation

In the early phase of this study, presented in chapter three, therapists who were consulted identified key features of VR systems that they believed would be important in stroke care. Reproduction of realistic environments that could enable users to practice tasks in safety was considered to be a potential role for VR in stroke rehabilitation.

Consultants suggested that pen and paper exercises have proven to be successful in the detection of visual field deficits and direct replacement of these by VR methods may not necessarily be advantageous. Instead the value of VR was seen as the ability to replicate environments and to embed treatment strategies within these simulations. Consultants added that computer simulations may also facilitate a form of assessment of function that is currently available only with practical tasks.

Stroke survivors resident in the community suggested that VR offered the opportunity to practice activities and reported that this was not always available in the hospital setting. The focus group discussions with stroke survivors in the community supported the argument that the hospital was more suitable than the community as a location for the assessment and practice of everyday activities.

These studies illustrate the differences in perspective of three different stakeholders. Therapists place importance in safety issues for their patients. Former patients who are resident in the community were more concerned about the timing and duration of their treatment. Stroke researchers considered wider applications and were able to speculate on a number of different roles for VEs in addition to those demonstrated. This diversity of perspective and insight shows the importance of including different stakeholders in consultations about the design of new treatments and technologies for rehabilitation.

6.3 Barriers to the Implementation of VR for Stroke Rehabilitation

The question of barriers to the regular use of VR to support stroke rehabilitation was posed during the consultation phase. Evidence of effectiveness and cost of implementation were the major concerns raised by the therapists. These practitioners understandably reported that a new strategy, technology or technique must demonstrate proven effectiveness before it is accepted into practice.

With little evidence to suggest that VR could offer a cost effective strategy, development and implementation costs were brought into question. In the lifetime of this project home gaming systems that display three dimensional simulations have become popular and inexpensive, thus cost of equipment is of reducing concern. The concept of a TUI has also become increasingly accepted and commonplace with the introduction of tangible inputs for popular home games consoles that are operated by naturalistic body movement (see for example the Nintendo Wii™).

Development costs for highly specialised interactive VEs are of greater concern. The tradeoffs between generic solutions and focused individual problem solving became apparent in the discussions with OTs and consultants. The development of a single VR package that addresses the diverse problems that stroke patients present with was not considered to be practical or particularly desirable.

In order to treat a diversity of cognitive and motor problems a modular approach was recommended by the consultants. This modular approach proved to be an important feature during the development of the VE, allowing for changes in the task and virtual objects to be accommodated as required.

6.4 Design Features of a VE for Stroke Rehabilitation

Monitoring the stroke patient's progress through a useful task was considered to be an important design requirement by the therapist consultant group in the early phase of the project. Specifically, a mechanism for objectively and reliably scoring and recording the patient's progress was considered by the focus group as a useful design feature.

Interaction was also discussed in the context of the stroke survivor as primary user. A particular design concern for practical tasks was impairment of the dominant hand. Versatility of input was considered by therapists to be of importance due to the mixed physical and cognitive ability of primary users.

Therapists were also concerned about issues of presentation of instruction and feedback. Communication impairments are commonly reported following stroke and therapists recommended that needs of dysphasic patients should be considered in the modes of feedback, with exclusion of those patients from VR based treatment in acute cases.

Therapists recommended that patients with short term memory problems would respond best to brief instructions that refer to actions comprising single stages. During the technology assessment prior to the development of the MR system (see chapter three), this was supported by the failure of stroke survivors to complete tasks that were accompanied by instructions constructed of multiple conjoined sequences of actions.

The former patients in the community expressed concern that being (mainly) elderly and inexperienced of using computers they would not want to have to learn how to use a computer as an additional skill to learning an everyday task. For them ease of use was a major design criteria.

6.5 Selection of an Activity to Simulate

Stroke survivors in the community who attended the focus groups were asked to recall activities that they were required to complete as part of their assessment of independence when they were in hospital. Useful everyday tasks were reported and in particular making a hot drink was identified by several participants as a task that was used as a component of their assessment.

As an activity to develop into a simulation, the choice of a hot drink appeared to be a sensible and logical choice because it is a common task that requires the participant to identify a variety of household objects. Additionally it requires the participant to be able to understand the purpose and function of these objects.

Making a hot drink involves the use of electrical appliances and the handling of hot liquids, both of these presenting serious hazards to a person with cognitive or motor impairments. The simulation of a hazardous activity was a key driver in the choice of task.

The final selection of a specific task was made following discussions with stakeholders (stroke survivors, OTs and consultants) and a review of published works as explained in chapters two and three.

Making a cup of coffee appeared to be a familiar and fairly straightforward task. In practice the activity comprises many stages, especially if optional stages are added, and the permutations of permitted and disallowed actions add to the complexity. This was evident during the design of the software.

6.6 The Design Team

The design process described in chapter two was based upon the international standard ISO 13407 for user-centred design (ISO, 1999). The principles of this standard identify a multidisciplinary team as key. In the early stages of development different stakeholders were consulted as experts on an ad-hoc basis but they were not recruited as part of a project design team.

The consultation phase enabled the author (as designer) to begin to understand the needs of the user, however the appointment of an OTs was important development for the project. The OT was able to interpret user problems in terms of possible design solutions. Furthermore her expertise was able to guide the design specification in terms of layout of the VE and positioning of equipment, and to specify the performance data that an OT would use in the assessment of the stroke patient.

The OT was primarily concerned as a patients' representative in ensuring that their needs were addressed and incorporated into design solutions. How this was done was not her concern but her expertise did contribute by ensuring that solutions were appropriate for the user.

Apart from identifying essential components of the simulation, the design team's role involved negotiation between what was desirable and what was practical. These tensions were most obvious at two critical stages of development: the stage when the OT decided to increase the task to include making tea, and the stage when the TUI was being constructed.

For the OT, adding a tea making task to the simulation as an optional alternative to coffee making required a review of the task description leading to the addition of several stages in the assessment sheet, for example obtaining a teapot, removing the lid and obtaining teabags from the jar.

The amendments to the VE task were agreed by the design team and were carried out by the author. VR models of teabags and a teapot with a lid had to be constructed.

and their behaviours programmed. An analysis of all the possible actions and object-to-object interactions, including incorrect or inappropriate object selection, had to be made. Audio files for new instructions and responses had to be recorded and animations of all the new actions, to be used for demonstrating correct actions to patients had to be produced. These amendments were made fairly quickly however due to the modular approach to the design.

The TUI was to be a coffee making task and for this certain components of the VE task were redundant. To construct a working prototype of a TUI required the merging of different technologies. In order to reduce the complexity (and fragility) of the prototype system the task was reduced to the minimal number of stages that retained the key activities, which was achieved following a period of negotiation.

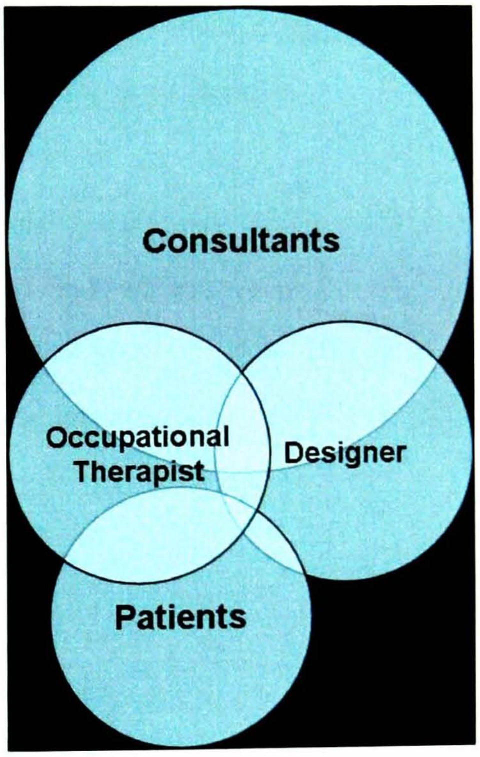

Figure 6.2: The working relationship between members of the design team

The working relationship between members of the design team and the way the team operated is illustrated in figure 6.2. The consultants made the ultimate decisions and judgments that guided the direction of the project and these were made through negotiation with the OT and the designer at regular meetings. The OT and designer met frequently to discuss minor details and improvements.

The emphasis of patients towards the OT is deliberate in order to show that the therapist worked closely with the patients, being the person who recruited patients, assessed patients for suitability to participate and, in the case of the VE evaluation, administered the patient trials. For the MR study the OT was also in attendance to ensure the wellbeing of the patients.

The OT was not required to understand how the system functioned at a technical level and was therefore not in a position to understand the limitations of the system.

The designer's role was to incorporate the patients' needs as identified by the OT into the product. This required an awareness of the limitations of the system and the technology, so that the practicality of ideas offered by the therapist could be judged by the designer and solutions arrived at by negotiation. Conversely awareness of possibilities enabled the designer to offers suggestions for design improvements that may not have been considered by the therapist.

The design of the TUI required technical support form a variety of departments and organizations. This included technicians at QMC, staff at VIRART, and members of the School of Computer Science at the University of Nottingham. Electronic component manufacturers were also consulted during the development of the RF sensors.

6.7 The Virtual Environment

Although versatility in choice of sequence had been recommended within the task, the OT requested versatility in the actual drink making activity. Her suggestion was to offer tea making as an optional task in addition to the coffee making task.

The modular approach to designing the VE meant that adding an extra object or stage was fairly straightforward. In practice as the author was involved with the project on a part time basis and the OT was employed to work on project TSA 13/02 on a full time basis there were inevitable time constraints and stresses as upgrades and updates were required.

A scoring system for the coffee and tea making task was developed by the OT for use with both real and simulated versions of the task. This was incorporated in to the VE by the author. A record of the details of interaction and intervention was requested by the OT for improved analysis of patient activity. This proved to be invaluable in checking actual patient activity against the score-sheet.

The register of input sequences recorded by the computer provided a comprehensive record of activity in the VE. A comparison of computer records and the actual events captured by the digital camcorder were used as a basis for identifying and differentiating between user errors and system errors. The patient data for the complete MR system studies are to be found in the appendices.

The definition of objects for the VE was straightforward based upon objects identified in the task analysis. The OT requested that rather than using a tap to supply water, a patient on a stroke rehabilitation unit would be expected to use a pre-filled jug. The virtual objects were modelled on their real world counterparts.

Simulating an assessment in the same format as a real one that would be used on the ward was important because there were no superfluous objects that could distract the patient. Furthermore the parity between virtual and real tasks enabled comparisons to be made of users' performance in each environment.

6.8 The Mixed Reality System

The TUI part of the MR system described in this thesis uses real and varied household objects, remotely sensed, as a means to control the input. Unlike some TUIs reported in the literature (Sharlin et al., 2004; Jacoby et al., 2006) each object in this project was of a unique shape and colour, each having different physical properties and with different ways of being used. This is a unique feature of this project.

Existing vision and sensor technologies were combined and adapted in the construction of a system for monitoring the position and status of real objects in the MR interface kitchen task. Techniques were developed by the author to use this data to control input to the VE.

Following construction and testing of the MR system, an investigation into patient usability and acceptability of this novel interface became the focus of the final study. Stroke patients resident in a stroke care unit of a hospital were invited to participate in the testing of the MR system.

Context was provided by a computer vision system. Colour is of considerable importance in choice of equipment for the vision system. The hue spectrums of individual objects must be unique for reliable distinction between objects to be made by the vision system. In the earliest versions a metallic spoon and glass jar proved to be unreliable due to light reflections from the glass and metal. Alternatives were sought. A yellow plastic spoon was found to be adequate. The glass jar was similarly replaced by a plastic jar with a red label.

Confidence scores recorded using the amended equipment demonstrate an increase in reliability of object detection. In effect there has been a compromise between the use of toy objects which were rejected in early studies, and real kitchen objects (commonly white or steel) which were not acceptable due to their incompatibility with the vision system.

The vision system was trained to recognise objects by their hue, not by shape and in early stages of development of the MR system problems arose when lids were used. The coffee jar and lid posed a problem of occlusion resulting in a conflict in establishing whether the jar was present in the scene.

A solution was attempted but not resolved satisfactorily because the initial conditions are indeterminate. If a lid is brought into the field of vision it cannot be reliably determined whether a jar is present or not using a vertically mounted camera because the camera would not be capable of detecting the jar if it was hidden by the lid. During the design process involving patients as users, the jar lid was removed from the task after consultation with the OT.

The MR system achieved its aim of facilitating practice of the 'compulsory' activities of a coffee making task as a safe and controlled simulation, recording user performance and identifying selection and sequencing errors.

In the study with the VE, errors of dexterity, initiation, sequence omission, selection and problem solving were more common than with the real world task. The TUI removed the dexterity and selection issues by eliminating the need to select small objects or on a touch screen using a wand.

Developing a TUI that encompasses the entire repertoire of possible actions was originally considered but early prototypes showed that errors of object recognition occur when the workspace within the camera's field of vision is populated with several objects. The confusion matrix presented in chapter five shows that real objects have hue spectrums that impinge on that of other objects, giving non-zero readings for other objects for which models exist, even when they are absent from the scene.

Commencing the TUI construction using a minimal task, involving just compulsory components enabled each interface object to be tested in the system so that its presence was reliably recorded.

6.9 Practical Issues of implementation on the Stroke Unit

Safety and storage of equipment were brought into question. For the Stroke Association project TSA13/02 in which the OT tested the VE with stroke patients on the ward, the software was loaded onto a Toshiba Satellite Pro notebook computer. The computer was stored securely away from the ward and taken to the ward as required. The OT was able to run the software without assistance and save user performance data. Portability, storage and practical use did not therefore pose major logistical or security problems.

Ironically the TUI objects must be kept apart from the real objects they emulate, and limited to a restricted environment such as a treatment or assessment room so that they are not used for their real purpose. For example the TUI kettle must never be plugged into a 240V mains electrical outlet. In this sense the TUI has introduced new sources of danger to the task whilst attempting to eliminate others.

The MR system comprised additional equipment that required substantial preparation and it would not be practical for a stroke patient to install the equipment before a training session. The current MR system would not be practical as a self directed learning tool without substantial development to develop a more robust system that is independent of user calibration and easy to run.

The requirement to provide unrestricted movement of the tangible objects has drawbacks. Apart from the cost of each object fitted with a radio frequency switch they are open to misuse or could even be mistakenly used as real objects. The sensors and associated electronics must be robust to stand repeated impact from patients using utensils.

Everyday tasks are not rigidly sequential and the actions that the user has carried out must not only be monitored with total accuracy but corrected and prevented whenever a dangerous or inappropriate action is taken. The approach to software design employed in the MR project and TSA 13/02 places the assessed subtasks central to its operation. The principle is adaptable to other tasks but there are clearly cost implications for developing a suite of different systems for a range of different activities.

During trials with patients an event occurred that could have implications for the design and implementation of physical interfaces for use in the hospital setting. On one occasion, trials of the VE had to be postponed due to an outbreak of diarrhoea and vomiting on the ward. Although the actual microbe was not known in this instance, the Department of Health identifies the bacterium Clostridium Difficile as a major cause of hospital acquired infection that can lead to severe illness, including diarrhoea and colitis. Over 44,000 cases were diagnosed in the UK in 2004 (Department of Health, 2005). It is spread by patient to patient contact, by staff or from a contaminated ward environment. Of the latter, keypads and other equipment are implicated as potential hazards (Department of Health, 2007). Sanitisation of equipment with a chlorine based disinfectant is recommended and equipment must be capable of withstanding such treatment.

Although the MR system showed that the design attributes of real objects were conveyed to the patient by observing how patients handled equipment, one feature of the task that is absent is the change in weight of a vessel when liquid is poured into it. This is difficult to achieve with TUI objects unless real liquids or weights are used. This would impact on the design of the TUI which would necessarily need to be more robust to withstand liquids however a development of this sort places the system closer along the MR spectrum towards the 'real environment' so that it reduces the gulf between the simulation and the real world task.

6.10 The Authors Contribution and Experiences

The author worked for two years with the OT on the design and testing of the VE as part of the Stroke Association project TSA 13/02. The OT was employed on a full time basis, dedicating her work to evaluating the VE. The author as developer of the VE worked on a part time basis on this project, being employed by the University Of Nottingham School Of Nursing, as a module convenor/lecturer in Health Informatics.

The conflict between the author's full time work and project work created difficulties and tensions in the timely delivery of requested amendments and alterations to the software. This was compounded by the need to deliver on time because patients who had passed the selection process and consented to participate could not be expected to experience lengthy delays in their involvement.

The author created the VE and programmed object's behaviours. The support system, audible and visual feedback and user performance recording mechanisms were all devised by the author although the vision system software was originally written and adapted by colleagues at the School of Computer Science at the University of Nottingham.

The author devised the method for transferring data recovered by the vision system (object identity and position) to the Virtools™ environment. The virtual objects were created by a colleague at VIRART. The author constructed all the electronic hardware: switches, sensors, RF transmitters and receiver. The circuit diagrams are available in the appendices with permission of the publishers.

The author planned, directed and conducted the studies with patients in the development of the complete MR system, with assistance from the OT, who was present to ensure good practice and to intervene if necessary.

The initial studies in the consultation stage were presented at ICDVRAT 2000 (Hilton et al., 2000) and the assessment of TUI designed by Tymms (2001) was presented at ICDVRAT 2002 (Hilton et al., 2002). The MR system designed by the author was presented at ICDVRAT 2004 (Pridmore et al., 2004) and the evaluation of the VE to which the author contributed was published in Stroke (Edmans et al., 2006).

Chapter 7 Conclusions

7.1 Findings and Recommendations

The study has followed a user-centred design and investigated the practical issues of employing an MR computer simulation for enabling people who have had a stroke to practice an everyday task. During the study design features and practical issues have been identified that have influenced the construction of the MR system, resulting in a prototype that was installed and tested on a stroke unit. The key findings are presented here.

In the early consultation stages, OTs recommended that the task should allow for a "hands-off" approach in which the patient/user is permitted to attempt the task without the sequence being prescribed. Therapists reported that intervention is only necessary if the patient perseverates, is unable to proceed, or performs a dangerous action.

Barriers to implementation were identified during the consultation phase as cost and evidence of clinical effectiveness. Therapists would not adopt a new strategy without evidence based practice showing that it was effective and they could not use this without sanction from consultants. The reduced cost of desktop VR and increased accessibility to VR has improved with the introduction of gaming consoles, thus also clinical effectiveness remains important, the expense of equipment is progressively of reducing concern.

The formation of the multidisciplinary team marked a turning point in development. Previously stakeholders had been involved as consultants in the design process, playing a passive role in that they were invited to contribute ideas but were not involved actively in the design. The formation of a multidisciplinary design team that included an OT brought about an increased collaboration in the method of working. The dynamics of the team as described in chapter 6 and illustrated in figure 6.2 brought about faster development than previously, due to better access to expertise.

The OT requested versatility in choice of hot drink for the virtual environment and the addition of new stages and new equipment was made easier by giving objects a complete and discrete set of behaviours. This was made possible by the Virtools™ development environment. A modular approach to design was therefore essential in accommodating frequently made changes to the hardware and to the task requirements.

Constructing the TUI from a minimal starting point enabled the hardware to be tested and constructed iteratively, and for errors and problems to be identified quickly before the interface became too complex. Working with few objects initially enabled the differentiation of objects by the computer vision system to be reliable.

Inserting RF sensors in vessels such as mugs and jars makes them unusable for their real purpose, although adaptations could be made to permit this. Adapting electrical appliances so that they interface with a computer introduces new dangers if the equipment is mistaken for a real appliance. Thus storage of the equipment and isolation from real equipment is of concern.

The apparatus used in the TUI must be robust enough to withstand treatment by patients who may drop or misuse equipment. Furthermore equipment to be used on a hospital ward must be capable of withstanding disinfection.

The following is a summary of the recommendations for developers of MR systems that are specifically targeted at treating stroke patients by facilitating an everyday task:

1. Make the positioning of the objects flexible.
2. Make the sequence in which actions take place flexible.
3. Ensure stakeholders are involved in the design process.
4. Consider the TUI in the context of the environment and make sure it is robust enough to withstand misuse.
5. Ensure that equipment that has been altered (especially electrical equipment) is not confused with the real counterpart.

6. The nature of everyday tasks means that there are diverse actions. Consider the construction of the TUI as modular and hybrid.
7. Start the task with few objects and increase gradually through an iterative process. This was important when using a vision system because everyday objects may exhibit a range of hue values that can be misconstrued as other objects.
8. The multidisciplinary team is essential to bring an appropriate skill mix. The nature of VR in stroke rehabilitation requires diverse professions.
9. Due to the different backgrounds of the multidisciplinary team there will be negotiation between what is desirable and what is practical. Ensure that the team agrees with the design specification at an early stage because major changes can be difficult to implement.

7.2 Future Developments

The MR system demonstrated feasibility of the concept of a TUI as part of a simulation of an every day task, however practical issues of using the MR system in self directed mode arose due to the process of setting up, which involved loading and running the software, calibrating the vision system and testing RF switches. Substantial development work would be required for a fully functioning system that could be used independently by the stroke survivor.

Hue matching for object recognition posed problems with kitchen equipment that was metallic or white plastic. Realism could be improved by relying less upon employing objects of unique hues and possibly seeking alternative strategies. For example Radio Frequency Identification (RFID) technology uses small RF transmitters to send a unique coded signal to a receiver, thus identifying the source emitter. This is similar to the technology used in this project and it does not solve the problem of computing the spatial relationship between objects.

An alternative is gesture recognition. Gesture recognition uses software to identify and interpret hand movements that are made in the field of view of a camera. The focus is on the movements that the user makes rather than the object and as with RFID it does not provide a solution to the issue of distinguishing between objects and ensuring that the correct objects are used appropriately.

The MR system presented in this thesis is unique in its physical attributes as an input device, providing realistic task cues, requiring real actions and without the encumbrance of input devices such as data gloves and HMDs. This project was unique in that it took the concept of MR onto the hospital ward.

The work presented in this thesis has demonstrated that an MR system is feasible as a means of enabling the stroke patient to practice an everyday task in a safe environment without encumbrance however there are practical issues to overcome for this to be implemented as a viable treatment in the hospital setting.

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Glossary of Terms

Affordance

This is the property of an object that informs the user of its purpose. The shape of a tool or control influences the user's interpretation of its mode of operation.

Constraint

Well designed objects have physical constraints to prevent users operating them incorrectly. For example the arrangement of pins on an electrical mains voltage plug prevents the user from incorrectly inserting the plug into an electrical socket.

Data Glove

An input device used frequently in immersive virtual reality. It measures hand and finger movement through transducers mounted in or on the glove. The input from the transducers is used to manipulate and control simulated objects in a virtual environment.

Head Mounted Display (HMD)

A head mounted display is an output device in the form of a helmet with two small visual display panels mounted so that they are close to each of the wearer's eyes. The images are usually slightly offset to give the user an illusion of being in a three dimensional space.

Immersion

Immersion refers to the extent that the illusion of reality gives the user a sense of presence within the simulation. Isolation from real world distractions contributes to immersion. In a fully immersive system distractions from the real world are reduced or eliminated.

Mixed Reality (MR)

Computer simulations may be combined with real world artefacts to enhance the experience. Virtual reality may be projected onto a real scene or real objects may be used to control virtual reality. The range of different interplays between reality and virtual reality constitute the mixed reality spectrum.

Tangible User Interface (TUI)

A tangible user interface uses real objects as input devices to a computer. The objects are sensed by different mechanisms and changes in the status of the object (position, orientation) may be used to trigger events in a computer simulation.

Tracking

Various technologies exist that monitor the precise position of a real object. Passive tracking works by triangulating a signal from a source object. Active tracking uses object recognition techniques to locate and identify objects in a scene.

User-centred design (UCD)

This is a design method in which the end users are involved in some stage of the design process. The extent of involvement may vary between different applications and for different reasons.

Usability

Usability is the extent that a procedure can be carried out with minimal errors and minimal support. Usability of a system can be measured by observing how people use the functions of a computer application, how long they take to complete a process and how many errors they make.

Usefulness

Usefulness describes the success with which an object or designed artefact satisfactorily matches the requirements of the user. If something is not useful it will not be used.

Virtual environment (VE)

The term virtual environment refers to the visible and audible components of a three-dimensional computer generated simulation.

Virtual Reality (VR)

Virtual Reality is the generation of three dimensional computer simulations. The term is also used in context of the technologies involved in achieving the simulations.

Appendices

Appendix 1 OT Score Sheets, Observed and Recorded Results for Mixed Reality Study on Hospital Stroke Unit.

Appendix 2 Computer Attitude Survey Questionnaire.

Appendix 3 Patient Instruction Sheet for Mixed Reality Study.

Appendix 4 Patient Consent Form.

Appendix 5 Questionnaire Used with Occupational Therapists in Consultation Phase.

Appendix 6 Manufacturer's Technical Data and Circuit Diagrams for Radio Frequency Switches (With Permission).

Appendix 1. OT Score Sheets, Observed and Recorded Results for Mixed Reality Study on Hospital Stroke Unit.

This appendix contains the complete recordings of user performance for patients using the mixed reality system on the stroke unit. For each patient the occupational therapist's score sheet generated by the computer is presented. This is followed by two tables: the left hand side is observed actions, the right hand side is the computers recording of user actions. Discrepancies are summarised and discussed in the main text in chapter 5.

FULL FUNCTIONAL ASSESSMENT OF MAKING A HOT DRINK (23.9.04)

PATIENT NUMBER: .... **DATE:** ....

Hand used during assessment	
Did patient normally make hot drink at home, prior to admission	
Type of kettle normally used at home (gas / electric, jug etc)	
Hand normally used for making a hot drink	

	New No.	Stage (any order)	Score	Comments / errors
1	1	Get jug of water		
2	2	Get kettle		
3	3	Get kettle base		
4	4	Take lid off kettle (optional)		
5	5	Pour water into kettle		
6	6	Put lid onto kettle (optional)		
7	7	Put kettle on to kettle base (optional)		
8	8	Plug kettle base lead into power socket (therapist to switch power on)		
9	9	Switch kettle on		
10	10	Get mug		
11	11	Get teapot (optional)		
	12	Take lid off teapot		
12	13	Get coffee / teabags jar		
13	14	Get spoon (optional)		
14	15	Take lid off coffee / teabags jar		
15	16	Put spoon into coffee jar / take teabag out of jar		
16	17	Spoon coffee into mug / put teabag into mug or teapot		
17	18	Pour boiled water into mug / teapot		
	19	Put lid on teapot (optional)		
18	20	Take teabag out of mug (optional)		
19	21	Get milk (optional)		
20	22	Pour milk into mug (optional)		
21	23	Pour tea from teapot to mug (optional)		
22	24	Get sugar (optional)		
23	25	Put spoon into sugar bowl (optional)		
24	26	Spoon sugar into mug (optional)		
25	27	Stir drink in mug (optional)		
		OVERALL SCORE	/	**% of possible total score (i.e. excluding optional stages omitted)**

Scoring: 2 = Independent 1 = Required verbal assistance 0 = Dependent n/a = Not applicable (optional stages only)

Patient MR1

mr1	Coffee			
Code	Comp	Score	App	Task
1	Yes	2	c	Get jug of water
2	Yes	2	c	Get kettle
3		0	c	Get kettle base
4		0	na	Take lid off kettle
5		0	c	pour water into kettle
6		0	na	Put lid onto kettle
7		0	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9		0	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14		0	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16		0	c	Put spoon into jar
16		0	na	Take teabags out of jar
17		0	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18		0	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	8	33.3333		

OT score sheet for MR1

Observed events	Observed Time
Started	0m 00s
Got jar	0m 10s
Got spoon	0m 13s
Got mug	0m 16s
Spoon to jar	0m 19s
Spoon to mug	0m 24s
Got kettle	0m 35s
Poured kettle to mug	0m 40s
Got spoon	0m 50s
Stirred spoon in mug	0m 52s
Stopped	1m 01s

Registered Events	Registered Time
	00m 00s 000ms
Get jug of water	00m 09s 810ms
Get coffee/teabags jar	00m 10s 954ms
Get mug	00m 18s 696ms
Get kettle	00m 35s 548ms

Observed and recorded results for MR1

Patient MR2

mr2	Coffee			
Code	Comp	Score	App	Task
1	Yes	2	c	Get jug of water
2	Yes	1	c	Get kettle
3	Yes	2	c	Get kettle base
4		0	na	Take lid off kettle
5	Yes	2	c	pour water into kettle
6		0	na	Put lid onto kettle
7	Yes	2	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9	Yes	2	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14	Yes	2	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16	Yes	2	c	Put spoon into jar
16		0	na	Take teabags out of jar
17	Yes	2	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18	Yes	2	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	23	95.8333		

OT score sheet for MR2

Observed events	Observed Time
Started	0m 00s
Got jug	0m 11s
Poured jug to kettle	0m 13s
Switched on kettle	0m 33s
Asked by OT to get the kettle	1m 23s
Pressed the red button: "get the base"	2m 28s
Told by OT to pour water, poured water	3m 23s
Got mug	4m 03s
Got spoon	4m 05s
Got jar	4m 07s
Spoon to mug	4m 18s
Spoon to jar	6m 18s

Registered Events	Registered Time
	00m 00s 000ms
Get jug of water	00m 14s 078ms
Verbal prompt given:...Get kettle	00m 59s 105ms
Get kettle	01m 29s 732ms
Verbal prompt given:...Get kettle base	02m 31s 915ms
Poured water from jug into kettle	03m 21s 097ms
Get mug	04m 09s 279ms
Get spoon	04m 13s 369ms
Incorrect: Put unloaded spoon into mug	04m 14s 783ms
Get coffee/teabags jar	04m 15s 830ms
Incorrect: Put unloaded spoon into mug	04m 53s 125ms
Already done: Poured	05m 01s 553ms

OT asked MR2 to put kettle on white base	7m 38s
Put mug on base	7m 58s
Put kettle on base (assisted)	8m 15s
OT what is the next stage?	9m 11s
Poured jug to kettle	9m 22s
Poured boiled water	9m 24s
Spoon coffee into mug	10m 20s
Stopped	10m 22s

water from jug into kettle	
Incorrect: tried to pour water before kettle boiled	05m 01s 553ms
Incorrect: Put unloaded spoon into mug	05m 14s 106ms
Incorrect: Put unloaded spoon into mug	05m 24s 633ms
Already done: Poured water from jug into kettle	05m 34s 872ms
Incorrect: Put unloaded spoon into mug	05m 42s 021ms
Put spoon into jar	06m 17s 426ms
Get kettle base	08m 20s 571ms
Put kettle onto kettle base	08m 20s 571ms
Switched on kettle	08m 20s 571ms
Already done: Poured water from jug into kettle	09m 23s 776ms
Pour boiled water into mug	09m 23s 776ms
Incorrect: Spoon already loaded	09m 23s 776ms
Spooned coffee into mug	10m 22s 244ms

Observed and recorded results for MR2

Patient MR3

mr3	Coffee			
Code	Comp	Score	App	Task
1	Yes	2	c	Get jug of water
2	Yes	2	c	Get kettle
3	Yes	2	c	Get kettle base
4		0	na	Take lid off kettle
5	Yes	2	c	pour water into kettle
6		0	na	Put lid onto kettle
7	Yes	2	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9	Yes	1	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14	Yes	2	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16	Yes	2	c	Put spoon into jar
16		0	na	Take teabags out of jar
17	Yes	2	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18	Yes	2	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	23	95.8333		

OT score sheet for MR3

Observed events	Observed Time
Started	0m 00s
Got kettle	0m 12s
Got jug	0m 27s
Poured jug to kettle	0m 38s
Put kettle on base	0m 45s
Problem with pouring demonstrated by OT	1m 24s
"put kettle on the base" by OT	1m 59s
Kettle on base	2m 04s
Got mug	2m 11s
Got spoon	2m 12s
Got jar	2m 14s
Spoon to jar	2m 26s
Spoon to mug	2m 34s

Registered Events	Registered Time
	00m 00s 000ms
Get kettle	00m 13s 578ms
Get jug of water	00m 28s 898ms
Get kettle base	00m 42s 348ms
Put kettle onto kettle base	00m 42s 348ms
Incorrect: tried to switch kettle on whilst empty	00m 42s 398ms
Incorrect response:	00m 46s 725ms
Paused	00m 51s 526ms
Resumed	00m 51s 581ms
Poured water from jug into kettle	01m 14s 974ms
Put kettle onto kettle base	01m 45s 893ms
Get coffee/teabags jar	02m 05s 628ms
Get mug	02m 06s 177ms

Prompt spoon coffee	3m 12s
Demonstrated by OT	3m 42s
"switch the kettle on"	5m 09s
Switched kettle on	5m 15s
Poured water from kettle to mug	5m 51s
ADT	6m 04s
ADT	6m 34s
Demonstration by OT poured water	6m 40s
Stopped	6m 45s

Get spoon	02m 13s 061ms
Put spoon into jar	02m 14s 408ms
Verbal prompt given:...Spoon coffee into mug	02m 57s 204ms
Spooned coffee into mug	03m 48s 391ms
Verbal prompt given:...Switch kettle on	04m 52s 634ms
Switched on kettle	05m 02s 983ms
Put kettle onto kettle base	05m 48s 198ms
Incorrect: already switched kettle on	05m 48s 244ms
Put kettle onto kettle base	06m 20s 452ms
Incorrect: already switched kettle on	06m 20s 545ms
Pour boiled water into mug	06m 24s 121ms

Observed and recorded results for MR3

Patient MR4

mr4	Coffee			
Code	Comp	Score	App	Task
1	Yes	1	c	Get jug of water
2	Yes	2	c	Get kettle
3	Yes	2	c	Get kettle base
4		0	na	Take lid off kettle
5	Yes	2	c	pour water into kettle
6		0	na	Put lid onto kettle
7	Yes	2	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9	Yes	2	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14	Yes	2	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16	Yes	2	c	Put spoon into jar
16		0	na	Take teabags out of jar
17	Yes	2	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18	Yes	2	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	23	95.8333		

OT score sheet for MR4

Observed events	Observed Time
Started	0m 00s
Got kettle	0m 07s
Got jug	0m 13s
Poured water from jug	0m 18s
Put kettle on base	0m 27s
Demonstration o	1m 15s
Kettle on base	1m 24s
Boiled water	1m 27s
Got spoon	1m 39s
Spoon to jar (jar not in scene)	1m 41s
Demo bring object into scene	1m 44s
Got jar	1m 46s
Got mug	1m 49s

Registered Events	Registered Time
	00m 00s 000ms
Get kettle	00m 10s 193ms
Get kettle base	00m 27s 184ms
Put kettle onto kettle base	00m 27s 184ms
Put kettle onto kettle base	00m 33s 856ms
Paused	00m 37s 692ms
Resumed	00m 37s 744ms
Get jug of water	00m 40s 618ms
Poured water from jug into kettle	01m 03s 379ms
Switched on kettle	01m 15s 467ms
Put kettle onto kettle base	01m 16s 663ms
Incorrect: already switched kettle on	01m 19s 722ms
Already done: Poured	01m 34s 073ms

Spoon to jar	1m 53s
Spoon to mug	2m 00s
Pour water from kettle	2m 08s
Pour water from kettle	2m 33s
Stopped	2m 45s

water from jug into kettle	
Get coffee/teabags jar	01m 42s 151ms
Get spoon	01m 46s 842ms
Put spoon into jar	01m 49s 253ms
Get mug	01m 52s 812ms
Spooned coffee into mug	01m 53s 061ms
Pour boiled water into mug	02m 25s 314ms

Observed and recorded results for MR4

Patient MR5

mr5	coffee			
Code	Comp	Score	App	Task
1	Yes	2	C	Get jug of water
2	Yes	1	C	Get kettle
3	Yes	2	C	Get kettle base
4		0	Na	Take lid off kettle
5	Yes	2	C	pour water into kettle
6		0	na	Put lid onto kettle
7	Yes	2	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9	Yes	2	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14		0	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16		0	c	Put spoon into jar
16		0	na	Take teabags out of jar
17		0	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18		0	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	15	62.5		

OT score sheet for MR5

Observed events	Observed Time
Started	0m 00s
Got jug	0m 10s
Poured water to kettle (not in scene)	0m 12s
Told by OT to bring object into scene	0m 17s
Got kettle	0m 24s
Moved base into scene	0m 31s
Put kettle on base	0m 35s
Switched kettle on	0m 41s
OT demonstrated get kettle	1m 11s
Poured water into kettle	1m 26s

Registered Events	Registered Time
started	00m 00s 000ms
Get jug of water	00m 12s 822ms
Get kettle base	00m 34s 504ms
Put kettle onto kettle base	00m 34s 504ms
Incorrect: tried to switch kettle on whilst empty	00m 41s 053ms
Incorrect response: lid on jar	00m 43s 650ms
Get kettle	01m 11s 014ms
Put kettle onto kettle base	01m 42s 168ms
Incorrect: tried to switch kettle on whilst empty	01m 42s 354ms
Put kettle onto kettle base	01m 46s 245ms

Kettle to base	1m 44s
OT intervenes on laptop	2m 06s
Poured water to kettle	2m 56s
Kettle to base	3m 14s
Switched on kettle	3m 17s
Got mug	3m 46s
Got spoon	3m 52s
Got jar	3m 58s
Spoon to jar	4m 07s
Spoon to mug	4m 13s
Spoon to jar	4m 23s
Poured water	4m 42s
Kettle to base	4m 52s
Spoon to mug	4m 57s
Stopped	5m 21s

Incorrect response: lid on jar	01m 46s 444ms
Incorrect: tried to switch kettle on whilst empty	01m 52s 297ms
Put kettle onto kettle base	01m 55s 575ms
Paused	02m 05s 132ms
Resumed	02m 05s 171ms
Poured water from jug into kettle	02m 27s 848ms
Put kettle onto kettle base	02m 50s 109ms
Put kettle onto kettle base	02m 52s 437ms
Switched on kettle	02m 53s 867ms
Put kettle onto kettle base	02m 54s 134ms
Incorrect: already switched kettle on	02m 55s 563ms
Already done: Poured water from jug into kettle	03m 10s 279ms
Get mug	03m 29s 815ms
Get coffee/teabags jar	03m 36s 510ms
Put kettle onto kettle base	04m 29s 396ms

Observed and recorded results for MR5

Patient MR6

mr6	coffee			
Code	Comp	Score	App	Task
1	Yes	2	c	Get jug of water
2	Yes	2	c	Get kettle
3	Yes	1	c	Get kettle base
4		0	na	Take lid off kettle
5	Yes	2	c	pour water into kettle
6		0	na	Put lid onto kettle
7	Yes	1	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9	Yes	2	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14	Yes	2	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16		0	c	Put spoon into jar
16		0	na	Take teabags out of jar
17		0	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18		0	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	16	66.6667		

OT score sheet for MR6

Observed events	Observed Time
Started	0m 00s
Prompted to start by OT	0m 04s
Got spoon	0m 06s
Got mug	0m 13s
Got jar	0m 21s
Spoon to jar	0m 25s
Spoon to mug	0m 34s
OT prompts "Push red button"	0m 52s
Got kettle	0m 57s
Poured kettle to mug	1m 32s
Pushed red button (no prompt)	1m 58s

Registered Events	Registered Time
	00m 00s 000ms
Get jug of water	00m 06s 851ms
Get coffee/teabags jar	00m 14s 898ms
Get mug	00m 19s 137ms
Get spoon	00m 34s 295ms
Incorrect: Put unloaded spoon into mug	00m 35s 548ms
Verbal prompt given:...Get kettle	00m 53s 953ms
Verbal prompt given:...Get kettle	01m 15s 466ms
Verbal prompt given:...Get kettle base	01m 56s 184ms
Incorrect: Put unloaded spoon into mug	02m 24s 997ms
Verbal prompt given:...pour water into kettle	02m 38s 465ms

OT prompts, explains	2m 00s
Got base	2m 02s
Kettle to base not placed appropriately	2m 12s
OT explains how to put kettle on base	2m 15s
Kettle on base	2m 23s
Pushed red button (no prompt)	2m 39s
Pour water into the kettle	2m 40s
Got jug	2m 46s
Demonstration by experimenter	3m 03s
Poured water	3m 43s
OT assisted, put kettle on base	3m 55s
Pushed red button: "switch the kettle on"	4m 06s
Switched on with some difficulty	4m 18s
Rocked kettle	4m 46s
OT prompt, try lifting the kettle	5m 03s
Poured water	5m 05s
Kettle to base	5m 16s
OT prompt, push the red button	5m 26s
Spoon to jar	5m 43s
Spoon to mug	5m 48s
Spoon to jar	6m 05s
Demonstration by experimenter: how to put spoon in coffee	6m 11s
Spoon to jar	6m 22s
OT prompted "put the spoon in the coffee"	6m 34s
Pushed red button " put the spoon in the coffee"	6m 43s
Demonstration by experimenter	6m 56s
Stopped	7m 01s

Put kettle onto kettle base	02m 58s 683ms
Poured water from jug into kettle	03m 31s 520ms
Incorrect: tried to pour water before kettle boiled	03m 31s 520ms
Put kettle onto kettle base	03m 52s 890ms
Put kettle onto kettle base	03m 54s 115ms
Incorrect: Put unloaded spoon into mug	04m 05s 586ms
Verbal prompt given:...Switch kettle on	04m 08s 214ms
Switched on kettle	04m 17s 524ms
Incorrect: already switched kettle on	04m 43s 895ms
Put kettle onto kettle base	04m 45s 613ms
Incorrect: already switched kettle on	04m 46s 888ms
Incorrect: Put unloaded spoon into mug	04m 54s 136ms
Already done: Poured water from jug into kettle	05m 02s 699ms
Put kettle onto kettle base	05m 13s 231ms
Incorrect: already switched kettle on	05m 13s 274ms
Incorrect: already switched kettle on	05m 16s 780ms
Incorrect: Put unloaded spoon into mug	05m 29s 233ms
Verbal prompt given:...Put spoon into jar	05m 32s 874ms
Verbal prompt given:...Put spoon into jar	06m 43s 022ms

Observed and recorded results for MR6

Patient MR7

mr7	coffee			
Code	Comp	Score	App	Task
1	Yes	2	c	Get jug of water
2	Yes	2	c	Get kettle
3	Yes	2	c	Get kettle base
4		0	na	Take lid off kettle
5	Yes	2	c	pour water into kettle
6		0	na	Put lid onto kettle
7	Yes	2	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9	Yes	2	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14	Yes	2	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16		0	c	Put spoon into jar
16		0	na	Take teabags out of jar
17		0	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18	Yes	2	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	20	83.3333		

OT score sheet for MR7

Observed events	Observed Time
Started	0m 00s
Got kettle	0m 04s
Kettle on base	0m 08s
Switch on	0m 12s
Got mug	0m 16s
Got jar	0m 18s
Got spoon	0m 20s
Spoon to jar	0m 22s
(hitting jar with spoon)	0m 23s
Spoon to mug	0m 32s
OT intervened	0m 42s
"the water has boiled"	0m 58s

Registered Events	Registered Time
	00m 00s 000ms
Get coffee/teabags jar	00m 01s 761ms
Incorrect: tried to switch kettle on whilst empty	00m 08s 295ms
Get kettle base	00m 08s 496ms
Put kettle onto kettle base	00m 08s 496ms
Incorrect response: lid on jar	00m 08s 712ms
Get mug	00m 22s 033ms
Get jug of water	00m 26s 968ms
Get spoon	00m 43s 677ms
Incorrect: Put unloaded spoon into mug	00m 44s 658ms
Put kettle onto kettle base	01m 16s 191ms
Verbal prompt given:...Get kettle	01m 23s 032ms

Poured water from kettle	1m 08s		Get kettle	01m 37s 213ms
Put kettle on base	1m 20s		Verbal prompt given:...pour water into kettle	01m 42s 700ms
OT prompted push red button	1m 27s		Incorrect: tried to pour water before kettle boiled	02m 15s 250ms
"Get the kettle"	1m 27s		Poured water from jug into kettle	02m 22s 088ms
Got kettle	1m 29s		Put kettle onto kettle base	02m 37s 002ms
OT intervened to help getting kettle	1m 35s		Put kettle onto kettle base	02m 43s 037ms
OT prompt press the red button	1m 43s		Switched on kettle	02m 46s 728ms
"pour water into the kettle"	1m 50s		Already done: Poured water from jug into kettle	03m 02s 807ms
OT "can you find a pink jug?"	2m 05s		Already done: Poured water from jug into kettle	03m 58s 810ms
Got jug	2m 14s		Pour boiled water into mug	03m 58s 810ms
Poured water	2m 24s			
Kettle to base	2m 37s			
Switched on	2m 47s			
Poured water	3m 03s			
Poured water	3m 23s			
Poured water	4m 04s			
OT intervened, put spoon in jar	4m 10s			
Stopped	4m 30s			

Observed and recorded results for MR7

Patient MR8

mr8	coffee			
Code	Comp	Score	App	Task
1	Yes	2	c	Get jug of water
2	Yes	2	c	Get kettle
3	Yes	2	c	Get kettle base
4		0	na	Take lid off kettle
5	Yes	2	c	pour water into kettle
6		0	na	Put lid onto kettle
7	Yes	2	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9	Yes	2	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14	Yes	2	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16	Yes	2	c	Put spoon into jar
16		0	na	Take teabags out of jar
17	Yes	2	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18	Yes	2	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	24	100		

OT score sheet for MR8

Observed events	Observed Time
Started	0m 00s
Got kettle	0m 04s
Got jug	0m 09s
Poured water into kettle	0m 11s
Poured water into kettle	0m 32s
Kettle on base	0m 44s
Switched on	0m 51s
Kettle rocked by patient	0m 51s
Got mug (two handed)	1m 15s
Got jar	1m 15s
OT prompts "There's a spoon on the table	1m 21s
Got spoon (holds spoon sideways)	1m 23s

Registered Events	Registered Time
	00m 00s 000ms
Paused	00m 04s 394ms
Resumed	00m 04s 429ms
Get kettle	00m 11s 461ms
Get jug of water	00m 18s 029ms
Poured water from jug into kettle	00m 30s 897ms
Get kettle base	00m 48s 913ms
Put kettle onto kettle base	00m 48s 913ms
Switched on kettle	00m 53s 874ms
Put kettle onto kettle base	00m 54s 143ms
Incorrect: already switched kettle on	00m 55s 404ms
Get coffee/teabags jar	01m 20s 196ms

Put spoon into jar, not registering	2m 13s
Spoon to jar	5m 36s
Pour kettle	7m 15s
Kettle to base	7m 20s
OT prompt "press the red button"	7m 23s
Pushed button "spoon coffee into the mug"	7m 31s
Put spoon into mug	8m 11s
Poured kettle	8m 18s
Poured kettle	8m 29s
Stopped	8m 39s

Get mug	01m 24s 402ms
Get spoon	02m 46s 351ms
Incorrect: Put unloaded spoon into mug	02m 47s 295ms
Paused	03m 50s 595ms
Resumed	03m 50s 612ms
Incorrect: Put unloaded spoon into mug	04m 50s 666ms
Put spoon into jar	05m 00s 269ms
Put kettle onto kettle base	06m 51s 531ms
Incorrect: already switched kettle on	06m 51s 581ms
Verbal prompt given:...Spoon coffee into mug	06m 57s 051ms
Incorrect: already switched kettle on	07m 38s 570ms
Spooned coffee into mug	07m 41s 561ms
Incorrect: already switched kettle on	07m 41s 715ms
Put kettle onto kettle base	07m 52s 151ms
Incorrect: already switched kettle on	07m 52s 205ms
Pour boiled water into mug	07m 52s 783ms

Observed and recorded results for MR8

Patient MR9

mr9	Coffee			
Code	Comp	Score	App	Task
1	Yes	2	c	Get jug of water
2	Yes	2	c	Get kettle
3	Yes	1	c	Get kettle base
4		0	na	Take lid off kettle
5		0	c	pour water into kettle
6		0	na	Put lid onto kettle
7	Yes	1	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9		0	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14	Yes	2	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16	Yes	2	c	Put spoon into jar
16		0	na	Take teabags out of jar
17	Yes	2	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18		0	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	16	66.6667		

OT score sheet for MR9

Observed events	Observed Time
Started	0m 00s
Got kettle (not in scene)	0m 11s
Got jug	0m 16s
Poured water	0m 21s
Switch on kettle	0m 28s
Spoon to jar (jar not in scene)	0m 55s
Prompt "push the red button"	0m 57s
Spoon to jar	1m 11s
Spoon to mug (mug not in scene)	1m 14s
OT prompts "bring the mug nearer"	1m 19s
Poured water	1m 30s

Registered Events	Registered Time
	00m 00s 000ms
Get spoon	00m 08s 911ms
Get jug of water	00m 13s 301ms
Get kettle	00m 13s 884ms
Get mug	00m 15s 047ms
Incorrect: Put unloaded spoon into mug	00m 28s 664ms
Get coffee/teabags jar	01m 07s 554ms
Put spoon into jar	01m 08s 283ms
Incorrect: Put unloaded spoon into mug	01m 08s 551ms
Spooned coffee into mug	01m 25s 927ms
Incorrect: Spoon already loaded	01m 28s 419ms

Noticed kettle persistently in VE, patients sleeve same colour as kettle	
OT prompt "push the red button"	2m 42s
"get the base"	2m 49s
Kettle on base	3m 04s
Lid off kettle	3m 10s
Poured water	3m 19s
Spoon to jar	3m 26s
Kettle to mug	3m 33s
Kettle on base	3m 38s
Stirring drink	3m 49s
Stopped	3m 59s

Paused	01m 34s 488ms
Resumed	01m 34s 542ms
Verbal prompt given:...Get kettle base	01m 45s 112ms
Get kettle base	02m 01s 156ms
Put kettle onto kettle base	02m 01s 156ms
Incorrect: tried to switch kettle on whilst empty	02m 01s 256ms
Put kettle onto kettle base	02m 06s 776ms
Incorrect: tried to switch kettle on whilst empty	02m 08s 206ms
Put kettle onto kettle base	02m 23s 801ms
Incorrect: Put unloaded spoon into mug	02m 28s 856ms
Put kettle onto kettle base	02m 32s 767ms
Incorrect: tried to pour water before kettle boiled	02m 41s 558ms
Incorrect: tried to switch kettle on whilst empty	02m 41s 808ms
Put kettle onto kettle base	02m 41s 972ms
Incorrect response: lid on jar	02m 42s 185ms
Incorrect: tried to switch kettle on whilst empty	02m 43s 288ms
Incorrect: tried to switch kettle on whilst empty	02m 44s 534ms
Put kettle onto kettle base	02m 45s 100ms
Put kettle onto kettle base	02m 46s 862ms

Observed and recorded results for MR9

Patient MR10

mr10	coffee			
Code	Comp	Score	App	Task
1	Yes	2	C	Get jug of water
2	Yes	2	C	Get kettle
3	Dep	0	C	Get kettle base
4		0	na	Take lid off kettle
5	Yes	2	c	pour water into kettle
6		0	na	Put lid onto kettle
7	Yes	2	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9	Yes	2	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14	Yes	2	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16	Dep	0	c	Put spoon into jar
16		0	na	Take teabags out of jar
17	Yes	2	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18	Yes	2	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	20	83.3333		

OT score sheet for MR10

Observed events	Observed Time
Started	0m 00s
Got kettle	0m 16s
Got jar	0m 26s
Got mug	0m 30s
Dropped jug	0m 33s
Poured water	0m 35s
Moved kettle	0m 49s
Difficulty holding kettle	1m 04s
Kettle to mug	1m 05s
Knocked over jar	1m 20s
SEF	1m 20s

Registered Events	Registered Time
	00m 00s 000ms
Get kettle	00m 11s 604ms
Get mug	00m 12s 668ms
Incorrect: tried to pour water before kettle boiled	00m 19s 552ms
Get jug of water	00m 24s 889ms
Get coffee/teabags jar	00m 26s 186ms
Poured water from jug into kettle	00m 28s 718ms
Get spoon	00m 40s 436ms
Incorrect: Put unloaded spoon into mug	00m 41s 550ms
Already done: Poured water from jug into kettle	00m 46s 554ms
Incorrect: Put unloaded spoon into mug	00m 48s 599ms

OT prompt "press the red button"	1m 24s
Patient pushed button twice so verbal prompt issued followed by demonstration	1m 32s
Got spoon	2m 00s
Put spoon in jar,	2m 03s
Pushed the red button: "get the base"	2m 14s
Verbal prompt followed by demonstration	2m 14s
Kettle to base	2m 29s
Removed kettle from base	2m 35s
Kettle to base, not properly on	2m 40s
Switched on kettle	2m 42s
Pushed the red button " put the kettle on the base"	2m 52s
OT assisted, put kettle on base	2m 54s
Poured water from kettle	3m 03s
Stopped	3m 11s

Incorrect: tried to pour water before kettle boiled	01m 16s 449ms
Verbal prompt given:...Put spoon into jar	01m 23s 980ms
Demonstration given:...Put spoon into jar	01m 24s 313ms
Incorrect: Put unloaded spoon into mug	01m 25s 235ms
Already done: Poured water from jug into kettle	02m 00s 275ms
Incorrect: tried to pour water before kettle boiled	02m 00s 275ms
Spooned coffee into mug	02m 04s 945ms
Verbal prompt given:...Get kettle base	02m 11s 553ms
Demonstration given:...Get kettle base	02m 12s 347ms
Put kettle onto kettle base	02m 27s 426ms
Switched on kettle	02m 46s 829ms
Put kettle onto kettle base	02m 46s 829ms
Verbal prompt given:...Put kettle onto kettle base	02m 47s 993ms
Incorrect: already switched kettle on	02m 49s 822ms
Put kettle onto kettle base	02m 52s 750ms
Already done: Poured water from jug into kettle	03m 00s 998ms
Pour boiled water into mug	03m 00s 998ms

Observed and recorded results for MR10

Patient MR11

mr11	Coffee			
Code	Comp	Score	App	Task
1	Yes	2	c	Get jug of water
2		0	c	Get kettle
3		0	c	Get kettle base
4		0	na	Take lid off kettle
5		0	c	pour water into kettle
6		0	na	Put lid onto kettle
7		0	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9		0	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14	Yes	2	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16	Yes	2	c	Put spoon into jar
16		0	na	Take teabags out of jar
17	Yes	2	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18		0	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	12	50		

OT score sheet for MR11

Observed events	Observed Time
Started	0m 00s
Got jar	0m 10s
Got spoon	0m 13s
Spoon to jar	0m 18s
Spoon to mug (mug not in scene)	0m 22s
Spoon to jar	0m 24s
Spoon to mug	0m 26s
Patient asks "no sugar? No milk?"	
Poured water from jug to mug	0m 48s
Experimenter prompts "there is a green kettle"	1m 15s
Stopped	1m 28s

Registered Events	Registered Time
	00m 00s 000ms
Get jug of water	00m 13s 168ms
Get coffee/teabags jar	00m 14s 299ms
Get mug	00m 14s 861ms
Get spoon	00m 18s 938ms
Put spoon into jar	00m 21s 449ms
Spooned coffee into mug	00m 39s 721ms

Observed and recorded results for MR11

Patient MR12

mr12	Coffee			
Code	Comp	Score	App	Task
1	Yes	2	c	Get jug of water
2	Yes	2	c	Get kettle
3	Yes	2	c	Get kettle base
4		0	na	Take lid off kettle
5		0	c	pour water into kettle
6		0	na	Put lid onto kettle
7	Yes	2	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9		0	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13	Yes	2	c	Get coffee/teabags jar
14	Yes	2	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16		0	c	Put spoon into jar
16		0	na	Take teabags out of jar
17		0	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18		0	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	14	58.3333		

OT score sheet for MR12

Observed Event	Observed Time
Started	0m 00s
Patient says "water, coffee, milk, sugar if you have it"	0m 13s
Touched jug, moved hand to kettle as if holding jug	0m 30s
Experimenter prompts "you can pick up the objects" patient replies "I cant reach them"	0m 37s
Spoon to jar (jar not in scene)	0m 43s
Got jar	0m 51s
OT got kettle	0m 53s
Got mug	0m 55s
Got jug	1m 04s

Recorded Event	Recorded Time
	00m 00s 000ms
Get jug of water	00m 28s 293ms
Get spoon	00m 44s 588ms
Get mug	01m 05s 559ms
Get coffee/teabags jar	01m 37s 347ms
Get kettle	01m 54s 854ms
Incorrect: Put unloaded spoon into mug	02m 04s 634ms
Get kettle base	02m 27s 773ms
Put kettle onto kettle base	02m 27s 773ms

Lifted kettle lid	1m 14s
Jug to kettle	1m 18s
Spoon to jar	1m 32s
Poured kettle into jar	1m 52s
Experimenter intervenes, explains that water must be boiled	2m 20s
Kettle to base	2m 29s
Poured kettle to jar	3m 00s
Stirred spoon in jar	3m 16s
Stopped	3m 23s

Incorrect: tried to switch kettle on whilst empty	02m 27s 836ms
Incorrect: tried to switch kettle on whilst empty	02m 29s 186ms
Incorrect: Put unloaded spoon into mug	02m 41s 140ms
Put kettle onto kettle base	02m 51s 116ms
Incorrect: Put unloaded spoon into mug	02m 56s 636ms
Incorrect: Put unloaded spoon into mug	03m 15s 894ms

Observed and recorded results for MR12

Patient MR13

mr13	Coffee			
Code	Comp	Score	App	Task
1	Yes	2	c	Get jug of water
2	Yes	2	c	Get kettle
3		0	c	Get kettle base
4		0	na	Take lid off kettle
5		0	c	pour water into kettle
6		0	na	Put lid onto kettle
7		0	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9		0	c	Switch kettle on
10	Yes	2	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13		0	c	Get coffee/teabags jar
14	Yes	2	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16		0	c	Put spoon into jar
16		0	na	Take teabags out of jar
17		0	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18		0	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	8	33.3333		

OT score sheet for MR13

Observed events	Observed Time
Started	0m 00s
"Push the red button"	0m 34s
Got jug	0m 50s
Got mug and spoon together	0m 55s
Got jar	0m 57s
Spoon to jar	1m 01s
Spoon to mug	1m 03s
Spoon to jar	1m 05s
Spoon to mug	1m 08s
Pour water from jug to mug	1m 16s
Poured kettle to mug	1m 26s
Stopped	1m 52s

Registered Events	Registered Time
	00m 00s 000ms
Get kettle	00m 53s 146ms
Get mug	00m 54s 261ms
Get jug of water	00m 56s 071ms
Get spoon	00m 58s 395ms
Incorrect: Put unloaded spoon into mug	00m 59s 514ms

Observed and recorded results for MR13

Patient MR14

mr14	coffee			
Code	Comp	Score	App	Task
1		0	c	Get jug of water
2		0	c	Get kettle
3	Yes	2	c	Get kettle base
4		0	na	Take lid off kettle
5		0	c	pour water into kettle
6		0	na	Put lid onto kettle
7	Yes	2	c	Put kettle onto kettle base
8		0	na	Plug kettle base lead into power socket
9		0	c	Switch kettle on
10		0	c	Get mug
11		0	na	Get teapot
12		0	na	Take lid off teapot
13		0	c	Get coffee/teabags jar
14	Yes	1	c	Get spoon
15		0	na	Take lid off coffee/teabags jar
16		0	c	Put spoon into jar
16		0	na	Take teabags out of jar
17		0	c	Spoon coffee into mug
17		0	na	Put teabag into teapot
17		0	na	Put teabag in mug
18		0	c	Pour boiled water into mug
18		0	na	Pour boiled water into teapot
19		0	na	Put lid on teapot
20		0	na	Take teabag out of mug
21		0	na	Get milk
22		0	na	Pour milk into mug
23		0	na	Pour tea from teapot to mug
24		0	na	Get sugar
25		0	na	Put spoon into sugar bowl
26		0	na	Spoon sugar into mug
27		0	na	Stir drink in mug
Poss	Actual	Percent		
24	5	20.8333		

OT score sheet for MR14

Observed events	Observed Time
Started	0m 00s
Got jug	0m 08s
Got kettle	0m 10s
Lid off kettle	0m 12s
Poured water jug to kettle	0m 18s
Kettle on base, PT had problem fitting the kettle onto the base	0m 29s
Prompt “push the red button”	0m 32s
OT placed kettle on base	0m 46s

Registered Events	Registered Time
	00m 00s 000ms
Get kettle base	00m 41s 376ms
Put kettle onto kettle base	00m 41s 376ms
Verbal prompt given:...Get jug of water	00m 43s 952ms
Get spoon	01m 02s 573ms

Got spoon, jar and mug together with both hands	0m 59s			
Spoon to jar	1m 01s			
Spoon to mug	1m 04s			
Stopped	1m 14s			

Observed and recorded results for MR14

Appendix 2. Computer Attitude Survey Questionnaire

Attitudes Survey: computers, virtual reality and coffee making task

User code......................
Date ..../.../....

I use computers:

[ ] Every day
[ ] 2 or 3 times a week
[ ] Once a week
[ ] Once a month
[ ] Less frequently
[ ] Never

Below are a series of statements. There are no correct answers to these statements. They are designed to permit you to indicate the extent to which you agree or disagree with the ideas expressed. Circle the label that is closest to your agreement or disagreement with the statements.

1. Computers do not scare me at all

   Strongly Agree **Slightly Agree** **Not Sure** **Slightly Disagree** **Strongly Disagree**

2. I could use computers for learning

   Strongly Agree **Slightly Agree** **Not Sure** **Slightly Disagree** **Strongly Disagree**

3. I will do as little work with computers as possible

   Strongly Agree **Slightly Agree** **Not Sure** **Slightly Disagree** **Strongly Disagree**

4. Learning to use computers is a waste of time

   Strongly Agree **Slightly Agree** **Not Sure** **Slightly Disagree** **Strongly Disagree**

5. Computers make me feel uncomfortable

   Strongly Agree **Slightly Agree** **Not Sure** **Slightly Disagree** **Strongly Disagree**

6. I think using a computer would be very hard for me

   Strongly Agree **Slightly Agree** **Not Sure** **Slightly Disagree** **Strongly Disagree**

7. I think working with computers would be enjoyable and stimulating

   Strongly Agree **Slightly Agree** **Not Sure** **Slightly Disagree** **Strongly Disagree**

8. I am sure I could use computers for work or learning

   Strongly Agree **Slightly Agree** **Not Sure** **Slightly Disagree** **Strongly Disagree**

Scoring instructions for Computer Attitude Scale (CAS)

For positive worded questions, score 5 = strongly agree, 1 = strongly disagree. For negative worded questions, score 5 = strongly disagree, 1 = strongly agree.

Negative questions are: 3, 4, 5, 6
Subscales are calculated by totalling appropriate questions. Total Computer Attitude score is obtained by totalling all questions. Subscales are:

Anxiety:	*1, 5,*
Confidence:	*2, 6,*
Liking:	*3, 7,*
Usefulness:	*4, 8,*

The coffee making task:

9. When the computer gave instructions, I could hear them clearly

Strongly Agree	**Slightly Agree**	**Not Sure**	**Slightly Disagree**	**Strongly Disagree**

10. When the computer gave instructions, I could understand what was being asked

Strongly Agree	**Slightly Agree**	**Not Sure**	**Slightly Disagree**	**Strongly Disagree**

11. I knew what I had to do to carry out the instruction

Strongly Agree	**Slightly Agree**	**Not Sure**	**Slightly Disagree**	**Strongly Disagree**

12. The device enabled me to do what was asked of me

Strongly Agree	**Slightly Agree**	**Not Sure**	**Slightly Disagree**	**Strongly Disagree**

13. The screen was useful as it showed me what I had done

Strongly Agree	**Slightly Agree**	**Not Sure**	**Slightly Disagree**	**Strongly Disagree**

14. If I could make changes to this, it would be:

Appendix 3. Patient Instruction Sheet for Mixed Reality Study

MIXED REALITY HOT DRINK TASK
INSTRUCTIONS TO PATIENT

There are some items that you would use to make a hot drink laid out on the table. A camera connected to the computer can identify these objects and the computer can keep a track of what each object is doing.

The objects work like toys in that they are not meant to be fully working. You will not be making a real hot drink. There is no danger of boiling water or spilling anything.

I would like you to use the items just as you would if you were making a real hot drink.

Pick the objects up and move them about and use them as if they were real. Try to keep them on the black board so they are in the cameras view.

If you are not sure what to do at any stage, press the red help button. The computer will then tell you what to do next. Try to follow this prompt but if you cannot then please don't worry. If you are still stuck the computer will show you what to do, and I will help you.

I would like you to do the following:

- Boil water in the kettle. The water is in the jug to start with so you need to think of the stages that you need to do to boil water. The electrical plug is already plugged in. Fill the kettle and switch it on.

- Put coffee in the mug. You must spoon coffee from the jar into the mug. The jar lid has been removed for this task.

- Pour boiled water into the mug

A score is produced at the end that shows you how well you did. The computer also saves a record of everything that you did so we can look back and find out what works and what doesn't.

This equipment is developmental and the scores will not be used to influence any part of your treatment.

Appendix 4. Patient Consent Form

Queen's Medical Centre Nottingham NHS
University Hospital NHS Trust

Study title **Evaluation of a virtual environment in stroke rehabilitation**

Please ask the patient to complete the following:
Please cross out as necessary

Have you read and understood the patient information sheet? YES NO

Have you had an opportunity to ask questions and discuss this study? YES NO

Have you received satisfactory answers to all your questions? YES NO

Have you received enough information about the study? YES NO

Do you understand that you are free to withdraw from the study

- at any time? YES/NO
- without giving a reason for withdrawing? YES/NO
- and without affecting your future medical care? YES/NO

Who explained the details of this study to you?
....

I agree to take part in this study. YES/NO

Name of patient ....

Signed .... Date ....

Name of researcher ....

Signed .... Date ....

Appendix 5. Questionnaire Used With Occupational Therapists In Consultation Phase

Applications of Virtual Reality to Stroke Assessment and Rehabilitation

Seminar for Stroke Therapists

Participants' Response Sheet

Please return this response sheet as directed during the seminar. If you are unable to attend, your views are still important to our work and we would appreciate it if you could spare some time to complete and return it to:

Dave Hilton, Nottingham University School of Nursing, B floor, QMC, Nottingham, NG7 2UH

Section 1: Your experiences with stroke patients
Are you directly involved with *any* aspect of the care of stroke patients? Yes No

If "yes", please indicate which aspects you are involved in: *(tick all that are relevant)*

Diagnosis	[ ]
CT scan	[ ]
Physical assessment	[ ]
Cognitive assessment	[ ]
Physical rehabilitation	[ ]
Hospital care	[ ]
Community care	[ ]

If you have ticked more than one, which is the most relevant to your work *(please give brief details):*

....
....

Section 2: Currently used assessment strategies
Please briefly describe how you would assess each of the following assessment strategies:

Please indicate:

- *what resources are required*
- *how long the test takes*
- *how results are scored and recorded*
- *what, in your opinion, is the strength of the assessment method*
- *what, in your opinion, is the weakness of the assessment method*

a. Ability to recall objects

Test name:..

Resources:
....
Time taken:
....
Results:
....
Strength:
....
Weakness:
....

b. Object recognition

Test name:..

Resources:
....
Time taken:
....
Results:
....
Strength:
....
Weakness:
....

c. Navigation around environments

Test name:..

Resources:
....
Time taken:
....
Results:
....
Strength:
....
Weakness:
....

d. Spatial (3D) awareness

Test name:..

Resources:
....
Time taken:
....
Results:
....
Strength:
....

Weakness:
....

e. Physical mobility

Test name:..

Resources:
....
Time taken:
....
Results:
....
Strength:
....
Weakness:
....

f. Visual field deficits

Test name:..

Resources:
....
Time taken:
....
Results:
....
Strength:
....
Weakness:
....

g. Attention deficits

Test name:..

Resources:
....
Time taken:
....
Results:
....
Strength:
....
Weakness:
....

h. Body image disturbances

Test name:..

Resources:
....
Time taken:
....

Results:

....

Strength:

....

Weakness:

....

i. Ability to perform sequences of tasks within an activity (e.g. meal preparation)

Test name:..

Resources:

....

Time taken:

....

Results:

....

Strength:

....

Weakness:

....

Are there any assessment which you use which you feel could be improved upon? If so, how?

....
....
....

Section 3: Your experience of virtual reality

Have you ever previously experienced virtual reality?

Yes No

If yes, when, where and for what purpose?

....
....

Can you describe what kind of VR system you used *(tick the following)*:

Head mounted display [ ]
Large projected display [ ]
Stereoscopic thin film displays worn as spectacles [ ]
VDU Monitor [ ]
dataglove [ ]
infrared tracker [ ]
Touchscreen [ ]
Mouse [ ]
Joystick [ ]

Additional details:

....
....

How did you feel about the experience?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

Section 4: The patient and VR

If you were asked to consider whether using a virtual reality based tool during assessment and/or rehabilitation was appropriate, how important would you say the following factors would be?

Please circle one number representing the rating scale:

***1** = not at all important **2** = not very important **3** = fairly important **4** =quite important **5** = very important*

Age	1	2	3	4	5
Gender	1	2	3	4	5
Severity of stroke	1	2	3	4	5
Motivation	1	2	3	4	5
Prior experience of using technology	1	2	3	4	5
Physical mobility	1	2	3	4	5
Anxiety (due to stroke)	1	2	3	4	5
Potential side effects	1	2	3	4	5

Can you think of any other user issues that would be important?:

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

If a suitable VR system was developed to be used in the assessment or rehabilitation of stroke patients, how important do you consider the following to be in the design and use of such a system:

Please circle one number representing the rating scale:

***1** = not at all important **2** = not very important **3** = fairly important **4** =quite important **5** = very important*

Easy to use by therapist	1	2	3	4	5
Intuitive interface	1	2	3	4	5
Easy to control by patient	1	2	3	4	5
Simple environment	1	2	3	4	5
Realistic looking environment	1	2	3	4	5
Objects behave realistically	1	2	3	4	5
Stereoscopic (3d) display	1	2	3	4	5
Provides quantitative data	1	2	3	4	5
Provides a printout	1	2	3	4	5
Tasks can be set at different levels of difficulty	1	2	3	4	5
Used under supervision only	1	2	3	4	5
Time limits for session	1	2	3	4	5
Inexpensive equipment					

Accessible via the internet	1	2	3	4	5
Could be used at patients home	1	2	3	4	5
Ability to manipulate virtual objects	1	2	3	4	5
Touch (haptic) feedback	1	2	3	4	5

Are there any other factors which would influence use of such a system?:

....
....

How would you feel about using a VR based system as part of the patients ongoing rehabilitation ?
....
....
....
....

Section 5: Potential applications of VR in stroke assessment and rehabilitation

The following potential applications have been identified as candidates for future development. Please grade the projects, depending upon which you feel would be most useful to you and your patient.

*Enter numbers in boxes provided, using **1** as most useful down to **10** which is least useful.*

[ ] Manipulating objects via a natural interface to support restorative motor rehabilitation

[ ] Displaying simple everyday objects in a suitable contextual environment to assess object recognition

[ ] Training the patient to navigate through realistic virtual environments, such as a building or street

[ ] Training the patient to cross a road using a simulated pelican crossing

[ ] Displaying simple everyday objects in a suitable contextual environment to assess ability to recall objects

[ ] Assessing stereoscopic vision and accuracy of reaching towards and grasping objects

[ ] Training the patient to perform sequences of tasks to complete an everyday activity (e.g. meal preparation)

[ ] Teaching the patient to recognise different parts of the body and how they relate to each other

[ ] Stimulating the neglected side with a variety of visual input

[ ] Teaching patients the function of objects by using demonstrations followed by simple tasks

If you have any further comments please write them below:

....
....
....
....

....
....

Section 6: Contact details

The following information is optional but it would be useful for our study:

Name ....

Occupation ....
Workplace ....
Contact ....

Do you wish to be kept informed of future progress with the study? Yes No

Do you wish to be involved in any aspect of the study? Yes No

If "yes", please describe how you would like to become involved:

....
....

Thank you for completing this questionnaire. Your responses will be used to guide future research in this field.
You will not be identified in any published work unless you specifically request to be.

Please return the completed papers to Dave Hilton, Nottingham University School of Nursing, QMC

Appendix 6. Manufacturers Technical Data and Circuit Diagrams for Radio Frequency Switches

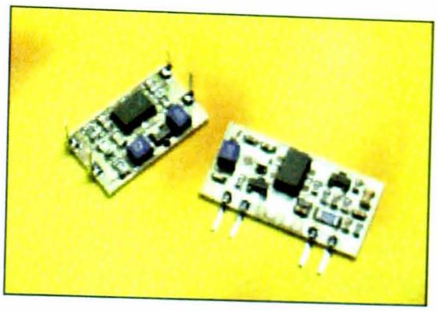
The following section provides the transmitter and receiver circuits that were used in the MR project. These have been included with consent of the manufacturers, RF Solutions Ltd.

AM Hybrid Transmitter

AM-RT4-XXX
AM-RT5-XXX
AM-RTQ4-XXX
AM-RT14-XXX

Features

- Complete RF Transmitter
- CMOS / TTL Input
- No Adjustable Components
- Very Stable Operating Frequency
- Low Current Consumption
- Low Spurious Emissions



Applications

- Wireless Security Systems
- Car Alarms
- Remote Gate Controls
- Remote Sensing
- Data Capture
- Sensor Reporting

RT4 / RT5

- Available as 315, 418, 433 MHz
- Range up to 70 metres
- Available in DIL or SIL Package
- Wide Operating Voltage

RTQ4 / RT14

- High Output Power
- Range 100+ metres
- Available as 433, 868 MHz

Description

The R F Solutions Ltd. AM hybrid transmitter module provides a complete RF transmitter which can be used to transmit data at up to 4KHz from any standard CMOS/TTL source.
The module is very simple to operate and offers low current consumption (typ. 4 mA). Data can be supplied directly from a microprocessor or encoding device, thus keeping the component count down and ensuring a low hardware cost.
The module exhibits extremely stable electronic characteristics due to the use of Thick-Film hybrid technology, which uses no adjustable components and ensures very reliable operation.
The modules are compatible with R F solutions Ltd. range of AM receivers to provide a complete solution.

Ordering Information

Part Number	Description
AM-RT4-XXX	DIL AM Transmitter Module XXX MHz
AM-RTQ4-XXX	DIL AM Transmitter Module XXX MHz
AM-RT5-XXX	SIL AM Transmitter Module XXX MHz
AM-RT14-XXX	DIL AM Transmitter Module XXX MHz, SAW Resonator

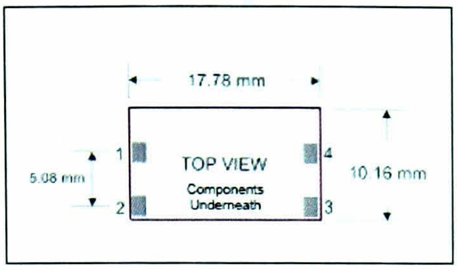
Frequency Availability

RT4 / RT5:	**XXX** = 315, 418, 433MHz	Other Frequencies available on request
RTQ4:	**XXX** = 868MHz	Other Frequencies available on request
RT14:	**XXX** = 433MHz	Other Frequencies available on request

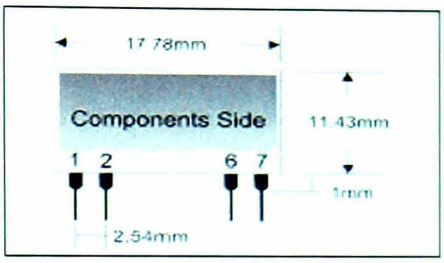
AM Hybrid Transmitter

Mechanical Dimensions

RT4 / RTQ4 / RT14



RT5

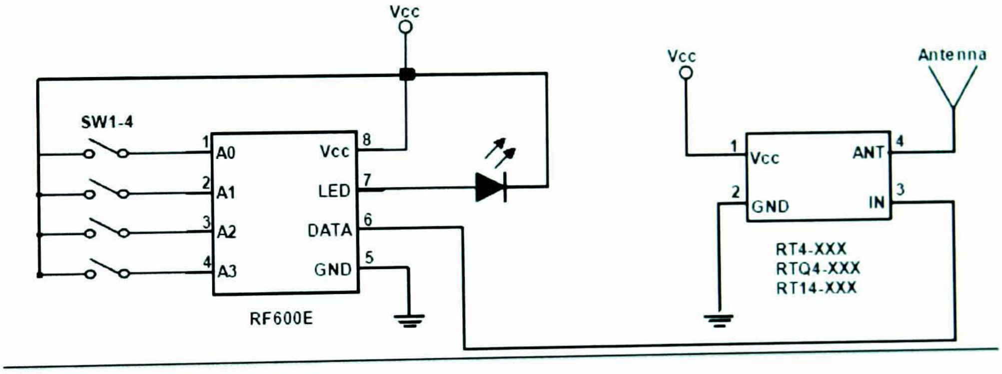


Pin Descriptions

RT4 / RTQ4 / RT14	RT5	Name	Description
1	7	Vcc	Supply Voltage
2	6	GND	Ground, Connect to RF earth return path
3	2	IN	Data input
4	1	ANT	External Antenna

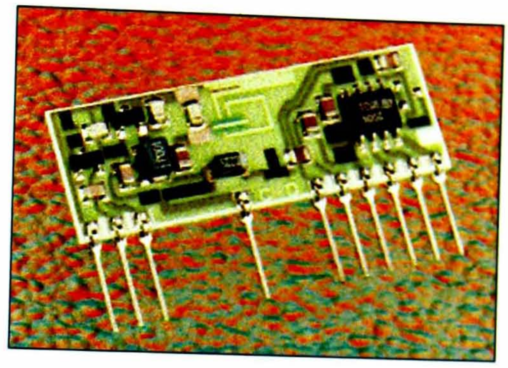
Typical Application
For further information on this circuit please see datasheet DS600

Transmitter Circuit



AM SUPER REGENERATIVE RECEIVERS. AM-HRRN-XXX

- Compact Hybrid Modules.
- Standard Frequencies; 315, 433, 868MHz
- Frequencies Available: 250-450MHz
- Very High Frequency Stability (With No Adjustable Components).
- Receiving Range Up To 50 Metres.
- CMOS/TTL Compatible Output
- Low Current Consumption;
  - ⇒ HRR3 Typ 2.5mA.
  - ⇒ HRR18 Typ 70uA.
- Single Supply Voltage 3V or 5V.
- Compatible With R.F. Solutions AM Transmitters.
- Patented Laser Trimmed Inductor.
- Compliant To ETSI300-220
- Requires No Radio Licence To Operate.



Description

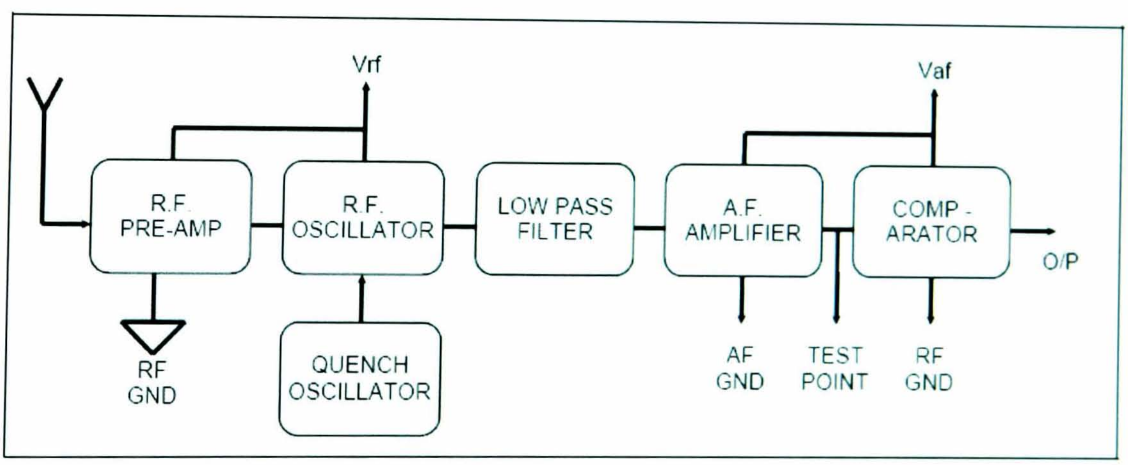
The R.F. Solutions range of AM 'Super Regen' Receiver modules are compact hybrid RF receivers, which can be used to capture undecoded data from any AM Transmitter, such as R.F. Solutions AM-RT4 / 5 range of transmitters. (See AM Transmitter datasheet DS013)

These modules show a very high frequency stability over a wide operating temperature even when subjected to mechanical vibrations or manual handling. A unique laser trimming process which has been patented gives a very accurate on board inductor, removing the need for any adjustable components.

All receivers are compatible, producing a CMOS/TTL output, and require connections to power and antenna only. The HRR6 is a version with Very Low Current consumption which has a typical quiescent current drain of only 0.5mA. In addition the HRR8 operates from a 3Vdc supply.

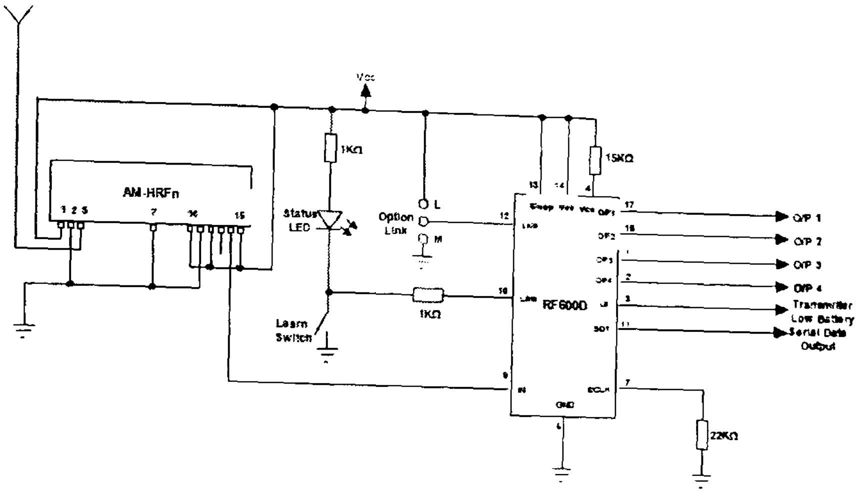
RF Solutions also offer a range of Super Heterodyne Receivers, for data on these products (please see Datasheet DS017).

Block Diagram



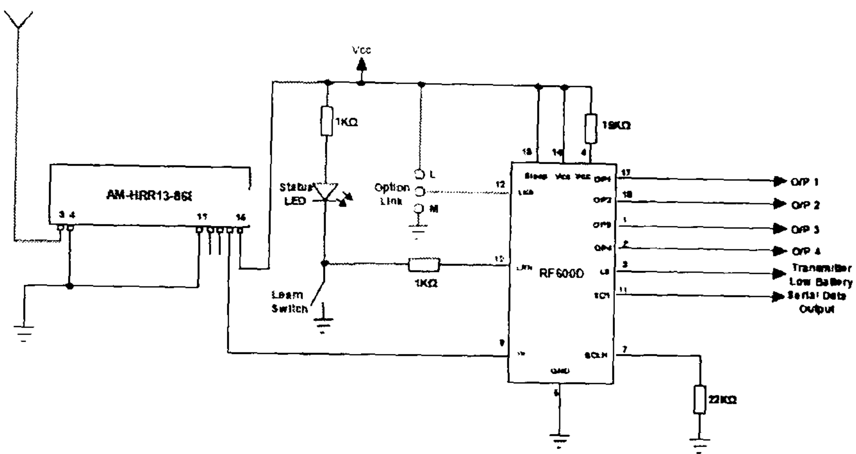
Application Circuits

Products From 250-450MHz



NOTE: For versions without PIN 10 all other connections are the same.

868MHz Products



For further information on this circuit please see datasheet DS600

Should you require further assistance, please call:
R. F. Solutions Ltd,
Unit 21, Cliffe Industrial Estate,
South Street, Lewes,
E Sussex, BN8 6JL. England.
Tel +44 (0)1273 898 000. Fax +44 (0)1273 480 661.
Web Site http://www.rfsolutions.co.uk Email sales@rfsolutions.co.uk
RF Solutions is a member of the Low Power Radio Association.