Virtual Environments for Stroke Rehabilitation: Examining a Novel Technology Against End-user, Clinical and Management Demands with Reference to UK Care Provision

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Abstract

In the field of post-stroke rehabilitation, there appears to be growing interest in the use of virtual reality (VR)-based systems as adjunct technologies to standard therapeutic practices. The limitations and the potentials of this technology are not, however, generally well understood. The present study thus seeks to determine the value of the technology with reference to end-user requirements by surveying and evaluating its application against a variety of parameters: user focus, clinical effectiveness, marketability and contextual meaningfulness, etc. A key theme in the research considers how a technology developed internationally might interface with care provision demands and cultures specific to the United Kingdom. The barriers to innovation entry in this context are thus examined. Further practical study has been conducted in the field with a small sample of post-stroke rehabilitation patients. The data garnered from these enquiries have informed a detailed system analysis, a strategy for innovation and a broad theoretical discussion as to the effectiveness of the technology in delivering VR environments by which the patient can undertake 'meaningful' therapeutic activities. The data reveal that there does appear to be clinical value in using this technology, yet establishing its maximal value necessitates greater integrity among clinicians and engineers, and the furthering of progressive channels for innovation by public health administrators.

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Chapter One – Introduction and Background

General introduction

This thesis is an exploration of the current and potential applications of virtual environments in the post-stroke rehabilitation, focussing in particular on the therapeutic treatment of the upper limb (a term used among clinicians to describe the functionality of a patient's shoulder, arm and hand). The research addresses the need for a systematic appraisal of a type of technology that is relatively new to rehabilitation and, to date, has neither achieved consistent and unified methods, nor demonstrated incommutable properties and intrinsic values.

The research responds to a client statement, which was drafted by a group of senior clinicians (presented in full below). The statement, in effect, demands a detailed review of the state of the art, as well as a thorough user study. Upon completing these exercises, I elected to focus on the simulation of the domestic environments of stroke patients, in particular the kitchen and preferred hobbies. This practical study prompted a more thorough enquiry as to the nature of commodities, socio-economic exchange and meaningfulness in relation to the clinical requirements of motivating and engaging the patient in the therapy process.

The research is also intended to examine the ways in which this unusual technology could be delivered to treatment centres. The user study thus revealed some of the possible problems of technology implementation and adoption, and an innovation strategy has been devised so that the value embedded in the technology can be readily demonstrated to clinicians, patients and administrators alike.

A key problem in delivering therapy programmes was found to be that of engaging the patient. One driver in achieving engagement has thus been posited as the provision of 'meaningfulness', which might suggest a tension between what is generally meaningful to all people and what is specifically meaningful to the individual. In attempting to devise a solution to this problem, evidence will be drawn from a variety of academic fields, including anthropology, psychology, philosophy, economics and architectural theory. Part Three of this chapter, below, provides the theoretical background to the concerns of VR in rehabilitation, including the ways in which a patient's perceptual experience might translate into the recovery of sensory-motor function after stroke: a challenging but ultimately fascinating area of enquiry.

The research projects that comprise this thesis have each been conducted with the cooperation of or in consultation with clinicians. As the research progressed, it emerged that there appears to be a general lack of understanding among engineers as to the needs of therapists. The review of literature and the user study are thus intended to provide documentation that is mutually usable among practitioners working in either virtual reality or stroke rehabilitation. For this reason, the language throughout the thesis is geared to the non-specialist. Where technical and clinical terms, or common abbreviations, are used brief definitions are given within the text.

Part One: Motivation and scope

The motivation for developing this research stemmed from a series of conversations with clinicians who expressed problems in performing their duties to me. Key among these problems were the limitations in providing suitable environments for patients to undertake their treatments and, in the first instance, virtual reality (VR) seemed to provide a means of overcoming this problem. An early review of the field revealed that many such research projects have been undertaken in the past years, each approaching the technology from differing points of view. At first sight the field appeared inconsistent in its methodology and outcome, thus providing a rich and worthy field for doctorate research.

In the first instance, I approached the field of VR in neurological rehabilitation using techniques developed from engineering design, in which the problem is disassembled, analysed, reverse engineered, prototyped, and so on – this process is presented in Chapter Two, Problem Analysis In commencing this engineering design a client statement was initially devised that profiled concisely the challenges, opportunities and requirements of the proposed research[1]. The statement is given in full below.

> In the physical rehabilitation of the stroke survivor, Carr and Shepherd have shown that a varied and rich rehabilitative environment can benefit the recovery process[2]. Based upon our unsubstantiated observations, we believe that virtual reality (VR) might provide the means to establish such variable and stimulating environments, while allowing the patient to engage in therapeutic activities that are meaningful and perhaps motivating.

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[1] At the time the statement was composed (summer 2003), the 'client' was an informally organised group of senior clinicians based at various treatment centres in the UK. This organisation subsequently diffused into more specialised units (focussing on areas such as task-based upper limb rehabilitation, sports physiotherapy and action observation).

[2] See Carr and Shepherd, 2003, for an overview of this issue

> The task at hand therefore is to identify an appropriate means to develop such a virtual rehabilitative environment, bring it to operation and test it for clinical appropriateness and effectiveness. This should involve a thorough review of literature pertaining to related research, including an evaluation of existing uses of VR in rehabilitation; the weighted analysis of system requirements; finally, the qualified development of a system suited to the requirements of the recovery process.
>
> We also believe that a virtual rehabilitative environment could serve as a generic tool for use in a number of clinical fields, including physiotherapy and occupational therapy. The system might therefore be designed non-specifically for the allowance of appropriation to the various needs of clinicians in these areas, while also affording possible adaptations for specialised interventions. The designer should therefore understand the general requirements of therapy in the major areas of stroke rehabilitation as well as possible channels of distribution.
>
> The outcome is expected to be presented an operational system - whether tangible or otherwise - that has been developed and tested, preferably in consultation with clinicians and recovering stroke survivors. While some or all results of testing might be negative, the designer ought to analyse any problems with the system as well as offer useful advice for future research.

My analytical response to the client statement is outlined fully in Chapter Two, Problem Analysis. Some of the content of this introduction does however comprise a response to the statement in that the information presented results from an essay in understanding the *general requirements of therapy* as demanded by the client. This is outlined below.

The scope of the research encompasses a critical review of all published research pertaining to the use of VR in stroke rehabilitation generally. Yet the system I have designed is intended solely for the purpose of rehabilitating the upper limb of the stroke patient. However, given the pivotal role of the arm and hand in the overall function of the body in its physical and existential performance, this apparently narrow field represents a considerable challenge to the designer. What appears a limited concern is, in fact, highly complex and embeds what might be called the ‘problem of infinity’. One of the key challenges has thus been devising and implemented a system that is at once usable to all patients while remaining specifically valuable to the individual. This problem is explored in depth in Part Three, below.

Part Two: Concepts and themes

This section will outline in brief areas of concern that are pertinent to the present study. This is intended to be neither comprehensive nor authoritative and much of the material has thus been gleaned from standard texts in the field. Some definitions of therapy practices would not be accepted by all practitioners but do serve as general codes for approaching the design problems of the present study (a more 'grassroots' picture of clinical practice is provided in the user study of Chapter Four).

Stroke and stroke rehabilitation

A brief introduction to stroke

The definition of stroke varies, but it is commonly said to be caused by a disturbance in the blood supply to the brain. For this reason, stroke is often referred to as cerebrovascular Accident (CVA); the term acquired brain injury (ABI)[3] might also refer to stroke, among other diseases. The disturbance in blood supply can be caused by any combination of ischaemia (a reduction in blood supply), infarction (the death of tissue resulting from impaired blood circulation) and haemorrhage (the escape of blood from a ruptured blood vessel). Thus the ischaemia or haemorrhage is caused by either thrombosis (coagulation of the blood), or embolism (blockage in the blood vessel).

Symptoms usually last for more than twenty-four hours, with some effects remaining for many months or years. The effect of the symptoms has been said to 'strike' the patient with paralysis or impairment to some part of body. An acute stroke patient requires immediate medical or rehabilitative intervention, whereas a chronic stroke patient requires post-acute treatment over a greater period of time.

A major stroke can have a catastrophic effect on sensory, motor and cognitive functions in the survivor. The brain is arranged in such a way that local areas have special functions. Damage to any one of these areas might in this way affect a special function of the body. For example, damage either to the visual cortex, or to the pathways that pass information from the eyes to the cortex, would lead to impairment of vision. Given also that the brain is arranged into two distinct lobes (or hemispheres), so damage to one side of the brain can often result in paralysis to just one side of the body (called hemiplegia)[4].

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[3] Not to be confused with Traumatic Brain Injury (TBI), usually resulting from external injury

[4] A full introduction to the causes, symptoms and treatment of stroke can be found in Brandstater and Basmajian, 1987

Symptoms lasting for less than 24 hours are caused by what is called a transitory ischaemic attack (TIA), with most lasting for just a few minutes. Symptoms of TIA often include temporary loss of sight, speech or sensory-motor control. Up to 50% of people who have experienced a TIA are likely to suffer a complete stroke within five years.

There are many causes of stroke, and some remain unclear, but atherosclerosis (thickening of the arteries caused by fat deposition) and hypertension (abnormally high blood pressure) among the middle-aged have been linked strongly to stroke in later life. Stroke is the third greatest cause of death in the UK; the greatest cause of disability (around 5% of health provision spending is attributable to stroke Warlow et al, 2001). Most victims are over the age of 65, with men and women being at equal risk and factors of affluence and lifestyle impacting on the likelihood of stroke (an issue further discussed on Chapters Four and Seven). Of the survivors around 50% regain functional independence, 25% are able to walk with some help and 25% remain severely disabled.

A brief introduction to stroke rehabilitation

Stroke rehabilitation is a broad field, usually involving a team of clinicians each with specialist skills. As the present study deals specifically with the rehabilitation of the upper limb in the chronic patient, so this introductory overview will only supply information relevant to this field.

The human nervous system consists of around 100 billion cells called neurons. These receive and transmit information around the nervous system. Reaching out of neurons are branch-like dendrites, along which information is transmitted, and where they connect to the dendrites of other neurons this region is called a synapse. The basis for the possibility of rehabilitation is the capacity of the nervous system to build and adapt by establishing new synaptic connections. This capacity is called neuroplasticity and it can allow for the recovery of sensory-motor and cognitive function, even after a severe stroke.

However, the process by which neuroplasticy leads to successful functional recovery must be directed and this requires the intervention of therapists, each working as part of a cohesive team. The team members relevant to the present study include physiotherapists, who aim to restore the patient's motor function and coordination, and occupational therapists, who aim to restore the patient's ability to perform the activities of daily life (ADLs), which might include washing or making a drink. Since the Second World War (partially resulting from the experiences of treating veterans), a number of treatment models have been established which are commonly applied today. These include the widely used Normal Movement Approach and Movement Science.

In brief, the Normal Movement Approach consists of training the patient to achieve smooth, efficient and coordinated motor control in order to achieve the correct actions necessary to perform a task, such as an ADL. Movement Science differs to this, in that it focuses on the functional movement of the affected limb and the avoidance of compensatory behaviour (as outlined below). A task therefore, which might include an ADL, is regarded analytically as a set of motor functions to be restored.

The approaches also seem to differ in their respective regard/disregard for 'normal' movement but some authorities have suggested that these two approaches can complement each other, (Edmans et al, 2001). Both approaches were acknowledged in the development of the present research and informed the therapeutic framework for the interaction models, presented in Chapter Five. A brief outline of their practical applications to the rehabilitation of the upper limb is also given below.

Function and rehabilitation of the upper limb

The present study is based upon research conducted into the rehabilitation of the upper limb, which normally provides the means to perform ordinary tasks. In manipulating objects in the environment, the upper limb must usually coordinate with information received through the eye. Impairment in this process can pose a serious problem to the subject and a challenge to patient and therapist alike. For the purposes of this introduction, a brief overview of the upper limb, sensory feedback and clinical treatment are provided below. Further details of the clinical practices with which the proposed VR system would interface are outlined in the user study of Chapter Four.

The function of the upper limb

In brief, the mechanical structure of the upper limb comprises levers, which take the form of bones, joints about which levers move and muscles that control lever movement. This structure allows movement to take place from a stable support, hence the hand might move freely to grasp a cup (a process called an *open chain*), while it will require support for handwriting (a *closed chain*). In this way, any part of the upper limb might play a closed chain role in support of open chain movement. The shoulder, for example, often plays a supporting role to the rest of the arm when, for example, washing up or the elbow might provide support while reading a book.

The hand provides a localised and flexible foundation for lever control and the ability to apply force from the arm muscles to form a grip. There are three common types of grip: power grip (holding a hammer, for example), dynamic grip (holding a pen) and pinch grip (holding a needle). The hand also provides a means of communication, in pointing to or describing the shape of something, in greeting, in caressing or in expressing anger. Hence, some authorities describe the significance of the hand in achieving fulfilment of each of Maslow's classic hierarchy of human needs (Maslow, 1954), including self-esteem and self-actualisation (Hinde, 2001).

These 'higher' human needs might be allied closer to the requirement for meaningfulness in task performance, as distinct from purposefulness (a theme outlined in Part Three, below). Hence, in rehabilitating the upper limb after stroke, the meaningfulness of objects, exercises and goals has been shown to affect patients' functional performance (see, for example, Wu et al, 2001; Jeannerod et al, 1994; Castiello, 2005).

The rehabilitation of the upper limb

We have already noted very generally some practices of stroke rehabilitation. The upper limb, however, has specific treatment requirements, which will now be outlined. It is also worth observing that rehabilitation differs from medicine (based, that is, on pharmaceutical and surgical intervention) in that it tends to be more individuated and considerate of a patient's subjective proclivities. Hence the upper limb, as a key component of task performance, appears to attract especially high levels of concern among task-orientated therapeutic clinicians.

After paralysis, the upper limb is prone to spasticity, in which the muscles become involuntarily and deleteriously flexed. Loss of sensory feedback can also lead to further damage. The overall loss of function can cause the limb that is unaffected by the stroke to over-compensate in performing tasks, further compounding the recovery process of the affected limb and leading to what is clinically termed 'neglect' and 'learned non-use'. Neglect might also affect perception-action function. Hence, when asked to draw a clock face, a patient might only draw one half of the clock yet consider it to be a complete drawing (Springer and Deutsch, 1989).

The process by which the sensory-motor and task-orientated function can be restored to the upper limb is not well understood and unfortunately prone to failure; according to some reports only 5% of patients gain normal function after complete paralysis (Gowland, 1987). It is also not uncommon for patients to become unmotivated during treatment, thus posing a further challenge to therapists. These problems have compelled a focussed response in the clinical field, and the common treatments will be briefly described.

Occupational therapy, physiotherapy and the upper limb

The occupational therapist (OT) is tasked with planning and implementing a scheme of treatment designed to restore performance function to the upper limb through meaningful and purposeful activities. The physiotherapist is tasked with the restoration of normal, non-compensatory mechanical movements, based principally on the subject's motor abilities. The focus in physiotherapy (and also to a lesser degree in OT) is thus on the analytically deduced correction of posture and balance resulting in part from restored innervation and sensory feedback/feedforward.

Common to both occupational and physiotherapy include three widely used clinical approaches: Carr and Shepherd's motor optimisation approach, based upon motor learning; the Bobath Approach, which prepares the sensory-motor components necessary for task performance and normal movement; Brunnstrom Movement Therapy, in which reflex responses are used to aid recovery after paralysis. The distinctions however between the approaches are not necessarily clear and prone to semantic confusion (Partridge, 1996). The manner in which they are often applied in practice is outlined in the user study of Chapter Four, *Setting the Scene: Remits of therapy.*

There are practical differences between the fields. Although, the occupational therapist might aim to re-educate sensory facilities, this is not well understood within the profession (Woodson, 2002). The OT is therefore more likely to focus on skill relearning, basing practice exercises upon the patient's own routines. She or he might also lead the patient with educative prompts, or the patient would be encouraged to describe what they are doing as they perform a task. The OT is also responsible for the facilitation of prostheses that might aid task performance. Commonly this involves the use of mechanical hands and arms, as well as implementing handrails and other adaptive devices.

The physiotherapist conversely would treat the upper limb in terms of the biomechanical and sensory properties that underlie the prehensile *transport component* (reaching) and *grasp component*. The physiotherapist will both directly orientate and manipulate the patient's limb and lead the patient in self-initiated exercises. Physiotherapists will also apply artificial devices that, in this context, serve as orthoses. (The various areas of therapy are further outlined in greater detail as part of the user study presented in Chapter Four.

The heterogeneity of the stroke survivor population and the possibility for spontaneous recovery each create difficulties in measuring outcome of therapy interventions. One major study does however suggest that patients do benefit from early intervention, although improvement in impairment does not tend to translate to improvement in ADL performance (Wagenaar and Meijer, 1991a, b). The time spent with therapists, as well as the quality of patient interaction, has also been linked to therapy outcomes (Tinson, 1989). Similarly, the intensity of treatment has been linked to greater ADL performance, although the real gains in this metric were shown to be in neuromuscular function (Kwakkel et al, 1997).

Participating in a virtual environment

Virtual reality (VR) is a sensory feedback system in which the content has geometry and dynamics (Ellis, 1991). A virtual environment (VE) is thus composed of 'objects', which can be seen, heard or even touched, or non-sensory events such as a collision between elements. In this way, the content's geometry comprises the dimensions and boundaries of the environment, while the dynamics are the ways in which the objects in the environment interact. The content thus allows the simulation of a three-dimensional space, while specialised input/output hardware (such as a touch sensitive dataglove or head-mounted display [HMD]) can provide the means of interaction. Interaction can also be achieved through motion tracking and video-capture, which bring the benefit to some applications of VR of non-contact interfaces.

Virtual environments can be used for many purposes including, for example, professional training through simulations (as in the case of flight simulators or of virtual organs for surgical training). VEs have also been used as aids to medical or therapeutic interventions, such as in overcoming pain or phobias[5].

Participating in an environment: a basic framework

There is a dynamic and integral relationship between the brain, sensory-motor response and the fulfilment of human needs, which has been alluded to in previous sections. This section will outline in brief some issues relating to participation in environments (whether real and virtual) with reference to object recognition and sensory feedback in prehension. The intention is to provide a basic framework to the current study as to how a virtual environment might encourage movement and task performance that is meaningful to the patient and thus support the rehabilitative process.

[5] A general discussion of these areas is beyond the scope of the present study. The interested reader is directed to http://www.hitl.washington.edu/projects/ or
http://www.cs.ucl.ac.uk/research/vr/Projects/SocialPhobias/research.htm
for examples of these [last accessed December 2007]

Vision: abstraction and 'ecology'

In the examination of human perception two broad schools dominated enquiry for the better part of the last century: *gestalt* and ecological psychology. In brief, the former supposed that the human brain has the capacity to recognise and respond to given forms 'as they are' in the external world. The latter also focused on the informational 'constants' available in the world, but supposed that the mind is a dynamical part of a causal chain (comprising: retina → cortex → perception) by which a sense of the world is derived[6]. This ecological model suggests something of the more dynamic view of the human mind currently adopted by scientists, although a persistent gap in our knowledge appears to remain. This gap will form much of the discussion outlined in Part Three, below.

As with the 'real' world, so examining participation in a virtual environment seems to incur many of the same problems of perception and interaction. The problems may well be highly comparable: one authority has gone so far as to state that "Virtual reality works because reality is virtual" (Stark, 1995). This can be regarded as meaning that the human mind is adapted through evolutionary means to meet the demands of any habitable environment (whether 'real' or 'synthetic') by way of its capacity for selectivity, abstraction and codification of external stimuli, which will be outlined below. However, one study has suggested that the neural correlates for observing actions in virtual and real environments are different, which might affect the use of VEs for neurology-orientated interventions (Perani et al, 2001).

Where the content of a virtual environment is created from simple geometric shapes the visual brain serves as a modular and dynamic *part of* the world in that it actively assembles information derived from light, space, movement and memory to create multi-dimensional 'sight'. This capacity for abstraction is more commonly shown in our responsiveness to a film, where the abstracted dramatic devices of the presentation serve to engage us emotionally with the overall narrative[7]. So, too, when using a virtual environment, the brain is able to process information hierarchically so as to construct a 'complete' and dynamic image of the world[8].

As with cinema and the 'real' environment, so the 'icons' of a virtual environment might be regarded as being indicative of a general property of the environment. Hence the abstracted edges of an object lead our perceptual faculties in identifying its other properties (Marr and Hildreth, 1980; Marr, 1982). This hierarchical approach has been regarded as the 'best

[6] See Hamlyn (1956) for an overview of these themes
[7] Zeki (1993) provides a persuasive case in favour of this argument
[8] Bruce et al (2003) provides an excellent overview of this issue

guess' (Palmer, 1999) we have to understanding how the visual brain receives, processes and acts upon images.

It might be argued that this view is contrary to the 'ecological' approach, whereby the environment is regarding as being imbued with all the information we require to perceive it. Here, the environment is described as 'affording' perception: a hammer, for example, 'affords' striking a nail or water 'affords' quenching thirst[9]. Far from contrary, however, the ecology of a virtual environment, being the textures and other surface details of objects, seems to play an integral part in affording a user's participation (as demonstrated throughout many of the studies reviewed in Chapter Three).

Prehension: the problem of degrees of freedom

The upper limb is a biomechanical object that has around seven degrees of freedom (DoF) (excluding the digits). As these descriptors provide theoretically infinite variety in reaching and grasping, this apparent boundlessness of prehension poses the 'degrees of freedom problem': where movements are normally task-dependent they must be executed selectively. Hence, some researchers have hypothesised that before movement to a target begins, a 'goal posture' is established, by which muscle lengths and joint angles are implied, memories of similar actions are drawn upon and a *cost analysis* is carried out (Rosenbaum et al, 1996), as well as an identification of the size and/or velocity of the object (Jeannerod and Marteniuk, 1992). This process, typically lasts less than 800ms.

Sensory feedback and motor control

In order to achieve appropriate function in the upper limb, sensory feedback and integration must be fully developed. Hence, nerves in the upper limb (in bone, joint, muscle, tendon and skin), must each detect movement, shape and dimension in the environment. This information must also be integrated with sensory feedback from the ears and eyes, as well as from proprioceptive feedback. Only when each of these factors in integrated can the brain command an action, a capacity described as *executive function*.

It could be supposed that reaching for a virtual object is behaviourally tantamount to reaching for a physical object, Viau et al (2004) sought to demonstrate. Yet this continuity does not appear to translate to the neural level: some research suggests that different sensory 'ecologies' impel different types of neural response. One study, for example, compared the timings of responses in subjects while hitting a ball with a bat to timings of the same action performed by closing a switch to release a mechanical bat to hit the ball (Bootsma, 1989). The fact that the

[9] An overview of this approach is given in Gibson (1979)

timings were less variable in the initial exercise appears to lend weight to the ecological view in that the nervous system detects properties inherent in the environment before a response is made.

Research presented in Castiello (2005) thus showed how the neural activity in the respective areas of the primate motor cortex is directly dependent on the visual stimulus received by the brain. Other research presented in Handy et al, 2003, similarly suggests that where an object represents a use to the viewer (the researchers tested subjects' reaching for a household tool), so this causes a greater range of cortical areas to be aroused, apparently in preparation for the associated activity. These fields of study suggest that the human nervous system sustains a dynamic and looped response to its environment by encoding in specialised areas of the brain the ecological content with which it is presented. Thus what is *seen* affects what is *done* by way of the brain's distributed cortical responses. The underlying neurology of this has only recently been discovered and is outlined in Part Three, below.

Reaching towards an object in a real or a virtual environment is normally a combination of open- and closed-loop activity. In the planning and execution of prehension, vision is a major factor in establishing the 'forward model' prediction and, subsequently, adjustments of the movement as the visual brain provides a 'self-cuing' facility prior to movement (Milner and Goodale, 1995). Put simply, the forward model is an open-loop action that gathers information from the world; subsequently becoming a closed-loop action as it employs afferent sensory feedback while honing in on the object to perform the highly refined grasp function (Desmurget and Grafton, 2000). Reach and grasp might thus be impaired through damage to the motor or visual cortex; the variability in which healthy and impaired subjects reach and grasp in a virtual environment was the focus of a study reported by Viau et al (2004), outlined in the literature review of Chapter Three.

Gesture in a virtual environment

The 'iconic' nature of sensory perception (described above) might also relate to the means by which we organise our gestures in the world in response to ever-shifting stimuli (Llinás, 2001). Thus recent research has pointed to the possible neural connection between language and the control of movement (Pulvermüller, 2005). Researchers in the field of anthropology have demonstrated a link between tool manufacture and predictive hunting by early hominids and the evolution of language whereby the capacity for gesture-orientated abstraction in creating a tool, locating prey or devising a sentence is brought about by common adaptations in the human brain (Hewes, 1973; Kitahara-Frisch, 1980; Gibson, 1993; Mithen, 1996].

Some authors have argued that language might be regarded as originating in gesture for social interaction, rather than in speech (Wilson, 1998), while others have argued that speech evolved to complement – and later to supplant – the gestures of grooming as the primary means of social interaction (Aielo and Dunbar, 1993). Yet, however important the transmission of information may have been in the evolution of our species, it appears that language as a whole does not have a logical syntactical structure which might reflect such routine activities (Crystal, 1985). That language is not logical might also reflect in the infinite possible variety of our actions (the so-called 'problem of degrees of freedom'). Hence, sensory-motor responses are, like sentences, engendered by arbitrary stimuli that are abstracted or, rather, iconic.

Peirce initially proposed that representations (signs) comprise a nested hierarchy of icon, index and symbol (Buchler, 1955). Here, the iconic content provides basic information about the object, the indexical content points to (indicates) something beyond the object and the symbolic represents the complex social transactions of which the object is part. Although Peirce was concerned with the philosophy of mind, the hierarchy appears to have been appropriated to many fields: Terence Deacon, for example, has applied it to the neurology of language generation (Deacon, 1997); Susan Goldin-Meadow (1993) has identified human gesture as a code-like hierarchy similarly comprising pointing, characterization and predicative structure; it might also be maintained that this representational hierarchy is not dissimilar to the hierarchy of visual perception. Csikszentmihalyi and Rochberg-Halton have also applied Peirce's hierarchy in examining what they describe as the 'cultivation of the self', outlined below, (Csikszentmihalyi and Rochberg-Halton, 1981). Such commonly observed hierarchies might thus serve to support the view that these capacities result from common neuropsychological patterns and could possibly provide a way of overcoming the problems of infinity in designing a unified system.

Skill acquisition, environmental content and transfer

Having identified the themes and concepts of the present study, the means by which a skill might be relearned in a virtual environment will now be outlined. The intention here is to offer a framework that builds upon the material presented above and show how clinical training concerns pertaining to environment content and ecological validity might be pertinent to existing research into the application of VR in rehabilitation. The following section serves as an introduction to the theoretical themes outlined in the section below, *Task Execution: a Framework*.

Skill acquisition

Skills are based upon a coordinated set of motor controls, which are either reflexive, for example blinking, or learned, such as drinking from a cup. This set of controls is called a *motor programme*, or an *engram*. We noted above that the process by which the nervous system successfully readapts after damage must be directed in order for an engram to be newly established.

The engram as a dynamic process can be broken down into stages (each taking around 180ms to achieve [Phillips, 2001]). Firstly, the nature of the initial stimulus is identified out of the vastly rich human environment – whether it is a smell, sound, visual stimulus, and so on. This is followed by the selection of a movement that might constitute an appropriate response, again based upon prior experience. Finally, the relative correctness of the response is evaluated and 'programmed'. When responding to a novel experience, these stages might also involve internal feedback, which may in turn inform subsequent responses. Such reflective feedback, whether instituted by the trainee or by an instructor, or potentially through a virtual environment (VE), has been called *knowledge of performance* (or *knowledge of results)*, the variant qualities of which have been shown to have a relative effect on skill retention over time (Schedel and Hagman, 1991).

In describing the human motor engram, a number of theoretical models have been established. Thus the influential Schema Theory (Schmidt, 1975) regards the motor relearning process in the context of long-term memory, where responses to sensory information are influenced by the subject's previous experiences, although the role of visual memory in this process (which is pertinent to the current study) has been deprecated in one extensive study (Proteau, 1992).

If the motor process that results from such neural 'rebuilding' is to be regarded as a skill, it must be shown clinically to be accurate, consistent and efficient (Higgins, 1991). Achieving such a degree of motor control can be problematic and is often dependent on a range of factors affecting the patient, whether physiological, psychological or environmental.

In training, skills are often regarded as belonging to one of two sets: closed or open (Adams, 1971). Hence, closed skills are those in which the motor control is achieved in an unchanging, stable environment, such as an athlete might experience when running on a treadmill in a gymnasium (also called closed-loop training). Open skills on the other hand involve motor control that, although achieved through closed-loop training, must be performed in an unstable environment, such as an athlete competing in adverse weather conditions and amidst a range of sensory distractions (crowd noises, other athletes, and so on).

The process by which skills are acquired can also be broken down into three stages (Bressan and Woollcott, 1982). Firstly the skill is constructed by repetitious practice, based upon prior experience and/or transferred over from other skills. Secondly, the skill is stabilised through knowledge of performance feedback into the motor engram. Thirdly, the new skill is differentiated from other motor tasks to eventually be performed sub-consciously. A further aspect of skill acquisition has been described as the capacity to invent and progress with autonomy (Whiting, 1980).

As an example, we might imagine a professional violinist who, during closed-loop training, would probably have repeated exercises and pieces for around 4500 hours (playing around 2.5 million notes in that time), (Kottke et al, 1978), and perhaps also drawing on the experience of having previously learned another instrument. After careful and considered practice, and probably with some instruction, the correct techniques have been established, as have the musician's 'ear for music' and the ability to play pieces 'by heart'. Finally, pieces are performed dexterously and fluently before an audience – an open skill – and the motor control is achieved without undue forethought. This automatic fluency means that more time can be dedicated to further gaining or refining skills.

Environmental content

The environmental content of the VE is of major concern to skill acquisition and neuropsychological rehabilitation generally, thus Rizzo and Buckwalter (1997) and Rizzo et al (2004) distinguish this concern as being an issue of particular pertinence to the clinical application of VR. To quote verbatim an excerpt from Rizzo et al (2004):

> *Rather than try to predict functional implications from a decontextualised measure of attention, for example, one can look at the effects of systematically increasing relevant attentional demands in a virtual environment (VE), such as a classroom, office, or store. VR technology allows for exquisite timing and control over distractions, stimulus load and complexity, and can alter these variables in a dynamic way contingent on the response characteristics of the client.*

This argument, substantiated by their overview of literature from the neuropsychology field, turns the focus of research away from concerns regarding system usage, such as those outlined in many similar papers – input, task sequence, cognitive loading, and so on (see the literature review of Chapter Three) – and toward the content of the VE itself. It points to the possibility that it is the controllable variability of a VE's 'ecology' – in complexity, loading and stimulus, for example – that allows it to be usable in rehabilitation. Indeed, the authors cite Neisser's highly pertinent assertion that neuropsychological assessment is often lacking in ecological variability (cited in Rizzo et al, 2004).

Rizzo et al (2004) also suggest that the ecological validity of a VE might not necessarily be to do with the 'realism' of the simulations and more to do with the patient's psychological sense of 'being there'. In this way, the clinical ecological validity might stem from what VR engineers call 'presence' – they cite Pugnetti et al (1995) as an example of a clinically valid VE ecology, created with primitive graphics, which resulted in high presence. This view is also held by Riva (2000) which the excerpt below alludes to:

> *Emphasis shifts away from quality of image to freedom of movement, from the graphic perfection of the system to the actions of the actors in the environment… the criterion of the validity of presence does not consist of simply reproducing the conditions of physical presence but in constructing environments in which actors may function in an ecologically valid way.*

There seems to be agreement therefore that presence in its various forms in a VE might be achieved through allowing appropriate action in the subject, and not necessarily from 'realistic' visual detail[10]. It has already been observed that vision is a hierarchical process and the visual field might therefore be presented in an iconic manner. Yet the role of visual imagery need not be denigrated entirely as Page et al (2001) demonstrated in successfully linking the use of patient visualisation to fuller recovery after stroke (this issue is discussed further in Part Three, below). Furthermore, recent data from the neuroscientific field has pointed to the requirement of rich visual stimulus for fuller recovery after stroke (Nithianantharajah and Hannan, 2006). As the present study relates to the rehabilitative reacquisition of motor skill, then such concerns from VE design might well be relevant to both the maintenance of ecological validity while engaging in therapeutic practices and the transference of skill from the treatment centre to the 'real world'.

Transfer

Once a skill has been acquired it may then be used in a variety of contexts. Although problems might arise in transferring new skills out of the training environment, the general tendency is

[10] A full account of this issue is beyond the scope of the present study. The interested reader is directed to Coehla et al, 2006, and Been-Lirn Duh, 2002, for comprehensive introductions to the various forms of presence and how they might be achieved

for people to transfer them to new tasks successfully (Holding, 1991). In assuring the successful transfer of skills after rehabilitation, however, Carr and Shepherd outline the requirement for training to be varied and the treatment environment to be flexible:

> *When practice is varied by changing aspects of the environmental context, the motor skill that develops is flexible and generative, facilitating a kind of motor problem-solving ability* (Carr and Shepherd, 2003).

In this way, a training environment designed for neurological rehabilitation could include the means to adapt to a range of contexts. This clinical concern can thus be addressed through the design of virtual environments for rehabilitation in their very capacity to simulate different types of environments. Furthermore, the requirement for presence, given the observations cited above, might now be correlated with the requirement for clinical ecological validity.

The effect of validity upon the transfer of skill has indeed been observed widely by Schank (1999). Rose et al (1998, 2000) also report on two experiments into the effect of validity on transfer in healthy subjects[11]. Their research was carried out in accordance with well-established parameters for testing transfer as outlined in (Carr and Shepherd, 1987). They found that the populations allowed to practice in the virtual environment were more successful in performing the task in the real environment than those who had not trained. The cognitive cost of training was also found to be no greater in the virtual environment than the real.

In spite of these experiments, however, the effect of VR upon transfer in rehabilitation appears not to be well understood (this theme is examined in greater detail in Chapter Five with reference to the value of gameplay in a VR system). On balance, therefore, we might hypothesise that the use of VEs in rehabilitation could help supply the validity missing in many treatment centres but that the *effectiveness* of VR must in this respect be evaluated. This is a core concern of the present study and will be discussed in the next section.

Part Three: Theoretical Background

General Introduction

Prior to commencing on a detailed literature review presented in Chapter Three, a more general survey of the literature has included broad-based monographs such as Rizzo and Buckwalter (1995, 1997) (which comprise two volumes of the now extensive Medicine Meets Virtual

[11] One of the authors of this paper, F.D. Rose, was also involved with the VR in stroke rehabilitation research outlined in Brooks et al, 1999.

Reality series). This review has revealed that little of literature appears to examine the intrinsic and incommutable value of virtual reality as an adjunct to therapy. In examining these themes, I aim to provide a practicable theoretical background to the rehabilitative use of VR, which draws upon themes from the philosophy of mind, anthropology of technology and the neuroscientific literature.

Here is it necessary to differentiate the intrinsic, incommutable and the extrinsic, commutable values of the technology. By 'intrinsic', I mean the benefit that the simulated sensory content itself returns to the patient within the period of system usage. This demands a different means of analysis to that of 'extrinsic value' which might include *epiphenomenal* outcomes (such as overcoming remoteness, establishing an effective user interface or promoting motor function); such extrinsic outcomes might themselves be engendered commutably through systems other than VR. For example, a simulation of a street scene might well help in reduced-risk road-crossing training by overcoming neglect or dysexecutive syndrome, as Naveh et al (2000), Katz et al (2004) and Lam et al (2004) have sought to demonstrate; yet none of these research projects set out to measure the benefits of the basic 3D models and simulated sensory feedback from which the virtual worlds are composed.

The intrinsic values of VR might thus pertain to the benefits afforded by the system to maintaining the patient's attention in performing a therapeutic task or of engaging the patient in the care process generally. A further intrinsic value might also be found in presenting the patient with a variable level of richness of environment content that optimises motor and sensory recovery. More speculatively, such intrinsic properties might also help differentiate the parameters of treatment while allowing the therapist to focus on those areas of clinical concern that the VR system can best reveal. In this instance, the VR system could not be substituted by any other technology and might thus maintain incommutable value.

The user study revealed that therapists might be willing to test equipment but that poor understanding of novel apparatus often leads to its abandonment (a factor affecting the parameter of marketability). The challenge to the designer therefore is to convince the therapist not only of extrinsic values (in relieving caseload, in improving recovery and so on) but also the intrinsic values (in promoting client engagement, in controlling cognitive loading and so on). It might thus be argued that many of the extrinsic values are not exclusive to VR. A good management system might help relieve caseload or better therapeutic practices (including more therapy time) might improve recovery outcomes. In this sense, it is the intrinsic values that might successfully convince the therapist of the technology's benefit in delivering a means to address common problems in the care process, such as patient engagement and meaningfulness of tasks.

The ultimate purpose of this chapter is to substantiate this model through identifying the *highly problematic* means by which the patient can interact with a virtual reality system in such as way as to ameliorate clinical outcomes. A key problem in designing such a system is the theoretical *infinity* of movement patterns, attention, meaningfulness, motivation and changing clinical needs that are evident within the patient population as a whole. In addressing this problem I have devised a model of interaction, a reduced zone of behavioural patterns, which might serve to identify the individual needs and intentions of any given patient at any given time as well as the dynamic clinical goals that must be achieved; this is outlined in Part Two, below.

In demonstrating the intrinsic value of VR, evidence from a range of fields will thus be presented. A model will be established, based initially on methodological frameworks from anthropology, psychology and phenomenology and substantiated with concrete evidence from studies of domestic environments, clinical practice and skills training. The model is intended to demonstrate how a skill relearning process such as that which comprises neurological rehabilitation might be supported through the selectively constructed simulated content (the 'ecology') of an immersive virtual environment. The areas under discussion are thus intended to provide design parameters for an intrinsically and incommutably optimal virtual reality system for active use in clinical practice.

Selfhood, material culture and functional tasks

Commodity and Selfhood: a Theoretical Framework

The specificity of the commodity

In undertaking occupational therapy, the patient is required to engage in activities which are meaningful, where meaning commonly relates to objects from domestic or work spheres. Yet while the therapist may easily supply a sink, table or any other everyday item for use by the patient, these mundane objects may have limited meaning to the patient. However, in providing the means to simulate objects, it is expected that a far broader range of objects might be supplied, each of which might have heightened meaning to the respective patient.

Where an object has been selected as being especially meaningful, and hence useful to the therapeutic process, a value has been ascribed to it and the object becomes a commodity. ‘Commodity’ in all human societies has thus maintained a dual meaning, as Sahlins has observed, in that it has both a ‘use value’ (to which an equivalent financial or barter value can be ascribed) and an ‘exchange value’ which only can only be described according to the social relations of which it is part (Sahlins, 1972). In this latter case, commodities can thus be regarded in terms of their ‘expressive and symbolic function’ (Miller, 1987) a theme further outlined below.

Hegel observed that objects can exist in the world without becoming part of a subjective exchange. Here they are described as being ‘alienable’ in the sense that they are regarded as being separate from the human subject and thus have no specific meaning. At the point where the good becomes part of a transaction, it becomes ‘inalienable’ in that a specific and fixed meaning is ascribed to it by the subject. Moreover, for Hegel the object is not simply a material product but can also be a ‘self-conscious’ human being: in recognising ourselves as having discreet qualities (whether they are needs or intentions and so forth), we ourselves become inalienable objects – objects with specific, subjective meanings. Hegel’s dynamic ‘objectification’ is thus perhaps contrary to the ‘dualism’, the separation of mind and body, which had thitherto dominated models of ‘being’ (see Singer, 2001).

This dynamism was further described by the economic theorist George Simmel in that, in order to transform an alienable good into an inalienable commodity, a value must be given up in exchange (Simmel, 1978/2004). Simmel’s view is perhaps contrary to the view that the commodity is a good designed intractably for the generation of profit (Appandurai, 1986) instead it surmises that commodities can never have intrinsic values, but only extrinsic and variable values that are set subjectively through the exchange itself. Thus, where a patient is provided with an object that is ostensibly ‘meaningful’, the actual value of that object in terms of its meaning must be ascribed through the process of ‘exchange’ that is the therapy. The object in question becomes a commodity when one value associated with it (for example, “tool *a* is useful for work”) is given up for another (“tool *a’* is now useful for recovering my arm function”). Meaning would thus be more accurately determined if the patient were to select his or her own object and thereby find value through this dynamic process of objectification and commodification.

As with the problem of the degrees of freedom, outlined above, the apparently infinitely variable and subject-specific value of the commodity poses a problem in designing a unified system intended for multiple usage. The commodity as an object used within a therapeutic process is not described linguistically in the context of the therapy ("this tool is useful") but functions only as the focus of a set of intended actions ("using this tool helps me"). As the value of a commodity is only expressed through a set of exchanges, so its meaning is only expressed in a set of actions. The symbolism of the commodity might thus appear to be devoid of rationality. Sperber expressed this supposition thus: *the symbolic is the mental minus the rational; it is the semiotic minus language* (Sperber, 1975). Douglas and Isherwood similarly describe the commodity as being, "A non-verbal medium for the creative faculty", that is beyond the readily rational yet involving the active behaviour of the subject. Thus symbolism, even as ascribed to objects arbitrarily (Holloway, 1969) appears to be a language-like yet non-verbal social process that can transform objects into commodities (or, rather, tools, as outlined above). Hence, where the commodity might appear to have been chosen non-rationally, its meaning is apparent in the exchange value that it offers to the patients' recovery: the hammer's value is exchanged in that it is no longer the tool of trade but now the tool of recovery.

The capacity for symbolism is an arbitrary, non-rational, language-like process by which we are able to identify and reflect upon our position in a social transaction and thus are able to create commodities through exchanges with others; those commodities that are tools can help to improve our lot in life. The means by which symbols are constructed is the result of the dynamic objectification by which Hegel sought to supplant the idealism of Descartes' duality of mind and body. There is, in this regard, a unity in the generation of symbols and functionality of our bodies, which is outlined below.

Problems in the philosophy of mind

Descartes famously reasoned that the self comprises a soul-like mind, and that such a mind is composed of unquantifiable thought. The body, in the Cartesian model, is merely the means by which we gain information about the world and hence the mind and body are mutually separate. In spite of the dominance of Descartes' theistic dualism in Western thought, many philosophers posed other models for the relationship between mind and body: Spinoza, for example, reasoned that the mind receives an 'idea of the body' and also an 'idea of ideas' by which a person can interact with the world, perhaps prefiguring current research into cortical mapping and perceptual 'metarepresentation' (Bear et al, 2001; Damasio, 2003; Spe94][12]. Kant similarly sought to overcome such dualism by distinguishing knowledge that is gained prior to direct experience – thus being innate and immediate – and knowledge that is gained as a result of experience. Yet in either such category, there exists no means to access the world as it is in its pristine state; all experience is, he deduced, mediated by our perceptual systems (Scruton, 1997).

[12] See also Hospers, 1990 for a review of these themes

Since the thinkers cited above proposed their deductive models against dualism, a debate has continued among analysts as to what is often termed the mind-brain problem. Pertaining to this issue, discoveries in neuroscience have since been made: Sherrington's theoretical model of the synapse; Eccles's elaboration of this model and Ramón y Cajal's discovery of the neuron; Pavlov's theory of sensory pathways through the brain and, importantly, Hebb's discovery of neuroplasticity by which neural connections grow stronger through increased excitement, thus creating 'cell-assemblies' that are capable of producing any number of dynamic responses to given stimuli. Yet while the basic physical means by which responses might be generated have been determined, this has not settled the debate over how we gain and act upon knowledge of the world.

The mind-body debate is of importance to the present study in that tasks, being executed as cognitive functions through physical means, might provide a way of engaging the nervous system in a way that promotes improved clinical outcomes (a view offered by one of the interviewees who took part in the user study). As understanding the mental-physical relationship in this regard might help in evaluating the intrinsic properties of a virtual reality system for rehabilitative tasks, so this debate will now be outlined.

There appear to be two commonly held types of mental state: a *qualitative state*, such as pain or sensing colours and textures, and an *intentional state* such as beliefs or desires. The former of these is a state in which the 'qualia', or sense-data, of the world are received as immediate knowledge, for example: I know I have a pain because I can feel it; I know green is there because I can see it; my body is correctly positioned because I am standing. The latter is a state in which we make mediated responses to the world, for example: it seems that it will be sunny tomorrow; in spite of the clouds I hope that it will not rain; I have a pain because I have a trapped nerve[13].

The existence of an *intentional state* might also be said to demarcate a separation of mental and physical in that a response is derived from a phenomenon that is not present. This might refer to religious beliefs ("How happy are those who believe without seeing me" [14]; "But you cannot see Me with your present eyes"[15]), perhaps also to the reception of high art (Steiner, 2001), or to more mundane phenomena, such as any one thing that is hated, loved, judged, and so on, without the thing that is being loved, hated or judged remaining physically present at the point of response.

[13] Kim (2006) provides an excellent overview of these issues
[14] John 20:29
[15] The Bhagavad-Gita, 11.8

The intentional state has also been used in therapy where patients with paralysis to their upper limb as a result of stroke were requested to imagine performing activities of daily living as an adjunct to regular occupational therapy and improvements to function was subsequently observed by Page et al (2001). More recent research has thus provided strong evidence as to the way in which behaviours are remembered as 'schema' in the brain, each including the involvement of the visual cortex, and how these provide the neural basis for our responses to stimuli (Castiello, 2005). Further recent studies have also shown that the neural physiology of imagined movements can be harnessed to control robotic limbs (Hochberg et al, 2006)[16].

Considering the corporeal basis of imagination, our ability to reflect upon a mental image of a quale has been described as being the *diaphanousness* (transparency) of experience. One view is that qualia are hence existent in the world (*externalism*) and that our mental image of them is a veridical representation of that *externalism* (*representationalism*). This *externalist-representationalist* approach may be valid when examining directly observable phenomena (for example, the parasitical worm's knowledge that its host's body is the correct temperature[17]), yet this view also holds that qualia supervene on constant and common mental capacities.

Other authors have suggested that what we perceive impacts directly on our behaviour. For example, throughout the 1930s-1980s, the colour theorist Faber Birren developed the argument that human societies might be optimised for well-being through generalised designs based upon the impact of the physics of colour upon our bodies and thoughts (Birren, 1988). In his proposed design for a hospital environment, Birren argued that bright colours and harsh hues surrounding the patient would affect visceral functions (raising heart rate, blood pressure, respiration and so on), while the resulting cortical activation would result in the patient's being drawn away from a state of repose, and thus argued that the patient should be surrounded by softer tones.

Yet, while there may be a case for establishing client-centred design in hospitals, Birren offers no further analysis as to why the parameters cited here are important for a patient's welfare and recovery. Indeed, repose as a state of passivity might be deleterious to full recovery and thus problematic for the therapist, as many of the interviewees who took part in the user study suggested. The physics of colour may be constant, but this does not translate to universality in human need and response and Birren's theory, with regard to healthcare, here appears ill-defined, if not fanciful.

[16] Further details of this work can be found at http://www.cyberkineticsinc.com [last accessed December 2007]

[17] This apt example was originally offered by Dretske, 1995

Where some authors have persuasively outlined the therapeutic benefits of light (for example Brainand, 1998), Birren's theory might be thus applicable to various other areas of design (a discussion of which is beyond the present study), yet his ideas do not appear to be applicable to rehabilitation. It also appears that Birren's basic research was based upon experiments with rats (Birren, 1961), which, in transferring the data to human behaviour, might be regarded as being problematic; Kaiser has further outlined further methodological problems in this field of research (Kaiser, 1984). Birren himself recognised that human responses to colour are *heightened* by subjective factors (Birren, 1961a) and Kaiser identified the influence of 'cognitive' functions in such responses (Kaiser, 1984a); it could perhaps be argued that our responses to colour are indeed *formed* by subjective factors.

Refuting Birren's theory need not, however, suggest that there is no constancy in our responses and that patients' environmental conditions cannot thus be improved (the refutation does however imply that our responses are more complex and oblique than Birren may have anticipated). A recent publication by the Royal College of Physicians has thus provided a more persuasive case that the sensory content of the hospital environment can promote recovery (Kirklin and Richardson, 2003)[18]. Yet here, many of the authors maintain that 'healing' might be ameliorated within environments that are enriched by a range of creative endeavours (such as dance, music or poetry), in which patients are often intended to actively participate (whether as viewer or creator). Although this notion remains untested through standard procedures, the value of the active engagement of patients in their environment has been testified to widely (as the user study of the present study demonstrates).

To conclude, where evidence has been provided that images are transmitted directly to the visual cortex and that our motor responses to stimuli involve a visual-cortical engram, the means by which the image leads to responsive behaviours is far from clear. It might thus be argued that, as human mental capacities are constant within the human subject but not common to all humans, and so our responses to qualia cannot be veridically *representationalist*. According to this argument, the only means by which we represent 'qualia' is in our outward behavioural responses to them.

The nature of the relationship between what is passively sensed and what is actively perceived is far from understood, leading an apparently exasperated Humphrey (2006), to declaim the 'apparent *uselessness* of sensation'. Given, too, the highly subjective ways in which we respond to stimuli, the very existence of qualia may be refuted altogether. Hence Wittgenstein

[18] Further details are available at http://www.enhancingthehealingenvironment.org.uk/publications.asp

argued that the quale is merely a theoretical construct that will be abandoned once neuroscience has achieved a description of the complex means by which we respond to the world. He illustrated this view with his famous parable of the beetle: several people have boxes each containing beetles, each person is only able to know what a beetle is by looking at his own beetle, yet it is possible that each person has something entirely different in his box and perhaps nothing at all[19]. The box, here, is the human mind and the beetles are the *intentional* content that neuroscience has yet to identify but remains existent in our ability to have a diaphanous experience of it.

Mind-body dualism may have been abandoned in favour of a more dialectical analysis of subject-object relations, but this has not resulted in a consensual understanding of the ways in which the mind receives and processes information from the world. There does, however, appear to be a 'response-value' which has yet to be fully substantiated (often called the 'hard problem' in the philosophy of mind (Kim, 2006a) and a discussion of this will be offered in the following section, Embedded Tasks, below.

Agency and technology: a framework

In the section above, a 'reduced zone' of behavioural patterns was introduced as a means of establishing a 'space' which could be problematised in accordance with the temporal and spatial needs of the patient. Such a zone, that comprises the bodily activities of the subject, has also been proposed by structuralist anthropologists – initially by Mauss and Elias – and developed into a practicable analytical model by Bourdieu (1977).

For Bourdieu, *habitus* is constructed from the constraints of social and ideological parameters that exist within the subject. Thus, rather than exerting limitless free will, the active subject has agency in the world, which, although unobservable, is the subject's means of traversing his/her own inner world and the outer world of the social relations. Giddens' theory of structuration also provides a model whereby the subject is knowledgeable of his/her social system which in turn provides the conditional structures with which he/she interacts**.** Hence, the reduced zone of behavioural patterns serves to formulate the needs of the patient within the temporal and spatial constraints of the rehabilitative process.

In reading Giddens, however, the model of habitus must be extended as society, in his view, cannot be understood as either a micro-level aggregation or a macro-level summation of all activities, but rather a dynamically modular process of *in situ* subject-object relations. Thus a social system is examined through its component *structures*, *modalities*, and *interactions*:

[19] Quoted in Kim (2006)

structure being the conditions and resources that substantiate agency; *modality* being the means by which structures are translated into activities and *interaction* being the activity instantiated by the subject as an agent within the social system (Giddens, 1984). The theme of modality was developed further by DeSanctis and Poole to form an *adaptive structuration theory* whereby technologies are *deep decision* social constructs that play an integral role in the formation of the very social relations that bring them into being (DeSanctis and Poole, 1994), (a view substantiated by Stefik and Stefik, 2004b, in their finding that innovative technologies create their own markets).

There are opponents to modality and agency in the social sciences, chiefly Margaret Archer for whom any such analysis is deleteriously reductionist. Hence, Archer's view is that individuals experience free will within objective, apparently immutable, social structures (outlined in Archer, 2000). Anthony King cogently refutes this view, arguing that Archer's rejection of social agency has the paradoxical effect of reducing society itself to myriad individualism (King, 1999). The full debate surrounding the issues of agency and modality are beyond the scope of the present study. It is, however, methodologically expedient to regard the subjective individual (the patient) as an *in situ* agent of the care process (the social mode), in which or she has exercises adaptive choice.

Conclusion: finding meaning in the everyday

Csikszentmihalyi and Rochberg-Halton conducted a study of the part played by the everyday objects of the home in constructing selfhood and meaning (Csikszenmihayli's work on *flow* is also outlined in the section, Symbolic tasks: achieving flow, below). For the authors, where meaning is found in an object, it is the result of its role in the social transaction. Transactions, for them, are thus intellectual and contextual activities comprising an 'communicative sign process'. Such transactions are, for the authors, 'aesthetic' (rather than purely utilitarian or purely hedonistic – although degree of both instances might be embedded in the aesthetic) in that they offer a perceptual experience that has the potential to engender novel values (perhaps in remembering a forgotten event, such as a family celebration, or in forming new goals, such as reaffirming a kinship tie), (Csikszentmihalyi and Rochberg-Halton, 1981). Hence, the authors describe a separation of purpose and meaning: domestic possessions might have a use value, but their meaningfulness is founded through their exchange value (a view reflected by many of interviewees throughout the user study of Chapter Four).

To summarize in brief, the aim of this section was to address the basic problem of infinity as it relates to meanings that might be attached to material objects. In addressing this problem, a novel 'reduced zone' of behavioural patterns was proposed which served to model the specific circumstances of patients according to a confluence of temporal and spatial axes: here the axes that describe the stage of the patient's recovery and the environment in which he or she is situated. This particular confluence thus shows how a material object can be imbued with meaning through the exchange processes of therapy, and can hence be regarded as a constructed 'commodity' or 'technology' in such exchanges (the exchange of one meaning for another, or of a previously held perception for a novel perspective). This confluence also serves to substantiate what is for Sahlins the distinction between the *use value* of a commodity and its *exchange value*. Exchange value is thus reflected in the findings of Csikszentmihalyi and Rochberg-Halton in their survey of how meaning found in domestic possessions and by Stefik and Stefik in their survey of the social construction and impact of innovative technologies.

This dynamic subject-object exchange might also be regarded in broader the existential themes through which the subject recognises his or her place in the world; a process that has been called, to paraphrase Hegel, one of *objectification*. This process has also been shown to be non-rational and hence in permanent flux as we propel our intentions toward what have been dubbed the 'qualia' that comprise the world, but which could equally be regarded as 'insubstantial' symbols and goals. The means by which intentions are propelled remains poorly understood, yet the zone of behavioural patterns might be regarded as comprising that very 'response value'. In this regard it constitutes what Giddens has called the modularity through which the subject informs itself and hence interacts with its world, a theme explored in the section below. The commodity thus serves, to adapt Giddens' model to this context, as a *structure* which instantiates patient engagement, a *modality* for undertaking the therapeutic programme and the means of *interaction* by which clinical outcomes are achieved.

Embedded tasks: Execution, mediation and intention

Introduction

The 'problem' of degrees of freedom reflects the infinite variety by which we can execute a functional task. Such infinity has also been described in the generation of language-like symbols and hence the making of commodities. So, too, the manifold existentialism of human life presents the analyst with similar such problems. Yet in designing a system that is intended to serve as an adjunct to neurological rehabilitation, the terms of the 'crisis' that the therapy addresses itself might provide the very parameters that such a system necessitates, as outlined below.

The influential anthropologist Clifford Geertz maintained that one of the most significant things about human beings is that, although we are born with the 'natural equipment' to appropriate any number of the boundless ways of life that our species exhibits, we each, in the end, will only ever have lived one (Geertz, 1973). Yet various accounts given by stroke survivors of their conditions and recoveries often reveal how the disease can have a catastrophic impact on lifestyle, behaviour, personal relationships, career, self-esteem, long-term physical and cognitive ability and so on. Such is the level of impact that it is not uncommon for stroke victims to distinguish their 'old' life before the stroke from their 'new' life after the stroke (see for example Robert McCrum's candid account of his stroke (1998) or Jean-Dominique Bauby's (Bauby, 2002) or the many others collated as a broad survey of the experience of stroke and its treatment (Kelson et al, 1998). Reflecting this level of crisis through clinical intervention, one of the interviewees who took part in the user study described how many patients must be counselled in adjusting to their new limitations.

Contrary to Geertz's argument, the experience of stroke victims might suggest that what we call our 'life' is not uniform or static. The experience of stroke can thus be regarded as a tragically stark illustration of what is, for every human, an on-going process of development and relearning in which our physical and perceptual abilities must forever adapt and readapt. Thus the countless tasks we perform throughout our lives, however commonplace and whether physical or mental, are never simply the results of mechanistic, self-same routines; while the myriad environments in which we perform our lives each demand a bespoke and unique response. Hence, occupational therapists will often aim to avoid 'stereotyped' or script-like patterns of functional performance, which may lead to deleterious compensatory behaviours, and instead embed the relearning process in the indefinite behavioural systems that we term the activities of daily living. Yet, while the relationship between task, environment and skill relearning is problematic, as outlined below, solutions to achieving a maximal engagement with the environment could well be sought through the application of virtual environments to the rehabilitative process. This possibility is dealt with in subsequent sections.

Task execution: a framework

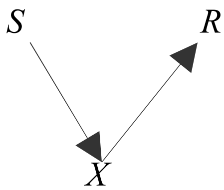
The user study presented in Chapter Four revealed how therapists often lead rehabilitation through embedded tasks and dynamic goal-setting. One of the interviewees who took part in the study thus cited A.R. Luria's highly influential work in demonstrating how such task performance can engage the nervous system at a deeper level, perhaps helping to promote fuller neural activity, which has been shown to help promote greater sensory-motor recovery. In Luria's model, now widely accepted (Andrewes, 2001) the brain is organised through functional systems which, in each to their own capacity, work integrally to respond to external stimuli by passing information to the decision-making area of the organ (the prefrontal cortex), which regulates general behaviour for the successful execution of a functional goal (Luria, 1973). This stimulus-response model was further developed by Luria's erstwhile cohorts to form Activity Theory. This model was later developed further still by their younger colleague, Bernstein, to form a science of motor development, which was subsequently applied to the broader field of work psychology.

Leont'ev's major observations pertained to reflexive animal behaviour which stimuli will result in predictable physiological responses; he cites, as an example, Pavlov's famous dog, which salivated in direct response to the sound of a dinner bell, even where no dinner was offered. Among humans, however, such reflexes to the initial stimulus are a far more complex, if not oblique, process. Hence, individual actions might not satisfy a given requirement as such, but contribute dynamically to the ultimate fulfilment of whatever the requirement may be. Furthermore, the action in its atomic form (in the literal sense) might only be described once the context of the activity has been described; this may be social, such as a work environment or, indeed, a clinical environment.

Through this analysis, Leont'ev thus distinguished activity, which satisfies a need, form the basic actions that compose the activity. Leont'ev also reflected on how an activity is often for a social goal and hence executed collectively. Relating this distinction to the present study, we might say that the physiotherapist (according to the delineations given in the user study) induces action in the patient to fulfil physical outcomes, whereas the occupational therapist impels activity to fulfil a broader set of clinical goals (ADLs, and so on).

Hence, activities comprise actions which dynamically process an object to achieve an outcome; the object in question might be external (a piece of wood) or internal (an idea). It might thus be argued that the objects to which rehabilitative activities are geared are, in this regard, neither exclusively external nor internal but comprise a novel spatial paradigm in which the very idea of the activity can be described through Heidegger's notion of the everyday existence as 'being-there', or elsewhere as 'being-in-the-world' (*Dasein*), even prior to a physical realisation of the subject's intention (Steiner, 1978). Yet *Dasein* is not without ambiguity and can either refer to the world as 'web of signifiers' which has overt salience in the mind of the subject or to the 'present-at-hand' objects that extend the subject, as those working in a state of flow might experience (a theme outlined in greater detail below) (Inwood, 1997).

This problem of 'being-there' was investigated elsewhere by Vygotsky who, further to Leont'ev's work, had himself developed a model of activity in which a tool (whether physical, such as a hammer, or semantic, such as an exclamation), has a mediatory yet integral role in responding to stimuli. This can be illustrated with a simple adaptation of Vygotsky's simple formula (where *S* = Stimulus, *R* = reflex and *X* = tool), (Vygotsky, 1978)[20]:



This formulation might reveal how 'technology' in its broadest sense could be regarded as a necessary component in executing an activity. In might also be supposed that the 'technology' of a virtual environment is not simply the hardware and software from which it is constructed, but also the way in which such a system compels unconscious mechanisms to promote the sense of 'presence' or, to employ Heidegger's term once more, of 'being-in-the-world'. It might also be regarded as what Giddens described as the *modality* by which what is perceived is translated into what is to be done (as outlined above), or perhaps, too, as Dewey's modes of specification and transaction, whereby knowledge of the world is communally attained, encoded and acted upon (Dewey and Bentley, 1949).

Further developments in action theory were initiated by Miller, Galanter and Pribram (1960), and later in Card, Moran and Newell's 'GOMS' model (Goal, Operator, Method and Selection, (Card et al, 1983)[21]. Part of Miller, Galanter and Pribram's thesis was that actions comprise an iterative series of Test-Operate-Test-Exit (TOTE) units, which paradigmatically supersede the earlier stimulus-response model. TOTE units thus include an analysis phase (whether conscious or unconscious) through which an appropriate response is selected and executed. The TOTE cycle is furthermore observable through a hierarchy of action and activity executions (sensory-motor → intellectual → conceptual), with a clear example being use of a word processor: a TOTE cycle is required at the sensory-motor level to hit a letter key, again at the intellectual level to type a word and finally at the conceptual level to compose a full text (Hacker, 1986).

Hence, in executing an activity, there is a sequence of regulatory processes comprising conscious goals and nested sub-goals, operating dynamically with knowledge of the world and the intentions of the individual executor. In this regard, the environment in which the activities

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[20] An 'x-factor' formulation has also been adopted by Dennett to describe the missing neural/perceptual phenomena that might account for the apparent gap in knowledge of the so-called mind-body problem (see Dennett, 1996)

[21] From such developments, a broader field of work psychology was further developed throughout the 1970s by researchers in Germany (both East and West) who sought to develop modes of promoting long-term human well-being through both grounded artefact design and self-determination in the workplace (Grief, 1991).

are undertaken have also been shown to affect the nature and efficiency of action execution (Grief, 1991; Bootsma et al , 1994).

Response mediation: a framework

To return to Vygotsky's formulation that action upon an object is mediated, the very means by which activities are mediated can now be sought by way of determining '*X*'. We observed above that such mediations might comprise a tangible technology, a concept or indeed a dynamic and ostensibly oblique amalgam of both. In seeking to identify how such an 'amalgamated' technology might operate on the object, an apt illustration might be found in the conundrum that Plato reports Socrates as offering to Alcibaldes: *Then what are we to say of the shoemaker? Does he cut with his tools only, or with his hands as well?* Alcibedes concedes that the shoemaker does indeed use both tools and his hands in making shoes, and also his eyes and his whole body. To this Socrates concludes that, as the body controls the tool, so it follows that the soul must control the body (Denyer, 2001).

In seeking to prove the existence of a soul in this regard, Plato could not conceive of the invisible, internal process that serves a processual function. Yet, with the knowledge that a learning process operating at a neural level (such as that attained through a TOTE cycle, outlined above) could be regarded as being as much a 'tool' (a means of mediation) as any physical apparatus upon a tangible object, so it can be supposed that a neural mode of mediation might be devised through the 'technology' described as 'media presence' (a contrived form of *Dasein)* to operate upon any object, whether tangible or intangible (Coehla et al, 2006).

To substantiate the theoretical formulation of an amalgam of the conceptual and physical as suggested by Vygotsky's $S \rightarrow X \rightarrow R$ model, examples can be cited from the recently founded field of the anthropology of technology. Pfaffenberger has, for example, reappraised the classic work by Malinkowski on the highly elaborate construction of specialized barns for storing yams by Trobriand Islanders, an activity which has been central to their social organisation (Pfaffenberger, 2001). Here, Pfaffenberger distinguishes the *activity* of construction from the *objective* of construction. He thus demonstrates that the physical objective (a building for storing yams) is not the meaningful goal for the islanders. The meaningful goal is actually embedded in the activity through which social order is established. In short, the 'tool' for creating socio-economic order is not the tangible barn but the intangible processes that the islanders described as the 'magic of prosperity'.

In a similar vein, the anthropologist Tim Ingold reappraised MacKenzie's observations of the way in which Telefol girls (from New Guinea) learn to weave baskets and he, too, distinguishes the physical product from the active process of creating (Ingold, 2001). The baskets are made exclusively by the Telefol women and are a means of establishing social status. Ingold cites a report from one of the women who had left a basket half-finished and whose untrained daughter decided unilaterally to complete the job independently. Her inchoate endeavors resulted in a ruinous basket that took the mother several hours to undo and correct. The problem resulted from the fact that the daughter could visualize a finished product but had not yet intuited the construction process, by way of the prolonged, mimetic training that Telefol girls normally undertake. The training, therefore, is not structural but processual and social, and depends upon establishing a highly complex sensory-motor engram. The 'tool' for making baskets is not only the grass from which the tangible object is constructed but also the intangible social process which ensures that baskets are completed successfully: flawed baskets are thrown into a river so that the errors are ritually washed away so, as the girl's mother put it, her hands should then move easily like running water.

Both of these examples reveal how an object (whether tangible or intangible) is produced through physical and conceptual processes that have amalgamated and integrated to form an complete and indissoluble 'technology', which Ingold developed further to serve as relational model for skill learning. Through this he refutes the distinction made by many evolutionary and cognitive psychologists that humans learn skills either through genetic disposition to skill generation or through cultural transmission from the skilled person to the unskilled (Ingold, 2000). Instead he maintains that skills are learned through an active and social process of 'guided rediscovery' through which such abilities are 'incorporated' (in its literal sense) into our 'person-organism'.

Ingold's model appears to stem from the ecological psychological model, founded by James Gibson, by which skill acquisition comprises an 'education of attention' to the learning opportunities that our surroundings afford (Gibson, 1979a). Pierre Bourdieu has further developed this premise by offering a more general theory of practice, through which the know-how we carry with us in life is generated tacitly through complex interactions with our environments that remain refractory to explicit codification (Bourdieu, 1977). Thus, where one of the therapists who participated in the user study stated, "If you tie your shoelaces, you probably couldn't explain to me what you've done", this illustrates the relational, ecologically derived task learning and execution process that Ingold and Bourdieu have described.

These oblique engrams of motor function might also remain in the cortex even after severe damage to the brain. A series of recent studies have endeavoured to demonstrate how imagining movements might result in improved motor recovery after stoke, even where direct movement is highly difficult or even impossible (see for example Crosbie et al, 2004; Page et al, 2001]); these studies might further illustrate the dynamic relationship between mind and world in which information is gathered and distributed throughout the cortex.

To summarise, it was observed at the beginning of this chapter that virtual reality's operability is based on the premise that the world, as we perceive it, is 'virtual', meaning that we are unable to gain unmediated access to the concrete as we exist in a stream of narratives that our minds construct. In performing a task we might thus be responding to a given stimulus (whether tangible or intangible), yet the precise mechanisms of our responses remain dynamically and obliquely distributed throughout our motor and sensory cortices. Furthermore, the range of stimuli to which we respond is boundless in its variety and hence requires manifold modes of response (whether tangible or intangible) as we ourselves change throughout our lives. The very means by which we respond are similarly indeterminate and open to constant evolution; yet our capacity to learn and relearn is boundless. Such a learning process appears to result from a dynamic integration of the physical and conceptual by which we maintain an ostensibly immediate 'being-in-the-world' (Heidegger's *Dasein*). Even in spite of the catastrophe of severe illness such as stroke, we each normally experience a consistent 'self' and stable behavioural patterns, which embody that amalgamation of concept and object through which relearning occurs. Hence, as relearning can only be accomplished through the embodied and semantic 'self', so the rehabilitative task must also embed meaningfulness.

In designing a technology that is to support this oblique skill relearning process (through the undertaking of meaningful activity), the activities themselves must allow for the myriad and indeterminate nature of stimulus-response reflexes (Vygotsky's $S \rightarrow R$), as well as the infinite means of response, (Vygotsky's X value); the means of response might thus comprise intangible, subconscious processes (as exemplified by the TOTE cycle or the modes of synthetic construction, outlined above). Yet, far from necessitating a technological system of improbable complexity, this principle allows us to establish a practicable parameter for the design, based upon the dynamic commonalities on which all 'selves' are founded, as well as our received propensity to exploit a *naïve knowledge of everyday physics*, which might correlate to Kant's *a priori* knowledge.

Where the review of literature presented in Chapter Three revealed a range of such systems that each provide virtual environments with given content, a more effective system might provide the user with an empty 'template' that can be filled with the content that he or she finds most meaningful and through which effective clinical goals can be established. As virtual reality can promote a sense of presence, of being-in-the-world, so presence emulates the conceptual-physical amalgamation which forms the process of stimulus-response mediation which underlies all skill learning as a process of ecologically derived attainment. In short, virtual reality can serve to invest $S \rightarrow X \rightarrow R$ with meaning.

Subjective intention: a framework

The final design parameter for an intrinsically optimal virtual reality system for neurological rehabilitation pertains to the manner by which such a system might serve to invest a therapeutic task with meaning so as to impel intention in the subject. As the extrinsic value in this process might be the possibility of setting functional goals through simulating items which are directly meaningful to the patient and therefore motivating (such as the stuff of hobbies or domestic activities), so the intrinsic value of such a system might lie in promoting the subconscious mechanisms (Vygotsky's *X*) through which the sense of presence leads to motor reflexes.

The initial analysis for examining such an intrinsic value has been provided by Bernstein through the formulation:

$$Intention = Sollwert - Istwert$$

Here, *Sollwert* and *Istwert* have simply been derived from German conflations which stand respectively for 'the value of what is to happen' and 'the value of what is currently happening'. Intention as a value is thus the difference between *what should be* and *what is*. However, recalling Vygotsky's formulation of stimulus-response, Bernstein's value of intention is similarly oblique and ostensibly indeterminate. Yet here, too, evidence from various fields might help determine its value and thus provide a further parameter for an interaction design.

Bernstein's own research demonstrated how the interactions between the peripheral nervous system (that gathers sensory data) and central nervous system (that releases command signals) dynamically generate the subject's 'desired future' (*Sollwert*), a model which is now widely accepted (Feigenberg and Latash, 1996).This desired future amalgamates knowledge of the environment based upon memories of former experiences with evaluations of actions based upon *in situ* sensory input (*Istwert*). Hence, Bernstein's formula allows the mind to be regarded as comprising a dynamic model of the body's self-organising actions in space, inseparable from the neural pathways and viscera which form the organism. In a discussion of this field, Esther Thelen, describes Bernstein's formula succinctly: *All behavior* [sic] *is always an emergent property of a confluence of factors* (Thelen, 1995).

Yet 'desired future' as a dynamically derived intention also suggests an ideal outcome and hence a capacity for stasis in the person-organism. Yet, the existence of such a stasis might return us to Socrates' conundrum in trying to determine where in the organism the model for this *telos* might reside and, furthermore, what creates it. Yet, although such a regulatory system does indeed exist, this too has also been described as an entirely dynamic process constructed *in situ* from myriad knowledge and has thus been termed *homeodynamics* by some biologists (Rose, 1998).

Such a dynamic regulatory system has also been described as forming the basis for the capacities we experience as feelings, in contrast to the emotions we consequently exhibit (Damasio, 1999). The data that comprise feelings are thus appropriated through an associative learning process by which bits of knowledge are passed to those parts of the brain that are responsible to varying degrees with more generalised cognitive mapping and behavioural response (Rose, 2003).

Such feelings, therefore, underlie our basic responses to the world and contribute to the active accomplishment of 'being there'. Though not unconscious in the commonplace sense of the term, the feelings we experience are often below the level of ready articulation, and it has hence been argued that they comprise the stabilised 'core consciousness' through which 'self' is maintained, and upon which the 'extended consciousness' of autobiographical and social values are founded (Damasio, 1999a). Some recent work in the VR field might well lend weight to Damasio's argument with reference to similar such layers of 'presence' in perception (Coehla et al, 2006][22].

Hence, following Damasio's argument, Bernstein's 'intention' is a dynamic system which operates at both the levels of core consciousness and extended consciousness, impelling action to form Vygotsky's oblique '*X*' value, while also informing the process by which we identify what is personally and socially meaningful. For the purposes of examining the intrinsic value of a virtual environment for rehabilitation, the manifold value of 'intention' might now be determined at what has been termed the 'working point' of task execution (that is, for example, the pinch or the grasp and so on), (Latash, 1996).

It was observed in Chapter One, Introduction and Background, that a virtual environment consists primarily of 3D visual models, among other means of sensory feedback, that afford all

[22]A strident refutation of this view has, however, been offered by Žižek from the historical materialist perspective, whereby consciousness is effected dynamically through socio-economic relations (Žižek, 2006). It might thus suffice to maintain that is there a neural correlation for consciousness, but that this need not account for historical selfhood in its socially transformative capacity.

manner of behaviours. Providing that the content and behaviours are ecologically consistent, and remain uninterrupted by technical failure or external interference, it appears that the human nervous system responds to the VE naturalistically. Hence, 'intention' is embedded in environment and thus driven by the given content: responsive assessments are made dynamically and 'unconsciously', with higher values ascribed to the actions through the field of 'extended' consciousness. In this regard, it is clinically valid for variable content to the supplied to the patient through a VE to impel intentional actions and activities. The content itself thus has intrinsic value, yet simulations of items which represent meaningfulness to the patient might further impel intention at a higher, extrinsic level (such as in meeting the demands of the care process as a whole).

Some insight into this elusive '*x*-factor' has, however, been gained in the recent discovery of the mirror neuron system. This comprises discrete areas of the primate cerebral cortex through which the actions we (as humans) observe seem to be converted into sensory-motor function (see Rizzolatti and Craighero [2004] for an overview of this important discovery). This has caused considerable excitement within the neuroscientific community and related disciplines, compelling V.S. Ramachandran, for example, to describe this emergence of this cortical facility as marking the 'great leap forward' in our evolution as a species[23].

Nicholas Humphrey has also addressed this discovery with reference to the mind-body problem. Humphrey has thus suggested that the mirror-neuron system might play a part in converting what is passively sensed to what is actively perceived, but that this would depend upon the brain dealing with such 'percepts' or 'qualia' as a cause for action; that, at the neural level, perceiving is a kind of movement within a sensory 'sphere of agency' (Humphrey, 2006a). Unfortunately, however, it is not clear whether the brain does indeed deal with perception as a kind of movement, but his idea is intriguing.

To conclude, Vygotsky's *X* value might comprise intentions and knowledge of which we are not readily conscious. Yet the more pragmatic perspective developed through the theories of action, outlined above, might provide an expedient model for the present design problem where activities are regarded as resulting from a *naïve knowledge of everyday physics*. This knowledge might, at some level, be inaccurate but is nevertheless based upon *deep decisions*: those decisions involving many stages of analysis and thus qualifying as 'sensible' (Norman, 1988). Hence, although we cannot accurately evaluate *X,* it does not follow that its effect is not made manifest in our 'naïve' actions. These actions appear to have distributed neural correlates

[23] His comments are published online at
http://www.edge.org/3rd_culture/ramachandran/ramachandran_p1.html [last accessed December 2007]

which dynamically underpin the production of those higher-lever activities that form our sensory-motor stimulus responses.

Symbolic tasks: achieving flow

Introduction

In the section above, the discussion pertained to the ways in which tasks can embed both a complex response mechanism and the subjective intentions of the executor. The present section will outline the ways in which the activities that stem from these dynamically arrayed actions might also embed higher meaning for the executor and evaluate whether VR can thus promote engagement as an intrinsic property of the technology.

The 'body-subject' and goal-setting

Heidegger's notion of Being-in-the-World was further developed by the phenomenologist, Maurice Merleau-Ponty, to posit what he termed the 'body-subject'[24]. Through the body-subject, knowledge of the world we inhabit is attained to support an integral engagement with our surroundings; yet our basic perceptions of objects remain imbued with the meanings that only the subject can find for them. To cite Merleau-Ponty's own example: a child may see a candle, which is objectively constant (forever a candle), yet for which the child might ascribe a different meaning after being burned and thus behaves accordingly in a newly derived, avoidant manner (Merleau-Ponty, 1989). Hence, the symbolic value of the candle, or of any other object, changes according to what it known about it and the generation of such symbols might thus be regarded as "a particularly creative form of problem solving" (Sperber, 1980). This 'embodiment' of self, where symbolism is generated through the body's interaction with the world, marked a departure from contemporary perspectives (Matthews, 1996).

Merleau-Ponty also argued that we experience our own bodies as being similarly imbued with meaning and able to interact with the world through the symbolisms that imbed our intentions. Hence, one type of action can become any variety of activities but this depends upon those intentions: the mechanical action of holding a knife can comprise the symbolic activities of carving wood, of butchering meat or of committing murder. Human action, like all animal action, is directed to the needs of the organism yet, unlike animal action, is individuated, self-conscious, symbolic and exclusively meaningful (Merleau-Ponty, 1965).

Knowledge and actions are, in this regard, contributions to the whole 'project' in which the body-subject is engaged. The project thus comprises our intentional activities and our

[24] Matthews (2002) offers an excellent introduction to Merleau-Ponty's philosophy

meaningful goals[25]. In the section above, the intrinsic value of a virtual environment in impelling *action* in the *Dasein* was determined; here an attempt will be made to determine the intrinsic value of such a system in impelling *activity* in the body-subject, being goal-directed behaviour at the symbolic level.

Goal-setting and flow

Mihaly Csikszentmihalyi has dedicated his career to determining the circumstances in which people feel most fulfilled. Drawing from vast resource of data, he and his colleagues have determined that people are happiest when engaged in an activity which they find challenging yet for which they have adequate skills and is furthermore meaningful. The threats to this engagement are the *anomie* of a surfeit of choice and inadequacy of certainty (leading to anxiety) and the *alienation* that stems from paucity of choice and rigidity of determinacy (leading to boredom).

Csikszentmihalyi has suggested that deep engagement with a task is thus formed when an individual has set a goal for him or herself, by which the activities needed to accomplish it are neither too easy nor too difficult, neither boring nor anxiety inducing. Self-generated goals thus become meaningful to the individual yet often depend on what he terms an *autotelic* ('generating goals for the self') personality.

Csikszentmihalyi thus outlined circumstances in which individuals who have found themselves in less than favourable, or even extreme, conditions have nevertheless set goals through which they have found meaning. Prisoners of war, for example, best survive their sometimes dreadful conditions if they are able to set themselves entirely mental challenges such as translating poetry, playing mental chess or imaging every detail of a long journey (Logan, 1985). Similarly, people who have suffered catastrophic disease or injury have often reported finding more meaning and purpose in their lives as they deal with the challenges of severe disabilities (Csikszentmihalyi, 2002). Yet it does appear that such individuals are not in the majority and that the *autotelic* personality is not generally formed as a direct result of such challenges but must exist prior to them.

The process by which meaningful goals are set and to which suitable activities are ascribed and performed has been described by Csikszentmihalyi as being one of 'flow'. In flow, as with the body-subject, our intentions, actions and our world knowledge each contribute to an activity

[25] Current research into so-called higher-order thought theory also suggests that the basic neurophysiological mechanisms of which we are not directly conscious also comprise this project in that the resulting mental state consists of the subject's thought of it (see Rosenthal [1991] for a discussion of this theme).

that is consistent with our environment, whether tangible or intangible (physical or symbolic). Flow pertains to both specific task execution and to our more generalised, longer term attitudes, social relations and material goals which comprise our existential *life themes* (Csikszentmihalyi and Beattie, 1979). These each result from subjective intentions that, as outlined above, cannot be ascribed by external means but must be engendered through the subject's own intentions and values. Yet flow at the various levels of task execution appears to promote the fuller cortical and thalamic activity that might lead to improved recovery after brain injury (Roberston and Manly, 1999)[26], (although this does not appear to be well understood [Bear et al, 2001a]). Achieving flow in task performance in virtual environments, and the associated neural activity, should thus remain an area of further examination.

Summary and discussion

It was observed how the therapist will often lead the rehabilitation process by embedding therapeutic activities in functional tasks. Such tasks comprise actions that are conducted in response to a stimulus and dynamically process an *object* to achieve an outcome. As the *object* in question might be either conceptual or physical, so it was argued that a novel spatial paradigm that, based upon the active response of the nervous system, comprises the tangible and intangible might be established. Such a paradigm has also been posited by Heidegger as 'Being-the-the-world' (*Dasein*), and this might also be regarded as comprising what engineers of virtual environments call presence. It was thus posited that presence might be the intrinsic technology which can drive intention and hence establish engagement in rehabilitative tasks through the hierarchical response model devised by Miller, Galanter and Pribram.

Reponses to stimuli are thus based upon regulatory processes comprising conscious goals and nested sub-goals and are executed within given environments. Anthropologists have thus described how an artifact being studied might belie the intangible processes through which it was created. Hence there appears to be a distinction between the activity of construction and the objective of construction. In this way, meaning can be embedded in the activity rather than the outcome, not least in the 'guided rediscovery' through which skills are attained.

Such intentionality has also been shown by Bernstein to comprise the difference between what is desired from what is actual, in which the 'desired future' is established through assimilating knowledge through an entirely dynamic regulatory system of *homeodynamics*; this system also underlies the 'feelings' that comprise our 'core self' and are linked to the generalised cognitive

[26] Robertson and Manly (1999) report on developments in 'sustained attention' research, which is perhaps the neuroscientific equivalent to Csikszentmihalyi's theory of flow

mapping and behavioural response upon which the ‘extended consciousness’ of autobiographical and social values are founded.

Neuroscientific research was then presented which suggests how neural activity in the respective areas of motor cortex is directly dependent on the visual stimuli received and consequently encoded through specialised areas of the brain. Hence, ‘intention’ is embedded in environment and thus driven by what is given, demonstrating how simulated content can also impel intentional actions and activities in the subject while offering intrinsic value to the therapeutic process.

Yet actions only comprise a higher level of activity, which is undertaken by the more complex body-subject to participate in existential projects and life themes. The body-subject is thus able to execute actions in a state of flow, which promotes well-being and also perhaps therapeutic recovery. In determining the intrinsic value of VR in achieving engagement at the symbolic level of meaningfulness, it might be observed that the value here is not as great as that of the value in achieving basic intentional action. Meaning is goal-orientated and comprises flow as an activity process; achieving flow appears to depend upon a degree of ‘autotelism’ in the subject and none of the VR systems that have so far been designed for use in rehabilitation appear to be capable of delivering or promoting such deeply subjective drives.

Existential and functional space: the home and disability

Jacob Bronowski concluded his television series on the philosophy of science, *The Ascent of Man,* with an exploration of the relationship between the human brain and the higher social functions it affords, as he observes, “A man's home is a proper place to study his biological uniqueness” (Bronowski, 1973/2005). This remark might well aphorise the problems that the present chapter has attempted to investigate. Hence, in the sections above, the everyday ‘commodity’ – the object that gains its value through the social exchanges of which it is part – was identified as being something that might be meaningful to people generally and thus provide a way of overcoming the problem of designing a system usable by all yet salient to the individual. The space of domestic life might thus be regarded as a rich source of such material. Yet as the present study is concerned with people experiencing disabilities as a result of stroke, their each particular ‘biological uniqueness’ would present a further problem to the system designer. This problem will be the focus of this section.

Bloomer and Moore identified the possible relationship between the domestic space and the body, as they surmise:

The relationship between a bodily boundary and the house boundary becomes evident when we realise that certain feelings associated with body transactions may be evoked by activities in the house (Bloomer and Moore, 1977).

This can be taken to mean the home might reflect the emotional and physical behaviours of its inhabitants. The impact of stroke can, however, be such that domestic life is profoundly unsettled (as illustrated in McCrum, 1998; Bauby, 2002; Kelson et al, 1998), with patients' and carers' relationships with their home environment equally disrupted and often requiring adjustment or even redesign. Hence, what was 'meaningful' in the home prior to stroke might have its meaning transformed after the stroke, a theme outlined by several interviewees in the user study of Chapter Four. Thus the radical change in the stroke patient's functional behaviour might impact on the semantic and physical composition of the home. This might also reflect a radical departure in our basic notion of space, resulting from the discovery of non-Euclidean geometry, to cite Bloomer and Moore once again:

Center [sic] *is not a concept of geometry but one of musculature with all its kinaesthetic ramifications, of orientation in response to the pull of gravity and of the sense of feeling inside* [Bloomer and Moore, 1977a].

In the context of the present study, the authors' assertion here might describe the need for reconfiguration of the home so as to help alleviate problems of functional deficit, perhaps resulting from compounded impairments in proprioception, executive function, sensory perception, mobility and so on. Thus the home of the stroke patient might remain 'meaningful' in it physical and semantic composition, yet the ways in which significance and meaning might change after the stroke might not become apparent until the patient has returned home. Hence the domestic space – perhaps signifying permanence and stability for many – exists not in Euclidean stasis but in relative flux and, much like its human occupants, is prone to the radical transformations for which it is seldom prepared.

The historian of design, Adrian Forty, has demonstrated that the home and its contents have no fixed identity yet reflect the social and historical conditions of its inhabitants (Forty, 1986). In a similar vein, Rybczynski (1986) has argued that the comforts of domesticity reflect the cultural environment in which the home is established. Yet neither author reflects on the way in which the 'significance' of the domestic space changes according the individual needs of its occupants, not least after the catastrophe of stroke (as outlined above). The ways in which the home can thus become a disabling environment have recently been outlined by Rob Imrie in a powerfully argued volume, *Accessible Housing* (Imrie, 2006) and elsewhere, with Peter Hall, in *Inclusive Design* (Hall and Imrie, 2001).

In outlining the problems of creating what they term 'usable space', Hall and Imrie highlight the market pressures to which housing developers are subject, as well as the formal conservatism and poor understanding of clients' needs observed among many architects. Where designers have attempted to design for all people, working to a discipline known as Universal Design, the authors here observe a tendency to reductionism in modelling the human form, while client-specific adaptations to 'standard' housing serve only to highlight difference in the disabled person, rather than providing genuinely inclusive spatial design.

The authors thus argue that the problem is not one of building design itself but of social and political processes: that environments become disabling as a result of attitudes and assumptions current in society, which are subsequently carried out through the building design. In creating a built environment that is truly inclusive, the authors cite a series of heuristic design principles (adapted from Sommer [1983]), some of which are relevant to the current study: that *meaning and context* supplant ornament and style; that the design is orientated to human rather than corporate need and that environments are created from the grassroots up rather than the top down. They also maintain that design should form novel approaches to problems of the environment and thus serve to challenge received attitudes [Hall and Imrie, 2001a].

Imrie builds upon these findings in the later work, which outlines the problems of functional and aesthetic standardisation in house building. He thus maintains that the home should remain the place where an individual's selfhood and particular community relations are made manifest, which, he argues, might be achieved through a newly formulated vernacular architecture that includes – yet not delineates – the needs of disabled people (Imrie, 2006a).

The possibility that such needs might be met through novel technologies and systematic customisation in house-building has been critically examined by Barlow and Venables, 2004.[27] Here, the authors outline the ways in which ICT-based systems might compliment client-centred developments in physical house-building by supplying the means for environmental control and for integration into support networks. One might imagine such systems also comprising virtual environments by which home-based patients could continue their therapy; yet the current physical and organisational obstacles the authors describe suggest that the wider adoption of VR in this context remains a distant possibility.

[27] A broader study of flexible housing has recently been authored by Till and Schneider (2007)

Housing design for disability is evidently in need of greater design sensitivity, yet the themes of embodiment, as outlined above, and of the home as a locus of generative selfhood might nevertheless offer ways of overcoming the specific-generic problem. Heidegger's notion *Dasein* has thus been developed further into a theory of existential space and design by Norberg-Shulz (1971). As non-Euclidean geometry and the Theory of Relativity made redundant any possibility for permanence in space and time, so we might also observe that any notion of psychological or existential stasis should also be discarded. As we interact with space, in the classic Piagetian model, so we perceptively and bodily assimilate the objects from which it is composed as a state of fluid interchange[28]. Our interactions with the world might thus stem from our intentional desires.

Concluding remarks

Where Heidegger asserts that dwelling is the *essential property* of existence, he is perhaps remarking on the body's dynamically functional relation with the world and, by extension, the self (Heidegger, 1975), which might also reflect Vygotsky's notion of intentional task mediation. Following Heidegger and Piaget, Norberg-Shulz thus postulates that the 'space' signifies not the tridemensional physicality of an architectural form, but the product of the interaction between organism and environment. For Bernstein this product was the *confluence of factors* which, as humans, we experience as the 'homeodynamic' image of our body's place in its physical context. Thus the physical basis of our selfhood emerges from our movement along intentional paths (*Wegen*) and towards existential goals (*Malen*) (Norberg-Schultz, 1971a). The means by which these processes might be supported through VR-based technologies will be discussed in the next section.

In evaluating a VR system with reference to theme of dwelling, an initial problem is that of infinity: in movement, material objects, symbolic generation and also in existential life themes. This problem is addressed in Chapter Five, Interaction Models, in which a series of design patterns and modes is presented that together might meet the proximal confluence of a patient's requirements. A further problem of infinity was also outlined in that responses to objects might be informed by highly subjective, non-rational and arbitrary symbolism. Yet it was also proposed that objects might gain their meaning through the activities that the subject might associate with them. Such activities are neither purely utilitarian nor purely hedonistic and might thus impel meaningful exercises for the therapeutic process. This theme has impelled the design of the practical study outlined in Chapter Six.

[28] See Piaget (1950) for an introduction to this theme

Part Four: a SWOT analysis

Having established fairly comprehensive overview of the relevant clinical, technical and psychological issues involved in this study, a more qualified overview of the fields can now be offered. In recent years, Rizzo and Kim have published an analysis of VR in rehabilitation and other therapies using the popular SWOT technique, which is most commonly used for cursory reviews of markets and business opportunities (Rizzo and Kim, 2005)[29]. In this regard, the technique is of particular relevance to the present study as a major part of the concluding chapter will comprise like-for-like response to Rizzo and Kim's analysis.

SWOT stands for Strengths, Weaknesses, Opportunities and Threats and the analysis therefore evaluates the existing and emergent findings in the field in terms of these concerns. The authors conclude that their findings represent a technology that will have 'a significant positive impact on the rehabilitation sciences'. The results of the analysis most relevant to the current study are presented in brief below.

Strengths

While many authorities have expressed concerns that clinicians are not often able to provide adequate rehabilitative environments, as noted above (Rizzo et al, 2004), Rizzo and Kim maintain that virtual reality might provide such hierarchically variable environments for systematic testing and training. They also argue that these VEs would be of benefit in their capacity to appear 'realistic'.

The authors maintain that such systems might provide performance feedback, as being 'essential to the learning process that underlies rehabilitation', a concern relating to motor control that we noted above. They identify the possibility of designing error-free training environments as being a strength as the benefits of this method have previously been demonstrated by other research, although they also identify successful trial-and-error training environments.

The minimisation of risk to patients is also identified as a possible, though questionable, strength (an issue outlined in Chapter Three, *Kitchen tasks, upper limb function, tangible user interface*), as are the possibilities for self-guidance and independent practice. In the latter cases, however, the authors warn of 'shoddy VR applications' being introduced commercially for home use.

[29] To avoid repetition this reference applies to all quotes throughout this section

Weaknesses

The authors outline two main challenges pertaining to interface design, being interaction methods and wires and displays, and also with the therapists input/output. They argue that interaction design has yet to achieve a unified method across the discipline and requires costly usability testing in any one project. The immaturity of the engineering process is identified as a weakness in a field that lacks 'models, methodologies, and tools'. The problem of platform compatibility is also a problem in that there is no consensus among designers as to the operating system that is most appropriate to the design (Windows versus IRIX, for example), or indeed the best graphics libraries and display equipment to employ. The cost of equipment is also cited as a weakness, yet this could be regarded as being of relative concern.

Problems associated with *aftereffects* (post-exposure problems experienced by the patient), and *cybersickness* (nausea caused by image processing lags) are identified as potential problems (although issues of cybersickness do not appear in the more recent literature). They do however mention evidence of post-exposure problems in patients with binocular vision impairments and rightly maintain that 'ethical clinical vigilance' is essential.

Opportunities

Identifying opportunities might be regarded an exercise in conjecture as the analyst is simply remarking upon emergent or imagined possibilities. The authors thus mention the advances in processing power of retail gaming equipment and display technology as being of benefit to the use of VEs in rehabilitation[30]. They highlight the market drivers of artificial intelligence for games and thus the possibility of further-automated rehabilitation tools as well as the possibilities for distributed, home use of the equipment. They also allude to their observed public and professional acceptance of this potential technology.

Threats

The authors' chief concern is that the field has yet to provide definitive cost/benefit analysis and this could impact on mainstream adoption of the technology. Poor understanding, or 'inappropriate administration', of the technology might also, they maintain, result in harm to the patient and legal claims resulting from post-exposure problems. They also cite clinical concerns that the technology might 'subvert the clinical relationship' between therapist and patient.

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[30] Researchers at Rutgers University have now 'hacked' a Microsoft Xbox for this purpose (see http://www.medgadget.com/archives/2006/08/xbox_for_for_st.html for further details).
On a similar theme see http://php.infc.ulst.ac.uk/vr-therapy/games.html, http://crave.cnet.co.uk/gamesgear/0,39029441,49285234,00.htm [all last accessed December 2007]

Rizzo and Kim's SWOT analysis shows that the use of VR in rehabilitation offers both opportunities and challenges to the designer. In conducting this research, I have thus considered their results and accordingly responded *in minutae* to the client statement, provided here, to establish an engineering design based upon weighted analysis of the 'design space' as well as the opportunities and constraints of the proposed system. Subsequent chapters present further evidence that might support or refute some of the authors claims, not least the study of user and stakeholder perspectives, presented in Chapter Four.

Chapter Two – Methods and Problem Analysis

General introduction

The client statement presented in the introduction proposed that a new technology based upon virtual reality is available for development in the field of neurological rehabilitation. The statement also revealed that the technology is not well understood. Considering this observation, I have elected to adopt a series of methods by which the design space can be problematized, analysed and systemised. These methods are outlined in this chapter, below, along with a series of objectives by which subsequent data will be evaluated.

The methods used throughout this study (revealed in subsequent chapters) have emerged as being both a selection of appropriate responses to the design problem as given, and as a means to address existing gaps in methods and data in the field as a whole. Hence, the methodology outlined in this chapter might be considered as being a transferable 'rubric' by which any other such design problems might be examined and solved (problems, that is, within an *open-ended* and *ill-structured* field (Dym and Little, 1999). This possibility is discussed in the concluding chapter.

Structure and methodologies

The studies outlined in this thesis are somewhat multi-disciplinary, ranging from engineering design to grounded theory to innovation analysis. The research was not conducted in a linear fashion, but is presented here with a view to establishing a narrative flow in the findings. Hence, even prior to commencing the review of literature, I was engaged in a series of informal discussions with clinicians, which led to the design problem being outlined in some detail (presented below). These problems were further outlined in greater detail in hindsight of the literature and user and stakeholder studies (Chapters Three and Four).

Through this process, the data from the engineering field was considered against the data from the clinical field and fundamental gaps in the general research were found. Lacking in all of the studies reviewed appeared to an evaluation of the 'intrinsic' effectiveness of the technology in assisting the therapist conduct treatment sessions, not least in its value in promoting patient 'engagement' while providing meaningful experiences. This theme appears to be unique in the literature and is placed to the fore of the present study, (Chapter One, Introduction and Background). These observations subsequently formed the basis of the interaction models

(Chapter Five) and practical work (Chapter Six) by examining the ways in which the technology might address the clinical concern of environmental meaningfulness.

A further objective for this research is the possibility for marketing the proposed system. This is not necessarily intended to lead to financial capitalisation (this was found to be problematic, as the stakeholder perspectives outlined in Part Two of Chapter Four demonstrate), but as a parameter to measure the way in which the system would be practicably utilised in clinicians areas of practice. As the user study also presented the problems of implementing technologies, so Part Two of Chapter Four also suggests ways of delivering such as a system effectively while gaining client confidence to win longevity in usage. Finally, the conclusion argues the toss in favour of implementing VR systems for rehabilitation, while readdressing a key technology evaluation made by experts elsewhere in the field.

Methodologies

As each of the chapters in this thesis represent discrete areas of study within the broader theme, so this section will outline the methods adopted for each of these areas. The field of VR in neurological rehabilitation appears to be somewhat immature. Methods in both the engineering and clinical spheres thus appear to be inconsistent throughout the field as whole. Hence the present study has, in part, been an exercise in researching and selecting suitable methods for analysing and designing such systems. The details of methodologies are hence intended to present novel data, which might further inform those working in this field of suitable analysis and design methods. The intention here is to provide a brief overview of the study methods, as well as a short introduction to the ways in which they have impacted on the outcomes of the study as a whole.

Problem Analysis: engineering design

As the initial design problem appeared complex and little work has been previously undertaken to design suitable and coherent methodologies, the initial task will be to impose a means of problematising, disassembling, interpreting and evaluating the design space. This will also be an exercise in developing design objectives, with weights assigned to each of these to reflect their importance in the system implementation.

Literature Review

As a standard practice, the state of the art will be identified, summarised and critically evaluated against the design objectives. Upon commencing the review, no similar survey had yet been conducted. Although a similar review has since been published (Crosbie et al, 2007), it has been suggested elsewhere that the authors' review analysis was misapplied to a field that is technically immature (Weiss and Ring, 2007). The parameters the review presented here thus include all published research that pertain to the testing of a VR system of any description that might be used for rehabilitation of the upper limb, whether directly or indirectly.

Given the considerable complexity of upper limb function, and the impact of deficit in this regard, the review thus encompasses the various clinical perspectives which are concerned with this practice, namely physiotherapy, occupational therapy and neuropsychology. One issue to consider in addressing this field is the variety of outcome measures used among therapists in various countries. For example, the Fugl-Meyer measurement of motor function is commonly used in North America but rarely in Europe. Semantic confusion might also occur over the use of the phrase 'Knowledge of Results' in one region over 'Knowledge of Performance' in another. These need not, however, influence the findings of the review as the variations do not affect the central aim of the study as a whole, which is to design an effective VR system as an adaptable adjunct for all manner of rehabilitation perspectives and techniques.

User and stakeholder studies

The findings of the review of literature were complimented by a user study, based upon interviews with clinical experts. The interview data was be transcribed and annotated manually according to a loosely adapted Grounded Theory method (as developed by Strauss and Corbin, 1998). The notes were compiled against the major themes of the discussion and also the emergent themes which form their subsets. The comments of the interviews were paraphrased and these, along with the themes and notes, and compiled in a spreadsheet (the full spreadsheet is presented in Appendix 5). The spreadsheet thus offer the opportunity to make a relational analysis of the interviews as a whole, intended to enable the development of substantiated parameters against which the proposed system must operate.

One possible avenue for developing a VR system is as an adjunct for the rehabilitation of children after brain injury. This was evaluated at an early stage of the study but abandoned due to the overwhelming ethical problems associated with testing such a system against the needs of its target users. Summaries of the two preliminary interviews resulting from this early stage are, however, presented in Appendix 4, which reveal interesting variations in therapists' approaches to this client group. Further data extending from the user study is similarly presented in Appendix 5 as a record of observations I made of a Senior Occupational Therapist undertaking a rehabilitation treatment session with two patients.

A key concern of this research is the successful implementation of VR system in a clinical context. This does not, however, appear to be without difficulties. Delivery is hence evaluated against standard metrics devised in the business field. These include the opportunities and challenges posed by markets (buyers) and industry (suppliers) at the micro and macro levels. Further analysis of possible demands on operational facilities are also offered.

This analysis is, however, expected to be somewhat problematic as healthcare in the UK is provided in the main by the state. While state provision serves the interests of patients by providing health care that is free at the point of delivery, it seems to have provided problems of access and capitalisation to the independent sector. Yet the NHS executive currently appears to be making allowance for this by developing strategic partnerships for service provision. Furthermore, it appears than therapy services are set to be delivered by market-orientated third parties, although this is clearly a politically problematic area (see, for example, Anon., 2007). Although the innovation strategy explores the possibility of these channels, this change in policy remains at an early – perhaps putative – stage.

System analysis: pattern modelling

Part of the standard engineering design process is to generate models, which can be evaluated against client needs. Possible systems are thus proposed using a pattern design method (as used in object-oriented modelling), which are presented in the form of flow charts. As the focus of this study is a user-centred design (rather than an exercise in efficient engineering), a full programme is not presented, but a small example of C++ code illustrates possible ways in which the system could be implemented.

Following the broad theoretical background already presented in Chapter One, Introduction and Background, the final part of the system analysis outlines ways in which the patient might achieve engagement in the therapy tasks as undertaking through a VR system. It is suggested here that gameplay might provide one such method.

System Testing: case method

One key concern of the system design was tested with post-stroke patients. In line with similar such studies, the sample population is set to be small (which appears to result from the difficulties associated with recruiting subjects who are at the rehabilitation stage). As with most research on human subjects, ethical considerations pose difficulties in this area; full ethical approval was thus gained through the Office for Research Ethics Committees (OREC).

Given the expectation of small sample population, I sought to maximise the gathering of data from the practical testing with human subjects by developing a case method. Here, all available details of the subjects' condition and medical history were gathered, along with physiological and qualitative responses to system usage (outlined in Chapter Six).

Discussion

In the sections above, the clinical concerns of stroke rehabilitation have been outlined and a broad framework for how virtual reality might be used in rehabilitation has been offered. The structure of the thesis was outlined, as were the methods used in the research. The next section, Problem Analysis, commences the body of the study by providing an engineering design approach to the research. The subsequent two chapters follow this analysis through a literature review and a user and stakeholder study, before returning to a further, more detailed series of interaction models.

Problem Analysis: an engineering design

Introduction

The engineering design approach is used to sort and evaluate the most appropriate means by which an apparently open-ended problem (which constitutes the 'design space' as a whole), might be approached and reasonably solved, initially by identifying the broad types of design problems and then by establishing a hierarchical flowchart of the objectives they imply. The engineering design approach might itself be broken down into stages and the various levels of the process can be presented diagrammatically as flowcharts.

Analysing the client statement: clarify objectives

The initial technique appropriated from engineering design is a thorough and searching analysis of the client statement that is intended to establish the 'problems' that are to be solved. With reference to the client statement, presented in Chapter One, the key concerns expressed therein are presented in the table, *Figure 2.1*, below. Each concern is designated as a type of design problem.

The types of design problems thus include Evidence, by which I mean a paucity of information, Engineering, Clinical and Business. Thus we might regard this table more programmatically by arranging the design problems by type, presented as a chart in *2.2* below. Regarding evidence-based problems, many of these have been addressed by providing a critical review of current literature, as presented in Chapter Three. Evaluating such evidence might be problematic in the sense that little of the material sourced for the review was seen to be mutually consistent. The current study is however set to offer evidence that can be evaluated, and this is dealt with in subsequent chapters. Thus the evidence sourced for this study could be regarded as resulting from 'qualified' development in that the systems modelled in Chapters Five and Six were each designed, wherever possible, in accordance with end-user requirements, as outlined in Chapter Four.

Figure 2.1. The key concerns of the client statement

Key client concerns	**Type of design problem**
unsubstantiated observations	Evidence
variable and stimulating environments	Engineering
meaningful and perhaps motivating	Clinical
appropriate means to develop…	Engineering
bring it to operation	Engineering
clinical appropriateness and efficacy	Clinical
review of literature	Evidence
evaluation of existing uses of VR in rehabilitation	Evidence
weighted analysis of system requirements	Clinical
qualified development of a system..	Evidence
…suited to the requirements of the recovery process	Clinical
generic tool / non-specific	Engineering
allowance of appropriation	Engineering
affording possible adaptations	Engineering
general requirements of therapy	Clinical
channels of distribution.	Business
operational system	Engineering
developed and tested	Clinical
consultation with clinicians and recovering stroke survivors	Clinical
results of testing might be negative	Clinical
analyse any problems	Engineering
offer useful advice	Engineering

Figure 2.2. Design problems arranged non-hierarchically by type

Evidence

unsubstantiated observations
review of literature
evaluation of existing uses of VR in rehabilitation
qualified development of a system..

Engineering

variable and stimulating environments
appropriate means to develop…
bring it to operation
generic tool / non-specific
allowance of appropriation
affording possible adaptations
operational system
analyse any problems
offer useful advice

Innovation

channels of distribution

Clinical

meaningful and perhaps motivating
clinical appropriateness and efficacy
weighted analysis of system requirements
…suited to the requirements of the recovery process
general requirements of therapy
developed and tested
consultation with clinicians and recovering stroke survivors
results of testing might be negative

Considering the clinically based problems, such as the need for consultation with clinicians and recovering stroke survivors, these were addressed through end-user interviews, as presented in Chapter Four. Clarification of the problems of other clinical issues – such as the need for meaningfulness, motivation, the requirements of the recovery process and the general requirements of therapy – have already been offered in Chapter One. Possible channels of distribution are outlined in Chapter Four, as a as part of study of stakeholder perspectives.

The engineering-based problems are however of direct relevance to the design engineering approach and a discussion of the issues raised by these problems are offered below with additional reference to the other types of concerns outlined above; the intention being to establish a hierarchical view of the design space.

Analysing the client statement: establish user requirements

Having established a more hierarchical structure for the design problems it might also be beneficial to attach values to some of the key concerns that we might identify from the problems flowchart. This helps gauge what is required in terms of time, work and other costs in the design and execution process. A degree of subjectivity is employed in this process yet it provides an expedient, consensual benchmark for the project development. To this end I have devised a pairwise comparison chart to offset the key objectives against each other, shown in *Figure 2.3*. Thus, a score of 1 represents one goal taking precedence over another, or at least equalling it in importance.

Figure 2.3. A pairwise comparison chart of the key design concerns

Goals	Clinically effective	Meaningful	Variable	Adaptable	User-focused	Marketable	**Score**
Clinically effective	x	1	1	1	0	1	**4**
Meaningful	0	x	1	1	0	0	**2**
Variable	0	0	x	1	0	0	**1**
Adaptable	0	1	0	x	0	0	**1**
User-focused	1	1	1	1	x	1	**5**
Marketable	0	1	1	1	0	x	**3**

Hence, we can now see that variability, for example, is weighted against marketability (we might interpret this to mean that the system is not marketable unless it is variable). Similarly, the system being user-focused takes precedence over adaptability, and so on. The scoring might also allow some priority to be given to some goals. In this way, user-focus achieved the greatest score, with the importance of clinical effectiveness and marketability also being highlighted. This is not to say that meaningfulness, adaptability and variability are not important, but that they simply do not take precedence over the other conditions in the design process.

Having established a value system among our design goals, a further chart might be drawn which demonstrates a system of precedence for the design process, as shown in *Figure 2.4*, as well as the possible relationships of precedence between the various design concerns (for example, how meaningfulness might have a stronger relationship with variability, and adaptability with marketability). *Figure 2.4* has also been annotated to show how the design problems might be grouped in relation to the weighted system of design concerns.

Figure 2.4, below, also serves to demonstrate that as user focus takes precedence over clinical effectiveness (as it perhaps ought to at the testing stage), the former design concern coincidently involves a greater number of design problems, an observation that might help in the planning of the project and avoid unnecessary time being spent on what might erroneously be perceived as a design concern of higher priority. This analysis has usefully shown the imperative of considering the user's needs in a specific treatment prior to clinical variability, for example.

Figure 2.4. An annotated objectives tree for the design process

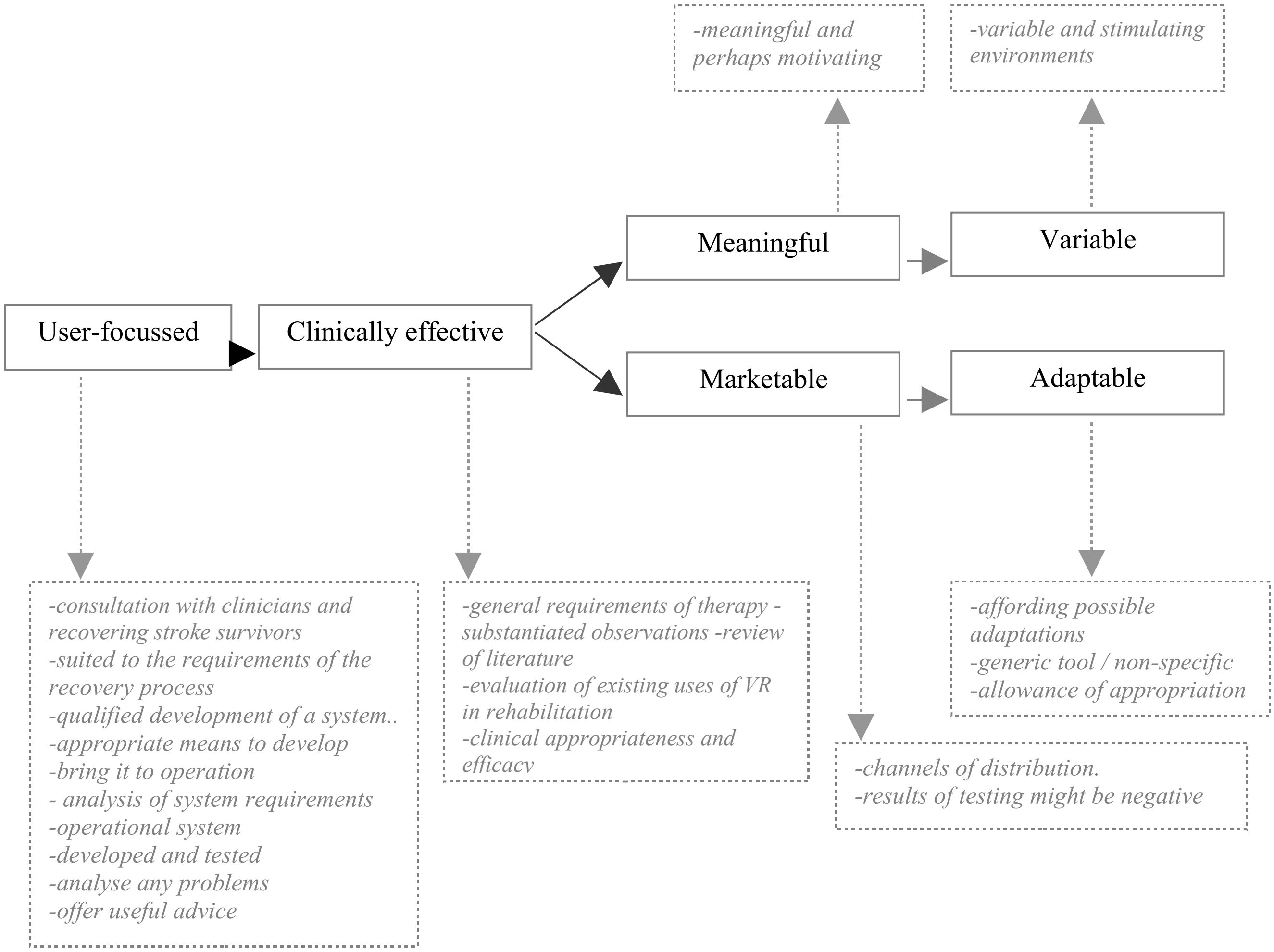


Figure 2.4 thus shows one possible hierarchical arrangement of the problems outlined in the client statement. Here we can see that the main objective of creating an operational system suggests certain criteria that must be fulfilled as, in turn, further criteria are suggested. Also included is an iterative process-based stage, ‘developed and tested’, and a decision-based stage, ‘analyse any problems’.

From this hierarchical analysis we might observe some new convergences of the design problems. For example, the need for ‘substantiated observations’ is at the top of one line of criteria along with the need to understand the ‘general requirements of therapy’. Similarly, the requirement for ‘consultation with clinicians and recovering stroke patients’ might now be described as being a starting point, rather than a general condition as the client statement suggests.

We might also observe that 'suited to the requirements of the recovery process' is now at the heart of the design space, along with 'bring to operation', as the first stage in the 'developed and tested' process. Also, the 'operational system' is now distinct from the other end product of 'channels of distribution', suggesting perhaps that the system being operable does not imply its suitability for distribution. And 'clinical appropriateness and effectiveness' might be regarded as a positive outcome, in direct contrast to 'negative results'. In this way, the nature of the ultimate outcome sought could be considered either an externally orientated strategy ('channels of distribution'), or internally orientated council ('offer useful advice').

Analysing the client statement: identify constraints

At this stage in the design process, a number of constraints have been given relating to the time in which the study was due to be completed, the financial cost and the normal ethical constraints. In testing the design with patients, the research must either be submitted to a clinical research review board for an ethical standards assessment prior to approaching a clinical centre, or provide an 'add-on' to an existing and highly similar study which has hitherto been passed for testing. The latter case might provide a favourable means for effective testing and would require collaboration with researchers at another centre.

Regarding the financial cost, inexpensive development tools do exist, but in developing these there is a 'cost' in terms of time spent in C++ coding[31]. Furthermore, although common and inexpensive input devices (keyboard, mouse and joystick) might be used, these might not be appropriate to the requirements of end users. Thus a collaborative project might also provide a solution to these problems.

The client statement: establish functions

The functions of the system differ to the design objectives in that they describe what the system must *do,* both as an end product and a field of study, in order to achieve the end goals. In designing a bird table, for example, we can observe that it must functionally withstand natural elements and discourage predators in order to achieve the end goal of supplying birds with food. We might therefore return to the list of client concerns and establish a possible function suggested by each problem, as shown in *Figure 2.5*, below.

[31]As of 2007, the NeuroVR system is freely available and easy to develop. Unfortunately, this very useful system was not available to the author when the practical work was under way

Figure 2.5. The functions implied by the client concerns

Key client concerns	**Functions**
unsubstantiated observations	Substantiate evidence from the field
variable and stimulating environments	Allow for changes in levels of complexity
meaningful and perhaps motivating	Allow patients to choose content
appropriate means to develop…	Select best equipment against given constraints
bring it to operation	Ensure system is effectively usable
clinical appropriateness and effectiveness	Avoid harm to user
review of literature	Present findings of other research
evaluation of existing uses of VR in rehabilitation	Quantify evidence from the field
weighted analysis of system requirements	Evaluate system's design problems
qualified development of a system..	Consult evidence and potential end-users
…suited to the requirements of the recovery process	Ensure users benefit from the system
generic tool / non-specific	Allow for various applications
allowance of appropriation	Allow for modifications
affording possible adaptations	Ensure system is configurable
general requirements of therapy	Avoid dominance of any one clinical field
channels of distribution.	Identify potential markets and risks
operational system	Ensure the equipment is usable
developed and tested	Analyse the system at every stage
consultation with clinicians and recovering stroke survivors	Evaluate system against users' experiences
results of testing might be negative	Avoid erroneous design imperatives
analyse any problems	Record system operations
Offer useful advice	Analyse systems operations

Having identified possible functions associated with each design problem, we might now assign metrics to them. These are the practical tests we might undertake to ensure that the design problems are suitably addressed. Hence, *Figure 2.6*, shows a possible metric assigned to each function.

Finally, we might present all of the tabulated details together and find that this design engineering approach has eventually led to proposing practical responses to the design problems that might not have been initially apparent and also suggested some order in which they could be executed. Some very general concerns such as 'developed and tested', for example, now have specific tasks associated with them, in this case 'Identify benchmarks in time and construction at which the system should be analysed with some objectivity; perhaps between experiment sets against a selection of functions'. In the same way, the somewhat ill-defined 'allowance of appropriation', now has the assignment, 'Provide elements for the VE that can be selected and placed easily and used in such a way that the environment is orientated to the user's needs'. These are not definitive and might be rejected or modified at a later point in the design, but they do provide a valuable 'springboard' for development. This is shown in Figure 2.7, below.

Figure 2.6. Possible metrics assigned to functions and metrics

Functions	**Metrics**
Substantiate evidence from the field	Review and criticise all results published, or communcate with other researchers/end-users for qualitative analysis
Allow for changes in levels of complexity	Create a task-based virtual rehabilitative environment in which the tasks become harder
Allow patients to choose content	Simulate various elements from different contexts, including workplace, household, popular hobbies,etc
Select best equipment against given constraints	Ciritically review all equipment currently avaliable against given constraints such as cost, weight usability
Ensure system is effectively usable	Observe users working with test models, make modifications according to their experience
Avoid harm to user	Engage the advice of a senior therapist
Present findings of other research	As well as reviewing research, also identify effective and creative means of communicating findings
Quantify evidence from the field	Frame a pertinant question and review literature/qualitiative data accordingly
Evaluate system's design problems	Include in the system some 'oblique' elements which might raise unforeseen problems/solutions
Consult evidence and potential end-users	Include in the analysis subjective criteria such as 'likeable', 'enjoyable', 'interesting', etc
Ensure users benefit from the system	At the testing stage, identify a goal that might be achieved during the experiment
Allow for various applications	Select a few standard therapy practices and build a system that can meet requirements
Allow for modifications	Provide elements for the VE that can be selected and placed easily and used in such a way that the environment is orientated to the user's needs
Ensure system is configurable	Design an interface that the therapist can use without interrupting the flow of the treatment
Avoid dominance of any one clinical field	Select a small and equal number of practices from physiotherpay and OT and design an environment in which
Identify potential markets and risks	Demonstrate the system to potential investors, guage and analyse their opinions
Ensure the equipment is usable	Test various types of hardware and software with therapists and patients; research other findings

Curiously, in spite of the pairwise analysis revealing that 'user focus' should take precedence over 'clinical effectiveness', the metrics associated with the latter design concern seem to require attention in the first instance:

1. Engage the advice of senior therapists
2. Frame a pertinent question and review literature/qualitative data accordingly

3. Select a small and equal number of practices from physiotherapy and OT and design an environment in which they can all be carried out
4. As well as reviewing research, also identify effective and creative means of communicating findings
5. Review and criticise all results published, or communicate with other researchers/end-users for qualitative analysis

The first metric of engaging a senior therapist also lends weight to the argument in favour of a collaborative study, as does the need to communicate with other researchers and end-users. The requirements of the end-user are of particular concern and compel the requirement for grounded qualitative analysis. The review of literature, presented in the next chapter, and a detailed user study, presented in Chapter Four, are intended to respond to these demands.

Discussion

This chapter has provided overview of the methods used throughout the study and described the process by which the client statement was analysed. It is hoped that this exercise has provided a means for further development to take place in a way that is consistent and coherent among engineers and clinicians alike.

The analysis thus led to the devising of a series of system requirements and functions, design concerns and outcome metrics. The design concerns were further subjected to a pairwise analysis, thereby developing a series of weighted objectives, which form an effective tool in examining both the state of the art and also the needs of potential users, as shown in the review of literature (Chapter Three) and the user and stakeholder studies (Chapter Four). The system requirements are be utilised (along with other metrics) in the generation of interaction models (Chapter Five).

Metrics	**Key design problems**	**Design concerns**	**Functions**
Identify the responses to observe, for example BVP or GSR, how expectation differ to experience, etc	*analyse any problems*	User-focused	Record system operations
Ciritically review all equipment currently avaliable against given constraints such as cost, weight usability	*appropriate means to develop…*	User-focused	Select best equipment against given constraints
Observe users working with test models, make modifications according to their experience	*bring it to operation*	User-focused	Ensure system is effectively usable
Interview patients and therapists about their expectations before and after using the equipment; measure these against physiological recordings	*consultation with clinicians and recovering stroke survivors*	User-focused	Evaluate system against users' experiences
Identify benchmarks in time and construction at which the system should be analysed with some objectivity; perhaps between experiment sets against a selection of functions	*developed and tested*	User-focused	Analyse the system at every stage
Describe how the subjective experiences described by the user correspond to physiological responses	*offer useful advice*	User-focused	Analyse systems operations
Test various types of hardware and software with therapists and patients; research other findings	*operational system*	User-focused	Ensure the equipment is usable
Include in the analysis subjective criteria such as 'likeable', 'enjoyable', 'interesting', etc	*qualified development of a system..*	User-focused	Consult evidence and potential end-users
Include in the system some 'oblique' elements which might raise unforeseen problems/solutions	*weighted analysis of system requirements*	User-focused	Evaluate system's design problems
At the testing stage, identify a goal that might be achieved during the experiment	*…suited to the requirements of the recovery process*	User-focused	Ensure users benefit from the system
Engage the advice of a senior therapist	*clinical appropriateness and efficacy*	Clinically effective	Avoid harm to user
Frame a pertinent question and review literature/qualitative data accordingly	*evaluation of existing uses of VR in rehabilitation*	Clinically effective	Quantify evidence from the field
Select a small and equal number of practices from physiotherapy and OT and design an environment in which they can all be carried out	*general requirements of therapy*	Clinically effective	Avoid dominance of any one clinical field
As well as reviewing research, also identify effective and creative means of communicating findings	*review of literature*	Clinically effective	Present findings of other research
Review and criticise all results published, or communicate with other researchers/end-users for qualitative analysis	*unsubstantiated observations*	Clinically effective	Substantiate evidence from the field
Demonstrate the system to potential investors, guage and analyse their opinions	*channels of distribution.*	Marketable	Identify potential markets and risks
Observe the hierarchical objectives already established	*results of testing might be negative*	Marketable	Avoid erroneous design imperatives
Simulate various elements from different contexts, including workplace, household, popular hobbies,etc	*meaningful and perhaps motivating*	Meaningful	Allow patients to choose content
Design an interface that the therapist can use without interrupting the flow of the treatment	*affording possible adaptations*	Adaptable	Ensure system is configurable
Provide elements for the VE that can be selected and placed easily and used in such a way that the environment is orientated to the user's needs	*allowance of appropriation*	Adaptable	Allow for modifications
Select a few standard therapy practices and build a system that can meet requirements	*generic tool / non-specific*	Adaptable	Allow for various applications

Figure 2.7. Metrics, problems, concerns and functions reconfigured according to precedence

Chapter Three – Virtual Environments for the Post-stroke Rehabilitation of the Upper Limb: a Review

General introduction

In Chapter Two, Problem Analysis, it was observed through the client statement that there appears to be a growing field of research pertaining to the use of virtual reality systems for neurological interventions in the contexts of physiotherapy, occupational therapy and neuropsychology. This review of literature represents an attempt to substantiate this observation while establishing a survey of the field as a whole.

Search and selection methods

The studies presented here are each reported in published papers in the English language. Much of the earlier material is available through conference proceedings and often describe pilot or other exploratory studies. More recent papers (after 2006) have been published in peer-reviewed journals and hence demonstrate more mature technologies and methods. For some major projects (such as the University of Haifa and Rutgers University projects), earlier papers alluding to pilot work have been excluded (although references to these have been provided).

The initial crude survey was conducted with internet-based electronic databases, chiefly Web of Science, using the search terms "virtual reality/virtual environments", "stroke rehabilitation", "upper limb", "activities of daily life/daily living" (given the immaturity of the field, search dates were not limited). The results revealed all manner of applications of the technology. A further research examined the bibliographies of each papers sourced through this method. A second, more refined, stage of research was conducted through a database of e-journals. This search focused too on the sensory-motor rehabilitation of the upper limb, functional performance of the activities of daily living (ADL) and matters of ecological validity (papers which lean more toward engineering and system design than clinical outcome have not been included).

Some of the papers selected for inclusion describe research pertaining to healthy subjects; these have not been described in length, but are referred to where relevant to the findings of the research regarding stroke subjects (e.g. where healthy subjects have acted as a control group). Generally, the literature reviewed here has been conducted no earlier than 1998 (with earlier papers cited in areas in which data appears to be scarce).

Where VR has been reviewed elsewhere in a clinical context, these have covered applications if the technology for motor rehabilitation (Sveistrup, 2004) or for brain injury treatments generally (Rose et al, 2005). Subsequent to commencing this literature review, other reviews of VR in stroke rehabilitation have been published, including Crosbie et al (2007)[32] and Henderson et al, 2007. The review presented here remains distinct to Crosbie et al (2007) in that it focuses specifically on the rehabilitation of the upper limb (including those VEs which might be of benefit to this, such as the shopping and ticket machine simulations outlined below), and distinct to Henderson et al (2007) in that it is considerably more comprehensive (only six are included in the latter paper, and their findings are explicitly inconclusive).

In some cases several papers report on various aspects or developments of a piece of research. Here, they are each assimilated and the data, where appropriate, is considered as a uniform set. A number of studies that care either lengthy or comprise a series of projects have been further summarised.

Review method

The material under review here remains largely at the exploratory stage (sample populations, for example, tend to be very small) and does not, on the whole, appear ready for 'industry standard' review methods (limitations and apparent inaccuracy in the findings of Crosbie et al, 2007, and Henderson et al, 2007, might thus stem from inappropriate scoring methods[33]). The field does, however, appear to be maturing (for example, more peer-reviewed material is emerging). Hence I would provide a caveat to the review in that it reflects the state of the art prior to autumn 2007[34].

<u>Applications of VR in the major areas of post-stroke rehabilitation</u>

Outlined below are many of the cases in which virtual reality has been used to support clinical interventions in physiotherapy, occupational therapy and in neuropsychology. Overlap in

[32]Crosbie et al (2007) adopted a formal scoring system (American Academy for Cerebral Palsy and Developmental Medicine [AACPDM]), in their paper, which led to a less than positive evaluation of the field of VR in rehabilitation. This, however, has come under criticism (Weiss and Ring, 2007). The latter authors' concern was that the AACPDM system was devised to evaluate treatments more mature than VR in stroke rehabilitation as it currently stands.

[33]A bespoke scoring system was applied to the review in the early stages of the research. Further details of this are provided in Appendix 2.

[34]The proceedings of Virtual Rehabilitation, September 2007, contain a number of projects that I feel change the character of the field in VR in rehabilitation, not least the public launch of NeuroVR, which offers a simple VR development tool and a database of useful models for a clinician to apply and develop – this is addressed further in the concluding chapter. Much of the hardware demonstrated at the conference also appears to have overcome many of the interface problems outlined in the present study

therapeutic practice does occur between these clinical fields, especially with regard to the present subject, but, generally, motor relearning is examined in the physiotherapy section, task-orientated interventions in occupational therapy and the treatment of cognitive disorders are, in the main, under neuropsychology.

Physiotherapy

Upper limb function

Post-stroke, haptic feedback, fine motor function, grip strength, speed, ADL

Broeren et al (2004) report on their research into a virtual reality and haptics system which was adapted for use as movement training stroke. The system was tested against a single patient, a male in his late fifties who had suffered a stroke 12 weeks previously and had deficit in his left arm. The subject was tested with the Purdue pegboard test (measuring unilateral and bilateral dexterity for gross movements of hands, fingers, and arms, and finger dexterity) and the dynamometer hand-grip strength. A third test for the upper extremity involved moving a PHANToM haptic device to various targets as part of game which was presented on a screen. The speed to which the targets moved was adjusted as the subject progressed.

A control group was also observed performing the same exercise. The subject was subsequently interviewed about his use of the affected upper extremity in performing ADLs. (Nine healthy men, all right-hand dominant, mean age of 50 years). The authors report that after training, the subject showed improvement of 11% in fine manual dexterity with the Purdue pegboard, with 17% improvement shown in a 20-week follow-up session. The results of the bilateral test showed improvements of 22% which persisted through to the follow-up. Hand grip increased from 13% to 57% in the follow-up, compared with a reference group of 9 healthy men. In the follow-up assessment, the subject reported that, after the training, he was able to use his left arm in several ADLs that had previously proved impossible to perform.

Physiotherapy, upper limb function

Jang et al (2005) report on their apparently unique study of the impact on the motor-cortical organisation of stroke patients using a virtual reality system. Ten patients were tested (6 men, 4 women; mean age, 57.1±4.5). Each had suffered a stroke at least 6 months previously and each could move the elbow against gravity. *A* physical therapist performed the box and block test (BBT), the Fugl-Meyer Assessment and the manual function test (MFT). In addition, after completion of VR training, the therapist conducted a Motor Activity Log (MAL) interview in order to assess subjects' use of the affected limb in performing ADLs. Unusally, the authors also took MRI scans of the subjects' brains before and after VR training.

The VR system was a non-immersive video-game system highly similar to that used by the University of Haifa team, cited elsewhere in this review (see Naveh et al, 2000; Kizony et al 2003, 2004; Rand et al 2005). Therapists trained in the VR system determined baseline functional performance, thus providing a scheme treatment, and subsequently monitored the clinical outcomes. Progression through the exercise was provided by adjusting speed, angle, and force feedback. In a selection of the subjects, a simple-to-complex learning strategy of 'knowledge of results feedback' was initially given (>90%). This feedback was gradually decreased as performance improved. The exercise was performed 5 times for each game and was given for 60 minutes a day, 5 times a week for 4 weeks.

Pre-training tests revealed no significant difference between the groups for the BBT, FMA, and MFT scores at the pretest (P<.05), indicating that both groups had similar motor function to begin with. Similar test post-training revealed change for each mean BBT, FMA, and MFT score with a difference between the groups (P<.05), that indicated an improved motor recovery. The control group did not show any significant change. Regarding cortical organisation as observed in the MRI scans, the authors focused on the sensory-motor area 1 (SM1) activation. The details of this part of the research are beyond the scope of the present review but, to summarise their intriguing findings, the authors demonstrated VR-induced neuroplasticity relating to hand motor recovery. The MAL interview also revealed how the functional hand motor recovery resulting from the VR training was transferred ADL tasks. The authors argue that the subjects who received sensory feedback during the VR training were able to internalize the motor representation of the target motor behaviour through imitation. This, they suggest (with some vindication), might have served to facilitate use-dependent cortical plasticity (that is, reorganisation of the brain), which was primarily effective in the SM1 area.

Critical summary of Jang et al (2005)

Jang et al (2005) describe their testing of a game-based rehabilitation system with en patients (6 men, 4 women; mean age, 57.1±4.5). Patients were allowed to train before using the system on a regular basis while the investigators adjusted the system through speed, angle, and force feedback. MRI scans were taken during activity and subjects also completed MAL questionnaires. The authors report that the subjects who received sensory feedback during the VR training were able to internalize the motor representation of the target motor behaviour through imitation, although this finding appears to require further substantiation.

Post-stroke hand function

The Rutgers Hand is an 18-sensor haptic, force feedback glove that allows the patient to engage in a considerable range of strengthening exercises including manipulating virtual pegs, which simulates a standard therapeutic practice[35]. Testing of motion and fractionation function was undertaken with a dataglove (Merians et al, 2006). Eight subjects (six males, two females; mean age 64±11); each were in the chronic post-stroke phase (stroke sustained 1-4 years prior to testing). The subjects were selected against the movement function criteria outlined in Taub and Wolf (1997) and were tested during an three-week programme (comprising thirteen days in total, with sessions lasting 2-2.5 hours each day) in which the hemiparetic hand was trained for range of motion, thumb and finger velocity and strength, fractionation (the ability to move fingers independently of each other), the Jebsen Hand Test of Hand Function[36] and a kinematic reach and grasp test. Subjects were also given a post-test questionnaire.

The authors provide a table of clinical data pertaining to the subjects' clinical conditions. One subject was excluded on the grounds that the nature of his or stroke (left-side lesion) was different to all other subjects'.

Training was followed by a one-week retention test (with two of the subjects who had improved significantly being retested after two weeks, and again after six months). The training programme was based on simple computer games that each allowed the functional performance of the individual digits to be trained and tested. After training, all seven remaining subjects showed significant improvements in fractionation and range of motion, with limited improvements in speed. Improvements were also observed in *post hoc* testing against Jebsen Hand Test criteria (these improvements were not reflected in the unaffected hand, for which no training had been undertaken). There were also improvements found against the kinematic measures, with four of subjects showing significant improvements to specific finger deficits, and one in speed of reaching and grasping. Another subjects showed improvements on hand and and finger preshaping (that represent an improvement in coordination function, rather than mechanical performance). Two of the subjects did not improve on the reach and grasp parameters, while one of these showed no improvement in transfer from training to real world (the other of the subjects found the VR system difficult to use).

Of the subjects were retested after two weeks and six months, one continued to improve upon previous performance in range of motion (8%) and speed (6%), although no further

[35]Publications relating to early testing of the Rutgers Hand include Merians et al (2002); Jack et al (2001) and Adamovich et al (2005) also report on system design and testing. The interested reader is directed to Deutsch et al (2002) where video clips of the system in use are available for viewing. A related system adapted for training the lower limb is reported in Merians et al (2004)

[36]A commonly used test which comprises writing, card-turning, picking, stacking and eating activities

improvements were found to fractionation. This subject also retained much of Jebsen-based performance in VR tasks, although this retention was not reflected in the transfer to real world tasks. The second subject to be retested also continued to improve on training, with considerable increases to range of motion (27%), speed (77%) and improvements in fractionation (101%). Other significant were found in the Jebsen-based parameters (22%), although here the subject did report that she had undertaken self-led training at home.

Physiotherapy, reach and grasp function

The goal of research presented by Viau et al (2004) was to determine the potential gains in upper limb function through training in two tasks, (reaching and grasping a ball; releasing the ball), performed in a VE in comparison to the exact same tasks performed in a real environments. The sample group consisted of 8 healthy adults (4 males, 4 females, aged a mean 56.8±17.1 years), and 7 patients with mild left hemisphere hemiparesis due to stroke (3 males, 4 females, aged a mean 48.9±18.6 years); patients were screened for other conditions that may have affected the motor abilities of their arms.

Functionality was measured by tracking the movements of the Cyberglove worn by each subject. Training in the tasks was undertaken for 20-40 minutes. The first trial task (reaching and grasping a ball), was divided into 4 temporal and 4 spatial parameters; the temporal being: movement time; time to peak wrist velocity (RPV); time to maximal hand aperture (RMGA); delay = (RPV-RMGA). The spatial parameters being: endpoint path curvature, maximal grip aperture; angular ranges of joint motion; elbow-shoulder interjoint coordination.

For the second trial task, (releasing the ball), one temporal parameter was determined, (movement time), as well as the four spatial parameters listed above. The authors have presented their data with exemplary clarity; the results of the task performances are presented in *Figure 3.1,* below.

The authors found that both healthy subjects and stroke patients were able to reach, grasp, transport, place and release the virtual ball using movement strategies that were similar to those used for the physical ball. In healthy subjects, the temporal and spatial aspects of the two phases of the task were almost identical between the physical and virtual conditions, although the stroke patients performed the tasks more slowly and used less wrist extension for grasping in the VE. During the second phase, healthy subjects used significantly less wrist extension (paired t-test, $p < 0.05$) and more elbow extension (paired t-test, $p < 0.05$) to place the ball on the virtual vertical surface. In these subjects, there were no other differences between any other temporal or spatial parameter for both movement phases.

Despite these differences, patients showed tendencies similar to healthy subjects when reaching and grasping in the VE compared to the real environment. They also tended to decrease the speed of movements made in VR compared to the physical environment, to use less wrist extension in both movement phases and to use more elbow extension in the second phase of the movement. Five out of seven participants with hemiparesis significantly decreased the wrist extension while four increased elbow extension at the end of the second phase of the movement in the VR condition.

Figure 3.1. Results of a 'releasing' task in VR and physical environments, adapted from Viau et al (2004)

	Healthy Physical		Healthy VR		Stroke Physical		Stroke VR	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Temporal parameters								
Onset to placing (Movemenent Time)	0.84	0.29	1.18	0.31	1.49†	0.45	2.28†	0/82
Spatial parameters								
Curvature index	1.14	0.03	1.23	0.29	1.37†	0.27	1.42	0.57
Wrist extension at placing (°)	18.2	12.1	4.0*	8.1	20.3	8.2	6.4	16
Elbow extension (°)	25.6	6.9	38.4*	10.9	26.9	11	37.3	19.6
Shoulder flexion (°)	24.8	5.2	33	7.1	28.4	4.9	35.5	18.2
Shoulder abduction (°)	13.6	5.2	16.4	4.6	18.5	6.9	20.7	8.9
Slope elbow extension/shoulder	1.08	0.08	1.21	0.16	1.01	0.26	1.18	0.15
Slope elbow extension/shoulder	2.36	0.76	2.88	1.19	1.51†	0.69	1.48†	0.51

* Significant difference between reality conditions, Student t-tests with Bonferroni correction (p <
† Significant difference between groups, Kruskal-Wallis, $p < 0.05$

The authors also found that movements made by individuals with hemiparesis in the physical environment were significantly slower than the healthy subjects and in the second phase trajectories were more curved and interjoint coordination was altered. In particular, the slope of the relationship between elbow extension/shoulder abduction was lower than in healthy subjects during the second phase of the movement ($p < 0.02$).

Decrease in use of wrist extension is common among both patients and healthy subjects as this function must work against gravity. Moreover, this behaviour is especially common to hemiplegic patients who might overcompensate with easier movements when engaging in grasp/release tasks. As it gains special attention in OT interventions, this problem ought equally to be a cause of concern for the clinical use of VR.

The authors describe how this similarity in movement kinematics between physical and virtual reaching and grasping suggests that virtual reality may be an effective environment for rehabilitation as the skills may be transferred from training to real-world situations. It would seem that these are a reasonable assessment of the results and that the authors achieved their research goals. In spite of the initial problem with an ill-defined research parameter (‘validity’), the success of this project appears to have resulted from clear sampling, careful choosing of appropriate parameters and conservative analysis of the data.

Critical summary of Viau et al (2004)

Viau et al (2004) describe the testing of a virtual reality system designed for reach, grasp and release function whereby the simulated task performance was compared to the equivalent real-world task performance. The system was testing among 8 healthy adults and 7 adults each experiencing post-stroke conditions to a broadly equal degree. The subjects had each been screened for other conditions which might affect motor function in the upper limb were all below the age of 60. The authors used universal physiotherapy outcome measurements pertaining to biomechanical function. The data were presented clearly and the analysis was cogent.

Physiotherapy, reach and grasp function, qualitative research

Working at the University of Ulster, the authors of Crosbie et al, 2004a, present the results of a study based upon the testing of the virtual reality based system for the rehabilitation of the upper limb and also the qualitative, user-focused research conducted around the tests. The system is a non-immersive virtual environment that simulates a domestic space and an avatarial arm and hand. The user interacts with the VE through a stereoscopic HMD and a dataglove. Visual and auditory cues are given as the user interacts with simple, geometric shapes within the environment. Magnetic sensors attached to the shoulder, elbow and wrist and the HMD to ensure that correct posture is maintained.

The system, in brief, was designed to incorporate reach, grasp, release and manipulate components at a range of levels of difficulty according to the patient’s therapeutic requirements. The activities involved specific joints, whole arm and fine motor control. A further wrist extensor task was instigated in support of the other exercises. Complex exercises were designed so that the sub-sets of the activity could be distinguished.

The authors interviewed two user groups: (a) one group of stroke patients (n=17) to ascertain their views of the tasks prior to and after treatment as well as their therapeutic requirements and (b) one group of users, (healthy; n=10) and (post-stroke; n=5), about their perceived levels of presence, exertion and any side effects. Tables 4, 5 and 6 offer a breakdown of the focus-group subjects.

Figure 3.2. Post-stroke focus group participants, adapted from Crosbie et al, 2004a

Group	Subject	Sex M/F	Age	Time since stroke (yrs)	Right/Left years	Upper limb movement
A	1	m	72	12	l	y
	2	m	78	2	r	y
	3	m	52	15	l	y
	4	m	65	2	r	y
	5	m	61	1	l	n
B	6	f	75	15	l	n
	7	f	78	7	r	y
	8	f	62	9	r	y
	9	m	63	6	l	y
	10	m	73	3	l	y
C	11	m	62	12	r	y
	12	m	72	5	l	y
	13	m	81	9 months	r	y
	14	m	60	10	l	y
	15	m	75	15	l	y
	16	m	65	2	r	n
	17	m	67	11	r	y

Figure 3.3. Post-stroke focus group participants, adapted from Crosbie et al, 2004a

Question	**Response summary**
What sort of activities can you do with your stroke arm?	Reaching tasks
	Everyday tasks
What would you like to be able to do with your stroke arm?	To hold objects
	To be able to use arm in getting dressed
What types of exercises/tasks do you think people with a stroke	Based on everyday actions
should be practicing with their arm?	Working above shoulder level
	Fine finger movements (expressed by a minority)
How many of you had any form of therapy after stroke?	Majority: some therapy involving in and out patients setting and
	lasting 6 weeks-5 months
Can you remember how much time was directed to getting	Majority: lower limb and walking treatments
movement back to your arm?	Minority: upper limb treatments
Do you think you would be able to use a virtual computer system	15 of 17 subjects said they would like to use such a system
to help you practice arm movements?	A few were concerned about their lack of knowledge of the system

The data presented here show that among both healthy and post-stroke subjects there was an equal balance of subjects more or less likely to become immersed in the VE (ITQ scores). Subjects from both groups also report a favourable experience in using the system (TSFQ scores). Side effects were experienced by some healthy users and one post-stroke user. The main difference between the groups appears to have been the perceived exertion (Borg rating), with the healthy subjects reporting none to weak levels, and the post-stroke group reporting moderate to high levels.

Figure 3.4, 'Side effects' focus group participants, adapted from Crosbie et al (2004a)

Healthy Group				
				Reported side
Subject	ITQ* (pos/neg)	Borg rating†	STFQ‡	effects (y/n)
1	Neg	2 - weak	13	No
2	Neg	2 - weak	12	Yes
3	Neg	1 - very weak	9	Yes
4	Pos	1 - very weak	8	Yes
5	Pos	0 - nothing	12	No
6	Neg	0.5 extremely weak	9	No
7	Pos	2 - weak	6	Yes
8	Pos	0.5 extremely weak	11	No
9	Neg	4 - weak-moderate	17	Yes
10	Pos	3 - moderate	11	No
Post-stroke group				
1	Pos	7 - very strong	12	Yes
2	Neg	5 - strong	9	No
3	Pos	3 - moderate	10	No
4	No data	5 - strong	15	No
5	No data	5 - strong	28	No

*Immersive Tendencies Questionnaire
†Borg rating
‡Task-Specific Feedback Questionnaire

Critical summary of Crosbie et al, 2004a

The authors of Crosbie et al, 2004a, describe their research into a virtual reality system designed for post-stroke upper limb motor functionality training. Subjects can perform tasks by interacting with simple virtual objects in a simulated, generic domestic space using a dataglove. The system was tested with a total of 27 subjects, 10 healthy and 17 post-stroke. Within the post-stroke population, there were disparities in age, in the length of time between the stroke and testing and in range and levels of ability. Extraneous factors which might affect outcomes were not acknowledged, but the research was intended to include a range of subjects in order to generate novel data. Outcomes were measured using qualitative methods, including a questionnaire pertaining to general functionality and use of the affected limb. All subjects were likely to become immersed in the VE and reported a favourable experience in using the system. One marked differentiation was the tendency for post-stroke subjects to feel tired after using the system.

Occupational Therapy

Task- and game- based interventions

Upper limb kinematic assessment and training (ADL)

Broeren et al (2007) describe the testing of a haptic force feedback training system based upon the adaptation of a 3D visualization 'work bench'. Subjects interact with the system through a haptic device handle and stereoscopic glasses. Five post-stroke subjects were recruited (all male, mean age 59±4.0 years; strokes occurred >9 months previously) and undertook training three times a week for 5 weeks, 45 minuted per day. Training involved playing a ball and target game. Basing their methodology on a previous study (Broeren et al, 2004, outlined above), the authors maintain that the system is designed for training for ADL, but this does appear to have been examined in this particular paper.

The authors observed that the subjects each improved against the kinematic criteria (velocity, timing and hand path ratios) but also maintain that such case-based work ought not to draw firm conclusions. Their discussion thus focuses on a finding that their graphs appear to reveal subjects' hesitations in motor planning of the tasks. The authors compared this finding to video-taped evidence of subjects' performance, which revealed kinematic problems and limitations in undertaking their training.

Game-based intervention (population includes subjects with spinal injury and cerebral palsy)

Kizony et al (2003, 2004) each outline testing and analysis of a system developed at the University of Haifa, Department of Occupational Therapy (additional comparative analysis of the system with healthy subjects was reported in Rand et al (2005). The researchers report on their attempt to adapt a video gesture-based VR system for use in neurological rehabilitation using VividGroup's Gesture Xtreme. Using the Gesture Xtreme system enables the patient and therapist to view an image of the patient that interacts, through the patient's own gestures, with elements within the VE. Their work provides a significant contribution to the field of VR in rehabilitation and are outlined here comprehensively.

The systems present a series of game-like virtual environments[37] including a touch-sensitive ball game, a goal-keeping game and snowboarding game. The authors opine that the advantages with this system are that is uses specific body part or all body parts; that the user views himself through video rather than a graphical avatar; that the user controls his movement

[37] The interested reader is directed to McComas and Sveistrup (2002) where videos of highly similar systems to those described here are available for viewing

directly and that they do not need to wear an HMD, dataglove or other external device. They cite the disadvantages as being that the scenarios and interactions are two dimensional and only visual and auditory feedback is given.

Their population includes subjects with a range of conditions, each raising markedly different clinical concerns and interventions, included patients with stroke (3 patients – specifically with left unilateral neglect), spinal cord injury (4 patients) and cerebral palsy with some mental retardation (5 patients). Regardless of this inhomogeneity, the authors presented each patient with an abbreviated version of the Scenario Feedback Questionnaire (SFQ), (Witmer and Singer, 1998), which includes eight questions pertaining to enjoyment, sense of being in the environment, success, control and so on[38]. All were able to use the system and were reported to have evinced enjoyment of the exercises. The authors also report anecdotally how one stroke patient improved in bilateral movement but they present no performance data in this paper.

Kizony et al (2003) members of the Haifa team tested their system with two stroke patients (both male, aged 72 and 68) and recorded their psychological responses to the SFQ, finding that both patients felt a high sense of presence during their VR experiences (scored between 4 and 5 for all VEs). The 72-year-old is also recorded as evincing considerable pleasure in using the VEs.

The team later advanced and extended the GestureXtreme project while further developing their methodology Kizony et al (2004). Using the Gesture Xtreme system they sought to examine the correlations between cognitive and motor ability and performance in using various VEs. Thirteen patients were selected for the task (four female, nine male, with a mean age of 66.3±7.9 years). The OT with whom the present author conferred remarked on problems with the ill-defined selection criteria: six of the patients had suffered a left hemisphere stroke, the remainder a right hemisphere stroke; the time of onset since the stroke ranged between 5 weeks and 11 months with the patients experiencing various levels of sensory and proprioceptive function. The selection criteria also included independence in performing ADLs but with little consideration of extant compensatory behaviour.

The patients were also tested for cognitive function with standard clinical tests including the Star Cancellation Test, the Mesulam Test and the Contextual Memory Test, and so on, as well as standard motor tests, the Fugl-Meyer Motor Assessment and the Ashworth Scale. Touch sensation and proprioception were tested with the Thumb Test. Here, the authors record that only eight of the patients had intact touch sensation, yet they did not allow this to effect the basis of their sampling.

[38] Problems with using this psychological technique have however been raised. See for example Slater (2004)

The patients participated in the ball game, soccer and snowboarding exercises described above. The patients all scored highly on the Scenario Feedback Questionnaire, reporting immersion levels of over 4, (out of a maximum of 5), in each virtual environment. The authors also note that high levels of success in the soccer game correlate with high levels of enjoyment, but the remaining correlations between presence, enjoyment and performance 'were not significant', although no figures are given in support of this observation.

The authors also report that significant correlations were found between some 'cognitive' tests and performance within the virtual environments: between the categorization test and response time in the ball game ($r=-.61$; $p<.05$) and per cent success in soccer ($r=.57$; $p=.053$); between the Mesulam attention test and per cent success in skiing ($r=.56$; $p<.05$) and between the Contextual Memory Test and per cent success in Birds & Balls ($r=.57$; $p<.05$). In the motor tests correlations were found only between the Fugl-Meyer coordination/speed test and per cent success in soccer ($r=-.84$; $p=.001$) and response time in Birds & Balls ($r=59$; $p=.54$). The authors claim that their results are, in summary, the greater the cognitive ability, the better the performance within the VE; yet good motor performance is related to poor performance within the VE.

In their discussion the authors seem to assert that presence in a VE is related to meaningful activity. They also point out inconsistencies between the motor tests and the activities performed within the VEs and accept that additional measures of motor ability, as well as sampling in larger numbers, ought to be employed.

Critical summary of Kizony et al (2003, 2004)

The findings presented throughout Kizony et al (2003, 2004) represent comparisons of three therapeutic games, each created from a video-based VR system designed for motor and cognitive training for a range of neurological conditions. The games were each tested with 14 subjects with a disparity in age, level of ability and experiencing very different clinical conditions. The authors employed qualitative outcome measurements, although these appear to be ill-defined and inappropriate to some of the subjects. The positive findings pertaining to motor recovery have not been substantiated.

<u>Activities of daily living (ADL) interventions</u>

Kitchen tasks, executive function

Christiansen et al, 1998, outline a project undertaken at the Virtual Reality for Brain Injury Project at University of Lund, Sweden. The team, comprising staff from the departments of ergonomics and rehabilitation, tested the effectiveness in cognitive rehabilitation of a training kitchen simulated in a VE. Thirty patients were selected to take part, each with Traumatic Brain Injury (TBI), each independently mobile (including use of a wheelchair) and with a mean age of 30.96±8.08 years. The mean level of 'trauma' was severe at 6.46±3.6 on the Glasgow Coma Scale, which usually indicate levels of consciousness, yet the researchers appear to have adopted this scale to describe head injury.

The patients were asked to perform an ADL task by clicking with a mouse on elements within the simulated kitchen to reflect its component stages. The ADL chosen for the trial, preparing soup, involves around thirty component activities. Each patient was assessed twice over a period of seven to ten days, with scores given based upon performance. The results of the component tasks were analysed with the Intraclass Correlation (ICC) approach, which can be used for test-retest analysis, and with a coefficient of variance for the method error (CV_{ME}).

The mean assessment score for the first ADL tasks was 156±14.33, and 161±13.02 for the retest, demonstrating some improvement in performance. These results show an ICC of .73 with a CV_{ME} of 9.43%. The authors point out, however, that there is little variability between the performance scores as a whole (admitting that the tasks may have been too easy). This might well affect reliability of the ICC score.

Outlining further work with the simulated occupational therapy kitchen at the University of Lund, Linden et al (2000) describe testing a simulated ADL task, brewing coffee, the results of which form part of the methodological basis of the VE treatment outlined in (Davies et al, 2002). It sought to determine whether a VE could provide effective cognitive treatment for post-brain injury patients; to determine the optimal interface for the most appropriate user and to investigate transfer of training from VE to the real world[39].

The authors go on to highlight issues regarding problems with VE interaction for ABI or TBI patients, including equipment loading problems, nausea and tiredness associated with extended VR use and extraneous cognitive load resulting from using the VR tools themselves[40]. Regarding these concerns, they go on to outline some guiding design principles, including (to paraphrase): only things that exist in the real environment should exist in the virtual; the user

[39]Research pertaining to transfer is not presented in this paper. The authors' earlier report Christiansen et al (1998) does provide useful information about their methodologies

[40] The article was published in 2000 and research undertaken since then has largely disqualified concerns over heavy equipment and 'cybersickness' (Sveistrup, 2004; Rizzo et al, 2004). The issue of cognitive overloading may continue to be a concern, but findings from research surrounding this issue are not recorded in this paper

must have free choice in the initiation and order of events; in choosing between one design element and another, the simpler should always be chosen.

The ADL task was tested with a sample group of two ABI patients (a man and a woman), and four healthy subjects. The only other information supplied about the group is that the subjects were together aged between 35 and 58; they had at least elementary PC experience and could all make coffee in the real world. Each subject was asked, after training, to perform the brewing coffee exercise five times. This process was then repeated a week later without training. The process was video-recorded for analysis and an interview, consisting of fourteen questions, was conducted pertaining to the subjects' experience of the VR tool and on the navigation and interaction.

Many of the subjects (no breakdown given) reported a series of problems regarding forgetting how to perform the task, as well as the disparity between their personal prejudices of the task (how a coffee machine works, where you put the coffee, and so on) and the way in which the VE is logically operated. The authors report that all subjects showed a 'reluctance to let go of these mental models', a phrase which arguably suggests an externally imposed normative system, perhaps contrary to their 'free choice' design principle.

The authors also report that one patient showed a tendency to mouse-click to the right of the object (perhaps stemming from a visual problem or neglect), while the other patient, *Subject C,* spent some time trying to place the objects to the right of the coffee machine, as was his or her requirement. Both patients became tired after repeating the tasks. In other words, 100% of the patients tested had difficulties in using the VE for reasons the authors have yet to investigate. They also report that 'only one' of the two subjects was disturbed by being filmed.

Subject C was the only subject that did not improve in performance time over the course of the treatment. The fact that this subject was one of the two patients being tested has not been fully acknowledged by the authors which, given the title of the paper[41], is a serious omission. Yet they conclude that the 'VE tool could well be usable for rehabilitation', a possibility which seems to require further investigation.

Similarly, Davies et al, 2002, the report on further research into patients' transfer of ADL skills beyond the hospital. Whether this approach is appropriate to the rehabilitation goal of the transfer of skills is not dealt with critically in this paper. In consultation with occupational

[41] "Task Performance in Virtual Environments Used for Cognitive Rehabilitation After Traumatic Brain Injury"

therapists, the project is based upon a real training kitchen and a very similar, simulated kitchen.

The preferred means of navigation is usually a large, programmable keyboard. The patients may also see a simulated 'carrying hand' if necessary. Both error-free and trial-and-error kitchen task training is encouraged and the patient may, under some circumstances, use the system entirely independently of the therapist. The exact means of manipulating the VE and of carrying out the tasks is not detailed in this paper. The kitchen VE also has aural stereo effects to aid the illusion of it being a real environment.

Kitchen tasks, upper limb function, tangible user interface

The authors of Pridmore et al (2004) and Edmans (2004) together describe two projects that have been established by the University of Nottingham with the intention of providing mixed reality (MR) systems to aid the transfer of clinical training into the real world while provided digital and physical information. The two MR systems are each based upon a standard practice in occupational therapy in which the therapist supervises, and intervenes where necessary, as the patient performs the ADL of making a hot drink[42].

The VE of the first MR system described consisted of simulation of the elements needed to make a hot drink (kettle, teapot, mug, spoon, etc.). The objects were manipulated via the touch screen of a notebook, as the patients could either point at the components needed to perform the task or use a drag-drop/proximity sensor option to move the objects around the VE. The system also provided audible feedback.

In a prior test of a similar system the *point-at* interface was found to be more usable than the drag-drop interface for all nine of the stroke patients examined, each at different stages of their recovery. All patients expressed a preference to use the *point-at* interface in the MR system described here. The authors do not, however, mention the findings of patient difficulties in performing these tasks, resulting in some frustration, irritation and even anger, as described in Edmans et al (2004) and presented at the same conference outlined below, This latter paper in fact suggests that the interface was abandoned in a number of cases. Their results are also contrary to the findings of another paper they cite (Linden et al, 2000)[43], but offer no explanation as to why this might be the case.

[42] Hilton et al, 2000, describes the qualitative research that forms the methodological basis for the work presented in Pridmore et al (2004), outlining the findings of a seminar designed to gauge user acceptance among occupational therapists working with stroke patients.
[43] This paper is largely beyond the scope of the present review

In the second MR system described, the VE is the same as that described above, but the elements are manipulated through a tangible user interface (TUI). This was created by attaching sensors to real kitchen artefacts, so that the VE elements would synchronise with their movements. The authors go on to provide information about the engineering of the TUI but not of the clinical results of the project. Marked by its absence in the conclusion is any reference to the issue of transfer, which the authors stated as being a chief concern in their abstract.

The authors insist that a participatory, iterative design process is necessary, as well as an understanding of individual patient needs, before their system gains value for stroke rehabilitation. In this respect allude to the work described in Edmans et al (2004) described below.

Edmans et al (2004) describes from a clinical perspective the same TUI research described in Pridmore et al (2004). However, the authors allude to a testing process not described in Pridmore et al (2004), where patients were provided with mouse, keyboard and joystick interfaces. All however were found to be unsuitable in their usability; hence the move toward a movement-sensitive TUI. They also offer further, though uncritical, information about the involvement of the occupational therapist (OT) in the project. They describe how the therapist's advice was derived from her or his observation regarding general patient preferences; not however from any corroborative source of data regarding task simulation in VEs[44].

In order to establish a measurable system for the task simulation, the therapist also conducted a task analysis for making a hot drink – finding twenty-five stages in the process. She or he also recorded common pathological errors often observed in this process. The authors cite an advantage to simulating this task in a VE as being the diminishment of risk (e.g. avoidance of scalding, and so on), yet it might be argued that the therapist should avoid exposing the patient to this level of risk in any event. Furthermore, the authors of (Davies and Wachtel, 2000) describe a number of instances in which, having used a simulated, high-risk car-driving task, patients have elected not to return to real-life driving. 'Risky' VEs, therefore, might affect attitudes to real-life risk in ways that researchers have yet to understand satisfactorily.

The authors also observed that the active intervention of the OT was instrumental to the success of the rehabilitative process, and therefore in using the MR system, especially given the educative nature of the OT's patient prompts: "What do you need to do now?" and "What do you need to do next?" etc. They also observed that the OT occasionally asked the patient, "What are you *trying* to do?" [my emphasis] and concluded that the MR system would not be able to handle in isolation such subjective motivation.

[44]Hilton et al, 2000, does however provide evidence of background research to this study into therapists' practices and attitudes

They conclude that not only is the system effectively inoperable without a therapist's presence but that additional staff is required to set it up. Either increased ward space or a specialised unit is also required, as is additional security (for equipment and data). They also report that both staff and patients have failed to relate the virtual task to the real world task. In spite of these problems, however, the authors go on to claim that they have established and tested a system that is 'well received' and 'fit for purpose as a rehabilitation tool'. The evidence presented in this paper, and in Pridmore et al (2004), point to the possibility that this assertion has yet to be fully substantiated.

Wheelchair training (sample includes various conditions)

The authors of Harrison et al, 2002, present their testing of two virtual environments which modelled rooms in the treatment centre. The environments were designed to allow inexperienced subjects to train in navigating a powered wheelchair and in route-finding: a hospital corridor leading to various therapy rooms and a large room in which chairs had been arranged to create an obstacle course, thus posing a range of navigation challenges. Training was given by auditory feedback which signalled when the subject had deviated from the intended path. The researchers also gauged the subjects' opinions about the aesthetics of the VE.

The hospital in which the research was undertaken normally treats clients with severe impairments; the sample population consisted of two females and four males (mean age = 31, a relatively young population). Four subjects were victims of traumatic brain injuries, one subject had suffered a brain stem stroke and one TB meningitis. Post-training improvement in manoeuvrability was recorded in three of the subjects, with no or limited improvements found among the remaining participants. It was found that the subjects each found using the virtual environments more challenging than using the real environments. The virtual wheelchair was also found to have limitations not found in the real equipment. Nevertheless the aesthetic content of the VEs was well received and two of the participants indicated that the VEs are clinically suitable.

Neuropsychology

Although a few examples of VR in neuropsychological interventions exist, the field in recent years has received less attention from VR engineers than occupational and physical therapy. It might however be argued that work at the University of Lund, cited above (Christiansen et al, 1998; Linden et al, 2000), have more in common with neuropsychological intervention than OT. Also, a maze environment requiring various levels of attention and decision-making was reported in (Wann et al, 1997) but no results of testing appear to have been published. Similarly, Riess (1998) has suggested that gait problems associated with Parkinson's can be overcome with particular visual cues (a clinical phenomenon called Kinesia Paradoxa) displayed through an augmented reality system, yet in this case also no further research is evident.

<u>Way-Finding</u>

Way-finding, assessment

Pugnetti et al (1995) describe an experiment in which a mixed group of neurological patients interact with a way-finding VE in that problems solved in the simulated room allow the patient to progress to the next virtual area. This task was in line with the Wisconsin Card Sorting Test (WCST) in that the choice criteria were changed after a few successful completions of the task. They found that use of the VE exposed different motor and cognitive problems than the WCST, perhaps stemming from the more complex and complete demands of the VE. Highly similar findings relating to executive function based upon a test with just one stroke patient, were reported elsewhere by two of the authors (among others), (Mendozzi et al, 1998).

Further way-finding VE tasks were reported in Brooks et al (1999) where a female stroke patient with amnesia successfully retrained her memory of the rehabilitation unit by navigating around a virtual model of the same space. The authors suggest this was due to the fact the VE offered greater freedom of traversal, hence greater training time, resulting from diminished distractions (the role of such 'clutter' in VEs is also assessed by the case study, Davies et al, 2002, outlined below).

Way-finding, ecology

The authors of Davies et al (2002) from the University of Lund, describe evaluating subjects' use of three different virtual reality systems, a simulated ATM machine, a virtual kitchen and a simulation of the working environment familiar to the university staff. The systems were tested among healthy subject although no further details are given. While the ATM and kitchen were generally operable among the subjects they also found that the staff did not, among other issues, recognise familiar corridors in the university simulation, understand how to use a simulated lift, that they mistook windows for mirrors and found that items missing in the VE that would have been found in the real environment (including general clutter) interrupted their experience.

The conclusions drawn by the authors pertain to their perceptions about the most appropriate software for creating VEs (WorldUp and Halflife[45]). They also point cursorily to the importance of visual cues and stimulations in navigating through a VE. Their knowledge of clinical issues is not however made clear and, unfortunately, the paper has a paucity of useful information in this respect.

Urban environment training

Virtual street-crossing task (pilot)

Lam et al (2004) describe a pilot study in which a non-immersive environment was introduced to a group of stroke patients to serve as a training mode for street skills (the scoring for this project refers only to the more mature version of the system, outlined below). Using a standard statistical method (a non-parametric Kruskal-Wallis Test), the researchers intended to test the effect of the VE against self-efficacy levels and behavioural skills.

The VE featured a 360º urban scene, including a road, which the patient was required to observe as fully as possible and then navigate towards a safe crossing point, move towards a station concourse, buy some tickets and then wait for a train (the authors have not recorded the preferred means of input). The usability of the system was also measured by timing the patients as they performed input tasks. The authors present the timings, but without analysis and a scale of usability.

Eleven patients were involved in the project: 6 males and 5 females, with a mean age of 46.5±5.0, who had suffered a stroke a mean average of 2.2±0.6 years previously. Five suffered left hemiplegia, six right. Most patients were ADL independent (the authors do not record which patients were not, and how this might have affected their sampling). The patients were separated randomly into three groups: one group of five participants using the VR system, another of three engaged in standard psychoeducational treatments (e.g. through coaching and role play), and a further control group of three receiving neither treatment.

The results showed that significant improvements were found in behavioural skills in the VR group as compared to the control group (U=000; z=-2.291; p=.022) and compared to the psychoeducational group (U=000; z=-2.306; p=.021). The VR group showed improvement in

[45] Neither application now seems to be commercially available

pre-post tests of behavioural skills (z=-2.032; p=.042) while the improvements in self-efficacy were not significant (z=-1.826; p=.68). They hence assert that their VR treatment could improve behavioural skills.

Public transport navigation

The research described in Lam et al (2006) pertains to further testing of the PC-based VR system described above. The authors tested post-stroke subjects using an additional simulation of a railway station (6 males, 14 females; mean age 70.8±15.55). The performance of these subjects was compared to that of a group using a video-based presentation of the same railway for the purposes of psycho-educational training (5 males, 11 females; mean age 70.8±15.42). The performance outcomes of these groups were compared to a control group who received no treatment (7 males, 15 females; mean age 72.5±10.31).

Subjects undertook ten training sessions in navigating to and around the railway simulations and using the various station controls in the VR system, and in viewing and imitating the content of the video system respectively. Performance outcomes were measured with a questionnaire that collected the subjects' demographic characteristics; with a assessment navigational skills pertaining to computer literacy and railway usage; a perceived self-efficacy navigational assessment. Post-training performance was measured with a 22-point breakdown of the navigational task (including traversing the street, identifying the machine machine, walking through platform the gate, exiting the station, and so on).

The results showed that both VR and video subjects had improved in railway navigation skills and significantly well in their self-efficacy assessment, and that the VR group improved on these outcomes to a greater degree. The authors maintain that the effectiveness of the VR system pertains to subjects' increased environmental control the lack of distractions (as outlined in Rose et al, 1998; Brooks et al, 1999).

USN, executive functions, virtual street-crossing task

Naveh et al (2000) describe the early testing of a VR-based system with keyboard control, also outlined by Katz et al (2005), below, where patients with Unilateral Spatial Neglect (USN) were treated with a street-crossing exercise with an avatar in view of the patient – a mouse click on the avatar would indicate that the patient perceived a safe moment to cross. If the patient chose a risky moment to cross the word “Accident!” appeared on the screen.

In the earlier study, 12 subjects were tested (the only breakdown given is that they were aged between 55 and 75 years), each had suffered a right hemispheric stroke at least six weeks prior to the study and all were independently mobile but were unable to cross a road confidently and safely. The researchers also tested the system with seven patients of matching age and condition who were also able to cross a road safely.

The authors present details of the times that the patients and the controls took to perform the street-crossing tasks, as well as the number of times each subject used the keyboard controls to look left or right. No analysis of the data is provided in this particular paper.

Katz et al (2005) outline research that sought to determine whether an immersive VE is an effective means to treat patients with Unilateral Spatial Neglect (USN), as a result of right hemisphere stroke, and who experience difficulty crossing roads. Participants included nineteen stroke patients, randomly assigned[46] to one of two groups: one group of seven men and four women (mean age 62.4±14.0 years) used the immersive, VR-based street-crossing training outlined in Naveh et al (2000); the other group of five men and three women (mean age 63.3±10.8 years), the control group, used non-immersive, PC-based visual scanning training. All groups participated in training for twelve sessions of 45 minutes each, over four weeks. Patients were tested with the Star Cancellation Test, Mesulam Test and ADL checklist.

After training, the VR group and control group showed equal improvements in the Star Cancellation and Mesulam Tests (the latter being significant at p<.01). Both groups also showed improved abilities in the ADL tests (p<.05). In the street-crossing measurements, the VR group showed greater spatial awareness (by looking left toward oncoming traffic) than the control group, with a significant improvement at p.<05, and also made fewer mistakes after training (down by around 50%). The control group made the same number of mistakes pre- and post-testing (with the exception of one patient who improved). The results were also reflected in a post-training, real road-crossing exercise, with the VR group showing improvements in spatial awareness and time to cross, while the control group showed slight deterioration.

Virtual shopping mall

Rand et al (2007) report on the testing of a simulated shopping mall, VMall, as a tool for clinical evaluation. The authors describe how the complexities of shopping entail executive

[46] The authors note however that the USN in the VR group was generally more severe than in the control group.

function (planning and problem-solving), cognition (categorization and memory), perception (visual, and so on) and motor skills (reaching and grasping)[47].

Subjects were required to select four specific items from the shelves. This was achieved through VMall reading the signals of a red surface (a mitten worn by the subject or, were necessary, a ping-pong bat). Products are thus selected by the subject reaching out with his or or her hand, palm down with fingers extended. Reaching to the item thus caused it to grow in size and its name announced. Full selection was achieved by 'dwelling' (i.e. hovering the hand) over the item for two seconds. A similar dwelling function was included for the navigational tools within the VE. VMall also uses the video-capture technology described in the University of Haifa projects, above, allowing the subject to see him or herself as part of the virtual environment.

The system was tested with 15 stroke patients (12 male, three female; mean age 65.3; eleven at the subacute stage, three at a more chronic stage; eight patients had suffered a right hemispheric stroke, the remainder left hemispheric strokes). Each subject was assessed against a Mini-Mental State Examination (ranging from 26-30 out of a maximum of 30) and Fugl-Meyer Motor Assessments (mean score 40±13.8). Performance was assessed against a modified presence feedback questionnaire (as described above) and a Borg scale of perceived exertion. Their assessment performances were compared with a far larger healthy group (93 subjects from three age-groups).

The authors found that the stroke patients took longer in performing the tasks than did the healthy subjects, reflected typical deficits and suggesting that the VE allows for ecologically valid training. The video capture component of the system also appears to have allowed for highly intuitive learning among both sample groups, lending weight to the author's claims of its advantage over other means of VR input (although the scene is not fully 3-dimensional).

Telerehabilitation

Whereas informatics provides clients and professionals with information about conditions and treatments, a sub-discipline of this field, telerehabilitation, not only provides information to the patient but also the very means for the intervention to be undertaken. The technology has furthermore been used to train therapists in remote areas (Iwatsuki et al, 2004).

[47] A further study of simulated shopping environments has been offered elsewhere (Cardaso et al, 2006), but Rand et al (2007) demonstrates the more mature application

When supplied through a PC-based virtual environment, such telerehabilitation systems can be implemented in just about any interior space. They might provide the patient with an environment that is meaningful and/or familiar yet not readily and physically accessible. Hence, the subject in hospital might interact with a virtual 'domestic' environment, or a subject at home might interact with a virtual 'workplace' environment. Furthermore, the clinician need not be present while the treatment in being undertaken – although arguably the clinician's presence is favourable to the clinical outcome, as opined by interviewees in Hilton et al, 2000. However, where it is not possible for the patient to be present at the treatment centre, the possibility for the implementation of a distributed rehabilitative system might gain currency.

Post-stroke, home-based intervention, feasibility study

Lewis-Brooks (2004) describes the testing of a system which allows post-stroke patients' limb movements and body posture to be tracked while at home and converted into pleasant, abstract images and a melody. The aims of the study were to find out if such a system can heighten activity, function and motivation in the patients, the technical and clinical suitability of the system, whether or not post-stroke training ought to be free of specific physiotherapeutic measures and aims, and the impact of the system on the rehabilitative process as a whole.

Five post-stroke patients were selected for testing (subjects were excluded due to cerebral dysfunction or any history of psychiatric disease or substance abuse). Each were ADL independent and had suffered a stroke between two and seven years previously and received therapy from zero to four years previously. Each could attend a maximum of 11 one-hour sessions over a three-week period (although the average attendance was 5 sessions), with a physiotherapist present during the trials. The author reports that all participants were 'positive' about the system, although this term is not elucidated in the paper. All but one enjoyed the auditory feedback and felt that the system would benefit from adaptability to individual preferences and limitations. No clinical data was collated but further testing of the system is apparently in press[48].

Post-stroke, physical therapy, game- and robot-based, telerehabilitation

Reinkensmeyer et al (2002) describe research into what they call Java Therapy, which is an internet-based physical therapy intervention for the upper limb (the application being written in Java and run on a standard PC). It required the subject to interact with an adapted version of the

[48] The interested reader is directed to http://www.soundscapes.dk for further information [last accessed December 2007]

arcade game, Breakout!, using a force feedback joystick and mechanical arm rest. Movement was tracked and feedback relayed to the subject through progress charts.

The system was tested on a 54 year-old male who had suffered a stroke 15 months previously. He was able to lift his arm from his side to his lap (which arm is not recorded but we might assume it was the right arm), but not more than a few inches above the lap. He had no hand grasp or forearm supination ability (he scored 1 out of 7 on the Chedoke–McMaster Upper Extremity Scale and 3 out of 7 on the Functional Test for the Hemiparetic Upper Extremity). In the first weeks of the trial the subject required assistance in attaching his hand to the joystick and arm rest but after practice he was able to achieve this independently by using his unaffected hand to move the paralysed hand to the joystick – this however could be regarded as the unwelcome, compensatory behaviour that furthers neglect in the affected limb.

The exercise program comprised 20 trials testing for speed, coordination, and strength and then ten minutes of the Breakout! activity. The subject logged in to the system 36 times over a 12-week period, meeting his weekly recommended frequency for the speed test and Breakout! interventions. Through this regularity the subject is reported to have improved his mean movement by approximately 40%. The Breakout! exercises resulted in improved arm movement, with the subject able to move more directly, if imperfectly, toward the game targets. In spite of the feedback provided to the subject, there was no evidence of within-session improvement, with performance appearing to improve between the sessions. The subject thus improved to score 2 out of 7 on the Chedoke McMaster Upper Extremity Scale (due to his increased elbow flexion/extension ability), but did not improve on the Functional Test of the Upper Extremity. He also expressed very strong approval for the system as a whole.

Post-stroke, reach, flexation and pronation

Holden et al (2005, 2007) describe the on-going research of a team comprising staff from MIT and Harvard Medical School – their research is based upon the earlier system outlined in Piron et al (2001). In this latest of their papers, they describe a telerehabilitation system whereby a patient uses a PC-based virtual environment to perform therapeutic exercises remotely while being monitored by a therapist through electromagnetic trackers and an audio-visual conferencing system. In spite of a very small sample and a range of technical problems, their report does offer useful, quantifiable information about their methods and analysis.

The system comprises three sets of exercises: posting a letter in a letterbox (a reach-to-workspace exercise), pulling up the sleeve of a garment (a hand-to-body exercise) and a repetitive pronation/supination exercise (reciprocal movements and grasp-release exercises). The patient follows as closely as possible the trajectories of the physiotherapist's movements, which have been pre-recorded, and an error-based score is provided after each exercise to provide knowledge of results. Velocity, orientation and rotation of the subject's movements are measured[49] and the system also allows the therapist to alter the parameters of the exercises as appropriate.

Early testing of the system with two stroke subjects was described in Holden et al (2005). The later testing described in Holden et al (2007) is outlined here. Of twelve subjects recruited for the test, eleven passed the protocol (six male, five female; mean age 56.7±15.6; stroke occurred >6 months previously). Training involved imitating a remote therapist's movements with visual guides, while subject's movements were tracked. The programme comprised 30 one-hour sessions, undertaken five days a week. Performance was measured pre-training, post-15 sessions, post-30 sessions and finally after a four-month interval. Outcomes were measured against Fugl-Meyer, Wolf Motor and shoulder strength parameters. Each subject made significant improvements on all counts (mean improvements after 30 sessions: FM 17%; WMT -15.5s, $p = 0.0097$; shoulder flexion 118%); subjects were able to generalise on their VR training to real world performance. However, the authors point out that major improvement only appeared after the 30-session test.

Summary and conclusions

Given the breadth and variety of the cases outlined above, the very disparate nature of the sample populations and the differing techniques and measures employed within the countries mentioned above, it is not easy to establish an integral perspective on the field as a whole. We might only say that the technology is generally usable and, on the surface, popular with patients. Also, the particular attitudes of clinicians to the technology do not appear to have been collated (with the exception of Hilton, 2000, outlined above). There also appears to be lack of uniformity within the field regarding clinical practice and outcome measures.

Figure 3.5, below, thus arranges the literature reviewed in this section according to the clinical or engineering concerns they touch upon (including some material mentioned elsewhere in the present study). This table might allow us to gauge where the focus of work has been. It is thus

[49] The interested reader is directed to Holden et al (2005) Section 4.4 for further details of the measurements calculated

evident that physical therapy of the upper limb has received particular attention, as have ADLs, way-finding/memory and executive function. It also appears that many of the studies have employed standard clinical assessment methods and outcome measures, although the appropriateness of some methods might be held in question (the use of the Glasgow Coma Scale to assess trauma in Christiansen et al, 1998, for example). A number of studies have also evaluated the feasibility of such systems as tools for occupational and physiotherapy, but not for neuropsychology. Some papers also conduct technical research outside of the clinical context and present their system, wholly or in part, an engineering problem.

General conclusion

In conclusion we might maintain that the technology is superficially ready for clinical trials with regard to its technical capacities, (signal speed; cognitive and physical loading), to patient acceptance and with apparent benefits to the post-brain injury recovery process. One caveat, however, is that the role of the technology in the recovery process is far from clear – indeed the possibilities for spontaneous recovery or the effects of other factors (whether clinical or otherwise) have yet to be precluded from any study in this area.

Regarding the field as a whole, we might observe some emergent common parameters. Hence, where little exploration has been undertaken, (the impact of ecological validity upon VR for way-finding/memory training, for example), the research parameters might be based upon the errors of prior studies:

- Simplicity in system design tends to result in clearer methods and outcomes
- Outcome measurements of the system must relate to clinical concerns
- The system can only be deemed usable if its acceptability to the therapist and patient has been evaluated
- Clinical disparities in the sample population have an effect in outcome measurements which ought to be included in the analysis
- The technology must interface with clinical practice
- There may a range of unseen factors impact on the recovery process which ought to be considered and precluded
- The consequences of ‘risky’ virtual environments are not well understood

Figure3.5. The research areas touched upon in the literature

	Occupational Therapy	Physiotherapy	Neuropsychology	Equipment training & engineering
Upper limb	Pridmore et al, 2004 Edmans et al, 2004 Lam et al, 2004 Katz et al, 2005 Rand et al, 2007	Broeren et al, 1999 Holden et al, 2005 Merians et al, 2002, 2006 Adamovich et al, 2005 Viau et al, 2004 Crosbie et al, 2004a Reinkensmeyer et al, 2002 Broeren et al, 2007		Jack et al, 2001
Lower limb		Deutsch et al, 2004		Deutsch et al, 2004
Whole/general body	Kizony et al, 2003, 2004	Lewis-Brooks, 2004		
Activities of daily life/ wheelchair training	Linden et al , 2000 Pridmore et al, 2004 Edmans et al, 2004 Lam et al, 2004 Katz et al, 2005 Rand et al, 2007		Christiansen et al, 1998 Lam et al, 2004 Naveh et al, 2000	Pridmore et al, 2004 Edmans et al, 2004 Harrison et al, 2002
Visuo-spatial\ USN	Katz et al, 2005		Lam et al, 2004 Naveh et al, 2000	
Executive function	Katz et al, 2005 Rand et al, 2007		Mendozzi et al, 1998 Christiansen et al, 1998 Lam et al, 2004 Naveh et al, 2000	
Way-finding/ Memory	Lam et al, 2004		Pugnetti et al, 1995 Brooks et al, 1999 Davies et al, 2002	Harrison et al, 2002
Clinical/ qualitative/ technical feasibility	Rand et al, 2005 Edmans et al, 2004 Reinkensmeyer et, al 2002 Hilton et al, 2000 Davies et al, 2002	Lewis-Brooks, 2004 Reinkensmeyer et, al 2002 Holden et al, 2005 Crosbie et al, 2004 Hilton et al, 2000 Deutsch et al, 2004 Broeren et al, 2007		
Ecology/ ecological validity	Rand et al, 2005 Linden et al , 2000 Lam et al, 2004 Katz et al, 2005 Rand et al, 2007		Davies et al, 2002	
Transfer of Training	Davies et al, 2002 Linden et al , 2000	Adamovich et al, 2003, 2005		Kozak et al, 1993 Rose et al, 2000
Clinical assessment & measures	Rand et al, 2005	Merians et al, 2002 Adamovich et al, 2005 Crosbie et al, 2004a Kizony et al, 2004 Reinkensmeyer et al, 2002	Pugnetti et al, 1995 Christiansen et al, 1998 Lam et al, 2004 Naveh et al, 2000	Holden et al, 2005
Clinical training		Iwatsuki et al, 2004		

Finally, as information technology in healthcare becomes distributed evermore globally, researchers might do well to regard the diversities of clinical practice and the subjective attitudes of various cultures. The challenge ahead therefore is to establish such a system that is at once bespoke to therapeutic methods and integral to clinical intervention as a whole, with adaptability to various contexts and variability to the changing clinical requirements maintained as design concerns. A further consideration that does not appear to have been addressed in any of the studies cited above is that, even where studies have proved successful in gauging improvements to users' functionality, the exact role of the virtual environment itself in achieving this recovery remains unclear.

There are two tasks at hand resulting from the findings of this review. Firstly, to conduct a systematic assessment of the requirements of clinicians, with a view to developing a full design analysis. Secondly, to explore further the manner in which the intrinsic properties of a VR system might offer value to the recovery process

Chapter Four – Interfacing Technology with Rehabilitation: User and Stakeholder Perspectives

General Introduction: the purpose of the study

The review of literature, presented in Chapter Three, revealed how a common problem in the development of virtual environments for clinical application is engineers' poor or inconsistent understanding of therapists' duties, routines and practical cultures. This has been shown to result in systems that are often misaligned to clinical practice or do not respond to the therapeutic and managerial complexities of rehabilitation.

Clinicians might be regarded as what Rogers has termed 'change agents', whose professional or consumer activities provide the means of diffusion for an innovative technology such as VR. Rogers has, however, outlined the prevalent problems in change agency, not least in the tendency to esoterism of innovators and early adopters, which can stand in the way of development (Rogers' framework for diffusion is also appropriated for the concluding remarks in Chapter Seven, below), (Rogers, 1983).

To address this problem, with the aim of avoiding it in my own research, I elected to interview a range of clinicians, each working in brain injury rehabilitation at treatment centres in the United Kingdom. The focus here is the development and implementation of VR in stroke therapy and care provision as its stands in the UK, with a view to identifying the professional diffusion networks through which the technology might be proliferated (whether based on clinical practice or policy implementation).

Innovating a rehabilitation healthcare product in the UK poses particular problems. In spite of increasingly strong validation from neuroscientific research, VR in neuro-rehabilitation seems to have so far gained little currency in this country (compared with, for example, Israel and North America, as the literature review revealed). The responses and preconceptions of the therapists selected for the study appear reflect this trend. The quotes provided throughout the text serve to reflect only the opinions of the interviewees (some of which are not quite accurate in terms of the literature). The quotes are intended to illustrate the limitations in knowledge and expertise that might affect the technology's entry. With this theme in mind, the general conditions for innovation in the UK are also described, with the developmental problems associated with state-led provision forming a significant barrier in this regard.

It was suggested above that a virtual reality system would need to be readily adaptable to a range of clinical needs. One task at hand, therefore, with regard to interviewing clinicians, was to gauge the level to which the system ought to supply a generic 'template' for therapy over a specialised tool for a specific intervention. Hence the interviews also serve as a means to gain a general overview of clinical practice, which would serve as a benchmark for generating parameters in further research.

The interviewees were selected through a brief 'pre-interview' (conducted over telephone or email) which gauged each of their levels of expertise and clinical specialism, as well as their ability to reflect upon their work. In this respect the sample population is not representative of the therapy field as a whole, but is representative of the high level of expertise that is expected to be required to implement and use virtual reality as an innovative technology. As an adjunct to the data gathered through interviews, I also observed one of the therapists at work with two stroke patients; the results of this are presented in Appendix 6.

Hence, four of the interviewees were (or had been) senior occupational therapists (OTs). Of these, one was a practicing Senior II Community Rehabilitation OT[50]; one a Senior I Clinical Specialist (Cognitive Rehabilitation) OT; one a Senior I Neurological Rehabilitation OT, who is undertaking post-graduate study in his/her field of work, and one who had qualified as a Senior I OT and is now the Assistive Technology Manager at a major neuro-disability hospital and is also undertaking doctoral research in his/her area of work.

Of the physiotherapists, one had been the Senior I Acute Brain Injury Physiotherapist at a major brain injury hospital and was now undertaking doctoral research in the field; the other was the practicing Senior 1 Acute Brain Injury Physiotherapist at that same hospital. I also interviewed the Senior Neuropsychologist at another major brain injury hospital, who is also undertaking post-graduate study in his/her field of work.

Both in order to secure the anonymity of the interviewees and to abstract from the data provided, each was given a reference code, comprising the initials of their profession and a random number (for example, OT2, PT1, NP1, and so on). Any other personal information has been omitted, while some quotes have been edited slightly for the sake of narrative flow (omissions are shown by […] in the text).

[50] Among OTs, Senior II is junior to Senior I

<u>Part One: A Qualitative Review of Service Providers' Perspectives</u>

Introduction: the interview questions

The interviews were semi-structured in that the questioning pertained to four main areas: 'setting the scene', which related to routines, management and professional overview; 'working with patients', which related to the direct interaction with contact with patients in all manner of settings; 'equipment', which related to the use and specialised apparatus, the benefits and problems this might pose and also the sourcing and uptake of innovations; finally a more focussed questioning about equipment pertained to 'ICT in clinical practice', regarding both the service providers' and service users' use of computers, software and telecommunications for service provision, therapeutic intervention and also meaningful activities (such as a hobbies or communication).

Within these main areas of questioning, a series of specific questions were posed (outlined below), but the discussion was not limited to these. In conducting the interviews in this way, the interviewees were allowed to reflect discursively on their experience and knowledge. As a result, some major areas of discussion emerged throughout each of the interviews, for which no question had been directly posed. These included the need for and problems of service integration; the problems of exposing patients to complex and dynamic environments; the prime importance of goal-setting, both in rehabilitation and management and, perhaps surprisingly, a fairly broad – if often speculative – knowledge about virtual reality in rehabilitation. The direct questions are presented in *Figure 4.1*, below.

Figure 4.1. Questions posed to interviewees

Setting the scene

What do your regular duties involve?

Do you have a typical day?

Where is the treatment normally undertaken?

How would you change the treatment environment?

If you have worked in other treatment centres, do they differ in any way?

Do you ever need to use outcome measures?

Does your current patient group have any special or unusual requirements?

Working with patients

If you do home visits, what do you sometimes see?

What do patients sometimes complain about?

Do you ever have to motivate patients? If so, how?

If a patient was undertaking treatment unsupervised, what can you imagine might happen during the session?

Equipment

How often do you use equipment, however basic?

What sort of equipment do you often require?

In what ways do patients respond to equipment?

Are the constraints to the sorts of equipment you can use?

Do you ever hear about innovations in the clinical field?

If so, how do you hear about them?

Can you imagine trying new innovations out?

ICT in clinical practice

Do you use a computer to perform your duties? If so, what do you use it for?

Have you ever come across a patient who has acquired information about their condition from the Internet?

Can you imagine your patients using a computer as part of their treatment?

If so, can you imagine problems occurring; what might they be?

Regarding the dataglove and head-mounted display [an illustration of these was shown to the interviewee], do you think these would be suitable pieces of equipment for a patient to use?

In the analysis, which was a loosely adapted Grounded Theory process (already outlined in Chapter One), I identified ‘major themes’, which were the disciplinary concerns common among the interviewees, and ‘emergent themes’, which were concerns specific to the individual interviewees yet forming sub-sets of the major themes. The specific point made by the interviewee was then paraphrased. As an illustration of this process, *Figure 4.2*, below, is a sample from the fully tabulated analysis (see Appendix 5):

Hence a major theme (in this case ‘contact with patients’) brings together concerns from across the four areas of questioning and also a range of emergent themes. The specific points raised by the interviewees pertain to all manner of clinical and managerial concerns relevant to this major theme. From the full analysis of each interview, 54 major themes and 172 emergent themes were revealed. 671 specific points were made by the interviewees and thus paraphrased; a narrative was then constructed upon these data, presented below. Full details of the interviewees are presented in Appendix 3.

Figure 4.2. A selection from the full interview analysis table

Theme*	Paragraph ref.	Major theme	Emergent theme	Specific point
work	PT2.5.4	Contact with clients	Goals reflect client's abilities and needs	Home visits are vital when clients return home
E & I	OT3.13.4	Contact with clients	National Service Framework/Long-Term Care	Technology can help elderly maintain contact
work	Tech1.11.3	Contact with clients	Rehab as a 'hands-on' process	Interviewee chose to do 'hands-on' work over technical work
work	PT1.6.1	Contact with clients	Rehab as a 'hands-on' process	Physical contact with client important in early stages for assessment
scene	OT2.5.3	Contact with clients	Clients don't receive adequate intervention	OT only sees patients for half the necessary time
scene	PT2.6.1	Contact with clients	Client's environment	Home visits done jointly to assess client environment and diasability
work	NP1.10.1	Contact with clients	Information provided to client	Communication delivered sequentially to avoid cognitive overload
work	OT3.9.2	Contact with clients	Positive reponse to VR	VR appropriate as a means of remote observation
ICT	OT3.9.3	Contact with clients	Remote monitoring	ICT technology maximises contact time
work	OT3.9.3	Contact with clients	Remote monitoring	Technology maximises contact time
work	NP1.7.1	Contact with clients	Technology reflects clients' needs	VR as an supplement to human contact

*Work = working with patients; E & I = equipment and innovation; scene = setting the scene; ICT = ICT in clinical practice

The major themes

This section outlines the data provided through the interviews according to the major areas of questioning. Further analysis of these themes is provided in the discussion, below.

Setting the scene

Remits of therapy

Definitions of the various therapies vary and there appears to be little consensus among therapists as to the commonalities and discontinuities of their respective clinical perspectives (OT2.8.4). OT2 does however offer a succinct description of post-brain injury therapy:

> *We try and use activities, everyday activities, and activities which have some kind of meaning for the patient, but we incorporate in that the kind of movement patterns that we want the patient to recover. So […] we're retraining the body in what we call normal movement. The point being that the central nervous system doesn't think in terms of isolated movements, it thinks in terms of patterns of movements. So for example, things like overlearned behaviour […]: if you tie your shoelaces, you probably couldn't explain to me what you've done, but*

there's a programme in the nervous system that can just like go in there and just tie the laces. It's a very complex procedure, a fine motor procedure, but it's kind of embedded in the nervous system. (OT2.1.5)

Where roles are prescribed with greater precision, this appears to be in teams that are integrated to an atypically high degree[51]. One interviewee did however offer a pithy delineation of therapeutic interventions in the field of head injury:

> *[Physiotherapists are] looking very much at pure motor, what's the sensory impairment, how that impacts on it, how the weakness impacts on it. The OTs do as well, but they're often looking at putting that together with planning, with understanding the concept of the task ahead, so theirs is much more holistic in that respect. So when patients say to you sometimes, "What's the difference between a physio and an OT in this process?" I would say to them, "We'll try and help you get the movement back and the OT will put that movement into something useful." (PT2.6.3)*

Greater delineation was however described between acute and chronic care. In this regard, acute patients were described as being 'medically unstable… often still in bed,' (OT2.1.4) and the chronic patients as being ready to engage more actively in the recovery process. It was also observed that the transition between acute, rehabilitation and return to home each require highly distinctive modes of intervention and goal-setting (PT2.2.3). PT2 offered a rounded illustration of the acute setting:

> *[We] had a real mixture and variety of patients, and with some patients it would be for them to be able to sit up in a wheelchair for half an hour and be able to eat their lunch in a sitting position, because they were so acute, so medically unwell – fatigue is a huge problem after stroke that a lot of people don't anticipate, or brain injury – and then with other people it could be that we were going to, for them to be able to walk around a busy street and be able to negotiate a road safely, for example, so it varied because we had, sort of, walking wounded, people who were physically quite well but cognitively had problems with busy environments or were distracted or who had poor safety awareness, and then you'd have very physically disabled people with very heavy paralysis who needed step-by-step physical goals, really. We tried to marry them together a little bit so it wasn't just focusing on one thing, so that the physical*

[51] General observation regarding the working cultures of the interviewees

goals were relevant to the person, that's why if for example a goal was for a person to sit out for an hour, then we'd try and do it so it was when their visitors were coming or when they were eating a meal, so they weren't just sat in a chair looking at the next patient. To try and give it some meaning, really. (PT2.2.4)

The break-off point for contact between therapist and patient also varies according to the therapeutic settings, with Community Rehabilitation being the last point of contact. Here, however, the parameters of care may be determined in part by the patient's wishes, as OT1 outlines:

Typically [the break-off point] would be at the point where the person's achieved their goals, what you identified at the beginning, the difficulties have been resolved or made better as far as possible. But if you were an OT working with, for example, complex environmental control systems, it might take some time. But it's about when you and the patient, ideally, are both happy with what you've done and you've done all you can. It sounds very vague but… if a patient has poor mobility, if that patient wanted to go down to the shops that are 200 yards away, you're rehab goal might be 'walk to local shop' and when the patient's done that, you can say 'We've achieved that now and is there anything else you want to achieve', and they might say 'No thank you'. (OT1.15.5)

Therapists' routines

Where therapists do have a routine, it normally involves handover in the morning, being the transmission of details concerning a patient either between the various agencies involved (such as rehabilitation and social services) or the various departments with the care setting (usually between acute and rehabilitation, or between different rehabilitation settings). Some therapists conduct handover within their specific teams – that is, between physiotherapist and occupational therapist – but this reflects an atypically high level of integration (PT2.2.2). Administrative duties are also normally undertaken in the morning, including writing reports and making various communications, with clinical work undertaken throughout the rest of the day (PT1.1.4). Some therapists also allocate specific days to specific areas of therapy, such as ward- or gym-based activities respectively (PT1.1.4).

Many interviewees commented that their routines reflect the rhythms of patient's therapy and other activities, such as mealtimes and visiting hours, with therapeutic goals and activities programmed to coincide with these times, and indeed be embedded in the associated activities (PT2.2.4), such as sitting-up exercises are sometimes conducted prior to visitors' arrival, and so on. Many therapists' routines also revolve around visiting patients at home, the regularity of which depends upon the patient's needs (OT1.3.3; OT1.3.2).

Some interviewees also commented on the transient nature of the patient's journey through the care process, with requirements and clinical goals thus changing on both a weekly and a daily basis (OT1.3.2; OT2.5.3; OT2.8.3; OT2.8.4; PT1.7.4). Therapeutic intervention is therefore often a dynamic process, involving continuous reassessment of the patient's requirements and therapy goals (OT2.9.1). It was however observed by one therapist that this need for dynamism is not understood universally within the profession (OT2.8.4).

Disparities among patient groups

The interviewees each work with patients from all manner of circumstances that each engender factors which impact on both the care provided and on clinical outcomes. Such factors thus include age and gender. Hence younger patients tend to be more concerned about return to work and family life, and therapy goals often reflect these concerns (PT1.7.5; PT1.8.1; PT2.4.2):

> *With a younger person you often […] get involved in work, so thinking about their physical ability, so for me as a physio, how their physical ability may on impact on their ability to access work, to look after their family, those kinds of things, and from an OT point of view looking at how they're going to manage at work in terms of their processing skills, their cognitive ability, those sorts of things. So whereas often our elderly population are retired, so obviously they still have other things that they do, but work isn't so much of a problem.* (PT1.8.1)

Younger patients also often evince greater anxiety about their conditions and the care process (PT2.4.2; PT2.5.1), although they can respond more positively to the equipment used in the therapy process, including gym equipment and PCs (NP1.11.2; OT3.6.1). Older patients often have greater co-morbidity[52] (PT2.4.2) and spend longer in the treatment centre (PT2.4.2), as PT2 illustrates:

> *Our older patients often needed a lot more time, slower-stream stuff, because they often had coinciding pathologies going on, they were arthritic, or cardiovascular problems, which can influence their rehab as well, so they need a bit more time and a bit more structure, which in a very fast-paced unit is quite*

[52] Meaning coincident or compounded medical problems

difficult to give. The younger people often there were family involvements, there were social-side considerations about work, a lot of anxiety among younger stroke victims. (PT2.4.2)

Among head-injury patients, young male patients are more frequent users of the service and have concerns similar to those of all younger patients. Return to work is a prevalent concern among males (OT3.3.3), especially including adjustment to the single, major problem of a career change, which often involves taking a job with simpler activities (OT3.3.2). Return to a normal sex life is also a greater concern among men (OT3.3.3). Younger patients might have less co-morbidity generally (PT1.7.5), but young males in these circumstances are often prone more social problems such as drug abuse, homelessness and vulnerability to assault (PT2.4.2; OT3.2.7). It was also observed by one interviewee that women respond better to the rehabilitation process as their pre-morbid lifestyles tend to be more fragmented and dynamic, more about 'juggling more than one thing at once', and are thus better adapted to the adjustments required in the care process (OT3.3.2).

Disparities in wealth, social standing and pre-morbid lifestyle were also outlined as factors affecting clinical outcomes, especially among interviewees with patient groups of high disparity in these areas (NP1.1.2; OT1.7.3; OT1.8.1; OT2.6.7; OT3.4.6; PT1.2.1). Hence wealthy patients often employ round-the-clock care (OT1.7.3); better educated, apparently more intelligent and more articulate patients might be more goal-directed, or indeed career-minded (OT3.5.3; OT3.4.6). Such patients thus engage in the recovery process to a greater degree, which directly and positively affects clinical outcomes (OT3.5.3). They are also able to gain greater access to specialised treatments for which there are limited resources, often with the support of similarly well-informed family and friends (Tech1.14.1).

Other, less positive, pre-morbid tendencies also affect engagement and outcomes in the care process, given especially that uncooperative, anti-social or risk-prone tendencies can remain consistent in goal-orientated rehabilitative activities (OT3.5.1; OT3.5.2). Such prevalent behaviours might also disguise existing cognitive problems, such as dysexecutive function (OT3.8.4).

Issues in management

For many interviewees, the limitation of resources posed a problem in service provision. Limitations included constraints in budgets, staffing, equipment, space and adequate environmental conditions, as well as time allocated for patients and for professional development. It was observed that constraints in staffing can impact negatively on clinical outcomes (OT2.1.6; OT2.5.3).

Regarding the provision of equipment, views tended to vary: while it was observed that complex equipment creates additional demands on staffing resources (PT2.9.2), which are becoming evermore squeezed (PT1.16.4), it was also maintained that, in some circumstances, equipment might relieve demand on staffing (PT2.10.1). This, however, is with the provision that interfaces could be used with minimum training and sufficient technical support (PT2.14.1); indeed one therapist maintained that cheap, basic equipment is more appropriate to therapy over expensive, complex apparatus (OT2.4.1; OT2.6.4).

It was also observed that although adequate space has a positive impact on the use of equipment, space is, in practice, often limited (OT2.6.8; Tech1.4.1). Limitations of space might, however, be overcome by providing 'tabletop' equipment, which is often more manageable for patient and therapist alike (PT2.10.3), and interfaces well with clinical goals (PT2.14.5). Lack of technical skills is also regarded as a factor affecting equipment uptake (Tech1.1.4; Tech1.9.1; Tech1.9.3; Tech1.12.4), with the bureaucracy surrounding innovation providing a further obstacle to equipment development (Tech1.9.3; Tech1.12.4).

Constraint on time was observed as a factor affecting both contact with patients and full therapeutic intervention (OT2.3.3; OT2.5.2), but also has a particularly negative impact on equipment provision, uptake and usage (Tech1.1.6; Tech1.9.1; Tech1.9.3; Tech1.12.4). The acute ward was also described as being a highly fast-paced environment which allowed scant time to be allocated to any duties beyond direct therapeutic care (PT2.4.2). Backlogs in caseload were furthermore regarded as causing limitations in time spent with patients (OT2.5.3).

It was observed that the NHS has limited financial resources for equipment development in rehabilitation (PT1.16.4; Tech1.4.2). Although many specialised items in rehabilitation cost around £500 (OT1.5.6), items costing upwards of £3,000 need to be authorized and this can cause considerable bureaucratic complexity (OT1.8.3). The provision of a 'prompting' telecommunications service costing £20 a month was also considered expensive, for which the therapist was required to make a special case (OT3.6.7).

Service integration

An area of concern that each of the interviewees raised, even without being questioned directly, was the need for service integration and the persistent problems associated with this, with one interviewee describing this as an urgent problem (OT1.4.2). The requirement for service integration thus relates to integrating and delineating the therapy services within the treatment centre (OT2.8.4; PT1.1.4), integrating the various agencies involved in patient care (OT1.4.3) and also the relationship the treatment centre seeks to maintain with the patient upon his or her return to a community setting – usually the return home (OT3.8.2). The transition through the care process is thus intended to be smooth, in spite of the inevitable changes to patient's physical and social environment, as well as to the clinical contexts, throughout this 'journey' (OT1.3.6; OT3.9.1).

In outlining the problem of this transition, two of the OTs also alluded to the manner in which a patient might be 'fragmented' by the various agencies and therapists involved in his or her care (OT2.5.3; OT3.7.2). PT2, working in a service which is integrated to an atypically high degree (PT1.3.1; PT2.2.2; PT2.3.1; PT2.6.2), described how the treatment centre in which his/her works as actively assessing the extent of such problems (PT2.5.2). PT2 also described the dynamic nature of the role and the need for multi-tasking, not least in the handover from acute care to rehabilitation (PT2.3.4; PT2.5.3) and remarked on the positive value an integrated team returns to the care of patients, and the value of an holistic approach which engages the patient in their own care (PT2.3.1; PT1.3.2).

The National Service Framework (NSF) for Long-Term Care was also discussed in this context, (this NSF was outlined in Chapter Four, Part Two), given especially the need to reduce duplication of therapeutic and administrative tasks and the need for standards to be introduced to the assessment process (OT3.8.1; OT3.8.2; OT3.9.1). It was also observed that technology could well play a part in addressing these problems and in providing the requisite connectedness between therapist and patient, not least in the care of the elderly (OT3.13.4).

The problems of service integration seem to vary from workplace to workplace (PT2.3.3) and thus pertain to the very specific requirements of the interviewees. Hence, Tech1 as an assistive technology manager outlined the poor communication between the technology team and the therapists in the treatment centre, who often have conflicting priorities (Tech1.12.4), which affects technical training (Tech1.15.1). Tech1 also maintained that solutions to these problems might be sought through ICT, given especially the support that such technology can give to multi-tasking (Tech1.13.3; Tech1.15.2), and that the success of this would itself rely on better integration between technical and ward staff (Tech1.12.4). Poor integration was also observed as having a negative effect on funding applications for equipment, which might become duplicated and thus create bureaucratic problems (Tech1.15.2).

OT3 outlined the poor communication between the departments of Occupational Therapy and Social Services (OT3.7.2), which often leaves the patient vulnerable (PT2.6.1), while highlighting the improvements to service efficiency when social workers were able to play an integral role in a patient's return home (OT3.7.3). This poor integration between agencies also causes bureaucratic problems, we well as delays, in the provision of equipment, especially when the patient is due to be means tested (OT1.8.1).

Given the physical distance between units, the efficiency of the handover often depends upon the informal professional networks that have developed between therapists over the years and is affected negatively by the rate at which staff members leave the service (PT2.3.4). Solutions in care provision are also developed along informal professional networks (PT2.3.4) and this observation is also reflected in the informal networks by which technology solutions are transmitted, both within and between treatment centres (Tech1.14.3), where staff longevity has a positive impact in this process (Tech1.15.1) and leads to greater service initiatives and technology development (Tech1.8.2). OT3 also described how staff longevity allows greater efficiency to service integration through such informal networks (OT3.7.3), which were also observed as promoting therapists' knowledge of a patient's journey through the care process (PT2.4.1):

Working with patients

Patient focus

In working with patients, each of the interviewees described the bespoke and often intimate means by which a course of therapy is designed and implemented. Each also described the manner in which the patient's needs and preferences are incorporated into the care process, especially given the value of this in the recovery process. This might include goal-setting and motor training for the activities of daily life (OT2.3.3; PT1.2.2; PT1.3.3; PT1.5.1; PT1.8.2), and also higher human needs such as independence, dignity and self-esteem (OT1.14.2; OT2.5.2). It was also observed that the various therapeutic perspectives can result in a clinical focus on specific body parts, such as physiotherapists' focus on trunk and lower limb for normal motor function and occupational therapists' focus of the upper limb for meaningful task performance (OT2.3.1).

One task of the therapist is to leverage the existing motor and cognitive functions, no matter how limited – examples of this were given in supplying communications and learning aids to patients with very severe disabilities (NP1.9.2; Tech1.7.2; Tech1.8.1). Adapted computers have been used in some areas to help maximise function in this regard for communications and entertainment (Tech1.3.3). Where equipment is to be used by the patient, it is also sometimes necessary for him or her to be assured of its safety and effectiveness (NP1.2.3); although patients can be happy to use equipment independently (Tech1.6.2), the possibility for this should be judged according to each his or her particular abilities (Tech1.8.1). A piece of equipment installed at home would be subject to a full assessment by the occupational therapist (OT1.5.6) (outlined below).

The patient's environment was also widely discussed as a source of clinical concern, which is expanded upon below. General allusions, however, included the limitations of the hospital environment in training for community settings, such as the return home or street training (PT1.3.4), and the hospital bed itself can pose limitations for the recovery process (Tech1.8.1), which therapists sometimes try to overcome:

> *It's one of our jobs to identify the roles that our patients had before they had their stroke or at the same time, so then trying to think about rehabilitation, how you can incorporate aspects of their normal life. In a hospital environment it's very difficult, and that's more going into the sort of rehab, a rehab unit further down the line.* (PT1.3.4)

> *It helps you to put into perspective the person in their own environment [...] but it's hard to mock up what their home looks like and so, if they do have mobility problems, how that might transfer into the home, or how they might, if the layout's so different in someone's house how they might transfer the skills they've learned in the kitchen in the hospital to the skills they've learnt at home.* (PT1.4.1)

Patients themselves often express a wish to be out and about, away from the ward environment, and their families often want them to return home (PT1.12.1). The patient's semantic environment is also of clinical concern in some circumstances, which might involve such things as enabling him or her to select a television channel (Tech1.6.3).

Patient engagement: an overview

Patient engagement was regarded by many interviewees as being of value to clinical outcomes: in purposeful and holistic goal-setting, in making choices about clinical interventions and equipment, in memory recovery, in physical movement and in achieving fuller attention to task performance. This insistence upon the patient's engagement appears to result from therapists' changing attitudes to patients, not least in recognising the importance of avoiding passivity in achieving positive clinical outcomes (PT1.3.2) but also in the insistence on service transparency (OT1.9.3)[53].

Participatory and meaningful goal-setting, embedded in complex tasks, has also been linked to fuller neural activity and thus a higher level of integrated engagement (OT2.1.6; OT2.3.2), which seems to result in improved clinical outcomes (PT1.2.2), as OT2 describes:

> *[Luria's[54] research showed that] if someone was reaching with the hand to perform a task, there was actually better recovery in the arm than if they were just having their arm stretched passively, they were just doing meaningless exercises. So if there's a meaning and a goal attached to it, the evidence suggests that it helps the recovery […] It would make sense that if you bring in the supplementary motor area, and associated parts of the motor cortex, you might be bringing in more goal-directed behaviour, which brings in the frontal cortex, all these kinds of things*. (OT2.3.1 / OT2.3.2)

The limbs affected by a stroke are also engaged as fully as possible as a dynamic part of a task, for example in weight-bearing for the unaffected side of the body (OT2.1.6). Such is the importance of engagement that, where a patient has very limited motor function, the value to recovery of *imagining* an activity or an environment is also being considered (PT1.4.1; PT1.4.3).

Some of the interviewees also observed that the patient must sometimes be actively won over to the 'rehabilitation way of thinking', as a process that is more engaged, dynamic and positive than the medical environment from which he or she might have recently moved (OT1.13.2; OT2.6.2), as OT1 illustrates:

> *Once you get that rapport with a patient and encourage awareness of that rehabilitation way of thinking, for want of a better phrase, then you start to get people on side, start to work with people more constructively. Because when you think about pretty much any other medical or healthcare treatment [it] is passive. [...] In medicine or surgery, treatment in medication, surgical techniques, investigations can involve actually looking at your body or part of your body, testing you blood, the treatment you're given is about advice about what to eat, what medication to take, what exercises you should do… it doesn't*

[53] An observation substantiated throughout many papers, for example Coulter, 1999, and Higgs, 2003
[54] Soviet neurologist, founder of modern neuropsychology, (1902-1977)

happen so often except in rehabilitation where you're asked, well, what is it you actually want to do? What are the difficulties affecting you in life, as a result of not just your impairments, but your environment? (OT1.13.2)

In participating in the care process to a greater degree, the patient might furthermore be encouraged to continue rehabilitative activities between therapy sessions (OT1.13.3), or even initiate and organise their own programme of therapy (OT2.4.2). However, the limitations on time for clinical intervention often result in this being unsuccessful (OT2.3.3).

Patient engagement is thus not always easy to achieve (OT1.14.4) – given especially the unpredictable or impaired nature of many patients' behaviour (OT2.9.1; OT2.9.2) and associations with 'illness' and passivity of the ward environment (OT2.8.1[55]; PT2.2.4). Patients are sometimes depressed, either generally or as a result of their brain injury, as OT2 illustrates:

Sometimes motivating patients can be very, very difficult and you will find that patients who are very demotivated often don't make good recoveries. It's quite noticeable. We've got patients here at the moment who everybody, the whole team, is saying should be doing far better, physically, than they are doing, but their psychological state, their mental state is holding them back, because they're depressed, demotivated, and they could well have been like that anyway, but that impacts on the recovery, which again tells you about how the way in which the mind affects the physical recovery process as well. (OT2.5.2)

Patients might not always even be aware that they have a problem, which can extend from impaired perception:

Insight is a huge issue in brain injury as well because people often don't recognise their problems, so then finding an incentive can be quite difficult, and sometimes it's about supporting people, I don't want to say fail, but to realise their limitations generally. (OT3.2.5)

Patients do sometimes actively resist this greater degree of engagement (OT1.14.5). Where this occurs it might be a result of the density of brain damage and resulting cognitive impairment (OT2.4.3; OT3.3.6), frustration with the slow pace of recovery (OT3.2.4) or tendency to fatigue, which are not always acknowledged (PT2.2.4). Further patient resistance might also

[55] The interviewee was here referring to the recent closure of the rehabilitation wing and the resulting negative impact of the ward environment in which the therapy was subsequently undertaken

arise through therapists' poor communication in such circumstances (OT1.14.6). A patient could also resist treatment due to negative media coverage of some interventions, however sensationalised (OT1.11.5); this might also be amplified by the problems of perception often associated with this area of care (OT1.12.1; Tech1.14.1), or pathologically derived lack of 'insight' into his or her condition (OT3.2.5), or simply poor understanding of this and the care process (OT1.13.2). Family members can also resist in-patient care (PT2.6.1).

Engaging the patient should thus involve communication that is sensitive to any cognitive disability. In this instance, communications are delivered to the patient discretely and selectively to avoid cognitive overload (NP1.2.2; NP1.10.1) or even, where appropriate, pictographically (NP1.9.2). Environmental distractions are also avoided in this respect (NP1.2.2).

Patient engagement: goal-setting and task-performance

The therapy process is suffused with goal-setting as a means of motivation, both as a clinical and a management exercise (PT2.2.2), which can be regarded as a discrete and refinable skill (OT2.8.2). Goals are often, but not exclusively, embedded in meaningful activities (OT2.3.1) and can address a range of multi-disciplinary concerns; they are thus set according to either task performance targets (OT2.1.6) or through analysis of motor function (OT2.1.6; PT1.9.1; Tech1.4.1). It was, however, observed that motor recovery does not always translate to improved task performance and that the two therapeutic perspectives are not, therefore, interchangeable (PT2.10.1). Many interviewees commented on the value of, and problems associated with, setting goals, from which some general themes emerged.

The means of motivating a patient can be highly subjective (Tech1.7.3) and the patient can even be affected negatively in this respect by the ward environment (OT2.8.1); there is also sometimes a gap between the goals of the therapist and those of the patient, which is to be avoided (PT2.14.5). Goals should therefore be set in consultation with the patient, as outlined above. Hence, for many patients the return to normal movement is an appropriate goal (OT2.1.6), while for others the return to work is the motivator (OT3.3.3). Patient's that are habitually familiar with goal-orientated activity often respond better to therapy, as OT3 illustrates:

> *I've worked [with ...] a lady in her early 60s who'd had a brain haemorrhage, she'd been a yoga instructor, she was American by background, and she worked incredibly well with a goal-focused programme, because she was used to that, that's how she'd lived her life. So I think that type of thing is much*

> *easier with people who have used goals in their lives before. Maybe that's a generalisation, but possibly career-minded people are more used to using goals.* (OT3.5.3)

Self-generated goals were deemed powerful motivators in the recovery process (NP1.11.3; OT2.4.2). Here, however, the patient must be encouraged to recognise their new limitations (OT3.2.3), so as to avoid risky or possibly unsuccessful activities (OT3.4.4; OT3.5.1; OT3.2.5). A goal itself might also reveal a patient's limitations and thus be adjusted dynamically (Tech1.7.3) as part of a trial-and-error process (NP1.1.2).

Goals should also be appropriate and achievable, leading to a sense of success, (NP1.1.2; Tech1.7.3), but challenge the patient sufficiently for the therapy to be motivating and successful (OT2.8.4; PT1.14.1; PT1.15.1; PT1.15.5)[56]. Games, in this regard, can serve as a stable award system and might thus provide a goal-orientated activity (PT2.15.1), given especially the need for repetition in motor recovery (OT2.5.3). Games can thus be delivered through a PC and more focused technology is currently being developed along this principle to achieve dynamic goal-setting (Tech1.13.3). Other means of providing awards through sensory feedback might serve a similar purpose (NP1.7.2; PT1.9.2). Using a PC in this context can also help in achieving goal-orientated behaviour while training is undertaken (NP1.11.1), as can using a virtual reality system (PT1.13.3; PT1.14.1).

Patient engagement in community settings

The hospital environment can be limiting in its lack of complexity (PT1.11.2), which might not reveal some of the patient's impairments (PT1.11.1) and does not reflect a patient's normal, community environment (PT1.4.1), where he or she might even function better (PT1.12.2). The patient engagement is thus often sought in community settings – at home, in shops, streets, a workplace, the gym, the library, and so on (OT3.1.3; OT3.3.4; PT2.2.4). These are areas where navigation and communication are important and the patient is impelled to overcome any tendency to withdraw from public life and build confidence in this respect (PT2.7.4). The patient might make the choice as to where this ought to take place (OT3.3.6) and family or friends, too, are sometimes engaged in this process (OT3.4.1), especially given the need for patient monitoring in this regard (OT3.3.6) and awareness of risk (PT1.11.1), as PT1 described:

> *Hospital is such a confined environment and there is this danger that someone who's functioning independently in hospital so that you send them home and, of course, you then suddenly, you don't suddenly expect that they're going to be*

[56] NP1 appropriates Maslow (1954) in this process for patients with learning disabilities

able to walk on a busy road, cross the road, when there's so much more things happening in an environment that's not very protected, there's nobody around you to ask for help. So [we] integrate somebody into the community and get them used to having other people moving around them, and having lots of other stimuli. Particularly for people who have spatial problems, who maybe have some cognitive problems, being outside where there's lots of distractions, there's obviously safety things like having cars, things like people who are very impulsive, then suddenly going outside can open up this whole range of problems that you didn't realise in such a confined environment. (PT1.11.2)

Responses to an environment might also vary from patient to patient: a gym induction can, for example, become an engaging, public activity through which long-term, structured and achievable goals are established (PT2.7.6; PT2.8.2); yet for many it is a noisy, technical and quite alien environment (PT2.7.5; PT2.8.1; PT2.8.2). The various levels of physical and semantic complexity in an urban area (a quiet square, a congested junction, and so on) can also provide a given range of environments in which the patient can be observed by all therapists (PT1.11.2; PT2.7.1) and where sequential behaviour must be restored and maintained, as in the example of street-crossing (PT2.7.3). The patient's observing and vocally describing the environmental richness of such public environments can also aid cognitive function and recovery (NP1.2.3).

In spite of the importance of patient engagement in these various areas, it was also observed that there are often problems in achieving this. Such problems include the patient simply not enjoying the process, not feeling relaxed and fearing failure (PT2.8.3). The clinician often endeavours to overcome this, which must naturally be accomplished within the legal remits of therapy (OT1.15.2), with the patient's permission, however frail that person may be (OT1.4.4), and without risk of harm to all concerned (OT1.15.3). There might, however, also be a tendency within the some quarters of the health professions to not wholly accept patient participation and other agencies involved with the patient's return to the community might not assign value to this endeavour (OT1.9.3).

Winning the patient over to the 'rehabilitation way of thinking' also often involves a series of visits to his or her home (OT1.14.7), not least after being discharged prematurely or with inadequate provision (OT1.3.3). In this instance, the patient is actively engaged in the assessment of the domestic environment (OT1.13.2) which the OT then relays back to the therapy team (PT1.4.1). He or she might also be required to reflect upon specific needs in this context between the therapist's visits (OT1.15.1). Patients are also encouraged to engage in the choosing of equipment from an approved stock catalogue, sometimes with the help of family members, professional carers or through peer recommendations (OT1.4.4; OT1.6.1; OT1.7.7; OT1.13.3). In recent years the patient has been aided in this process through the provision of a Department of Health grant called Direct Payments, apparently to the sum of around £200 (OT1.7.3). The implementation of equipment is followed by a training session, which is kept brief to avoid cognitive overloading (OT1.6.2).

The use of ICT technology has been shown to improve the organisation of home visits around a patient's daily routine; it can be used as a tool to train the patient's cognitive function (OT3.6.3) and is also of relevance for training for return to work, as in the examples of a communication, organisation and prompt systems established through PC-, PDA- and web-based applications or developed with MS Outlook (OT3.2.1; OT3.9.3; OT3.13.5; NP1.11.1). Basic equipment, such as a medicine box or diary, might also provide a means for patients to organise their days (OT3.6.1; OT3.6.4); it was also observed that technological innovations might aid patients in this respect (PT2.9.2)

Equipment, technology and innovation

Equipment provision: an overview

Much of the equipment utilised by a therapist is designed to help a patient perform the activities of daily life. Although such provision always incurs a cost, it is nevertheless economically advantageous in achieving patient independence (OT3.6.7). Such equipment thus includes adapted kitchen utensils, a sofa-raise, bed lever, toilet transfer frame and bath board (OT1.5.6; OT1.5.3; OT3.6.1), each of which provides a simple, robust means of leveraging existing motor function (as outlined above). Other equipment is implemented to maximise and retrain cognitive function or to overcome neuropsychological impairment (to vision, memory, and so on); this might include a diary, personal organiser, talking watch, pager or mobile phone (NP1.2.3; OT3.6.1). Funding for all equipment is largely from the public purse but occasionally through a charitable source (OT3.6.5).

Items of equipment are usually supplied and implemented by a third-party distributor at a relatively low cost and often with the cooperation of social services; the therapist might deliver only very small, light items, such as a walking stick (OT1.2.7; OT1.3.1). The involvement of these various agencies can, however, create problems (as outlined above), not least when more complicated, expensive or labour-intensive equipment (hence authorisation) is required (OT1.8.1; OT3.6.6; OT3.6.7) or where the patient is due to be means-tested (OT1.8.1). There is often a waiting list for such items (OT1.7.7) and the relative affluence of an area might also impact on the availability of specialised equipment (OT2.6.7).

The therapist often incorporate the patient's wishes in choosing equipment, but might disallow any preferences if the equipment is too costly, time-consuming, requires a high level of expertise to implement and operate or is inappropriate to the patient's needs (OT1.5.3; OT1.7.7; OT1.5.6)[57]. The factors of cost and time were thus described as being prime to the development and delivery of innovative equipment (PT1.17.3; PT1.17.4). Regarding such principles, it might also be observed that expendability, ease of use and high adaptability could also be maintained as design measurements. Indeed, equipment designed along such lines tends to maximise existing function (OT1.5.6; OT1.6.1), as the widespread use of cheap tubular foam for cutlery adaptations might illustrate (OT2.3.3). There hence appears to be a tension between supplying equipment that is bespoke to the patient's needs yet appropriable to the broader clinical context; in short, a conflict between *specific* and *generic* care provision (Tech1.10.2).

Once the equipment is chosen, the patient's body measurements are taken and this data relayed to the equipment suppliers (OT1.5.3). The patient is often required to use the equipment independently, to varying degrees (OT1.5.3; PT2.10.2) and with appropriate ability (PT2.10.2), and the therapist will therefore instruct him or her – as well as family members and social services as necessary – in using the items (OT1.6.3; OT1.7.2; PT1.17.4) and in basic maintenance (OT1.6.2); family members have been observed as being instrumental in successful use of such equipment (NP1.10.3).Where direct supervision is required, health and safety regulations necessitate the presence of two qualified members of staff (PT2.10.2). The therapist is thus also required to ensure the patient is using the equipment safely and appropriately, especially when errorless learning is required (OT3.15.1) or where inappropriate use could lead to learning aberrational behaviours (OT3.14.3). Complexity of equipment can thus cause a delay in the break-off point for therapists' contact with patients (OT1.15.5), as can the patient's particular own goals in using the equipment (OT1.16.1).

Knowledge and take-up of innovations

Innovation in clinical provision and management might be regarded as a by-product of the care process (Tech1.9.3; Tech1.10.1), with many therapists willing to use, or consider using, innovations (PT2.13.3):

[57] Patient choice is not acknowledged to any degree by some of the non-clinical agencies involved in this process (OT1.9.3)

You tend to find most therapists in neuro and other areas are a pretty dynamic bunch really, and anything they think will enhance the recovery, and you can see how this would be a really useful adjunct, and allow practice, and […] motor learning, so I think people would be very keen to have a look at it and get a feel for it. The real test would be, when you have this set up, would be to get a group of therapists to have a play and give you feedback and see how useful they find it […] just for an afternoon or something and you had three sessions with ten physios, you could get quite a lot of opinion. I think that's quite important, if they're the people you're targeting to be the main people to set it up and use it it's important to, not to get them on board, because they'll be on board, but us to ensure they'll find it easy. Because what you find is (and we've got a good example of this tucked away in a cupboard upstairs) is that if it's difficult to set up, if it's time-consuming and it's complicated, it won't get used. (PT2.13.3/ PT2.13.4)

Innovation as a principle is considered to have especially high value and potential in interventions for severely disabled patients (Tech1.6.3; Tech1.10.1) and for patients relearning independent function (OT3.10.7) or in need of continuous means of contact (OT3.13.2; OT3.13.4). Innovative equipment is thus often requested by patients (PT2.8.4) and their carers (Tech1.14.2). Its general value in this regard was recognised by some of the interviewees (PT2.9.2; Tech1.11.1; Tech1.13.3).

Yet moreover, all interviewees outlined the general problems associated with innovation in the clinical context, not least in the bureaucracy (Tech1.9.3); the skills gap (Tech1.12.4) and poor uptake within the service (PT2.9.1); the need for specialist advice (PT2.8.4; Tech1.1.6) and the lack of time for working with complex interfaces (PT1.17.2), as well as the poor integration and occasional conflict of interests between technologists and therapists (Tech1.11.1; Tech1.15.1), which might include technologists' poor understanding of patients' limitations (PT1.10.4).

The qualitative shift between the designing, testing and delivery of technology was also raised as a concern in this regard (Tech1.10.2), which relates to the lack of specialist capability (Tech1.10.1) and commercial backup among design companies (Tech1.10.1); the lack of market dynamism (Tech1.10.1), as Tech1 outlined:

The equipment we do [create] is very low volume, so a lot of the companies wouldn't be interested. It's a very specific market for very severely disabled

> *people, so your really big companies wouldn't be interested. The small companies who exist in the assistive technologies field may not have much capability for that anyway. We've got good links with a couple of the companies and we will eventually look to them manufacturing some of our stuff. But initially we're doing it all in-house. But the huge healthcare companies who would be needed to push VR stuff wouldn't be interested in the size of the market.* (Tech1.10.1)

In spite of these problems, therapists will often seek out innovations by various means, including through commercial avenues (Tech1.10.1; Tech1.13.1); by word-of-mouth among professional peers (PT2.11.1; Tech1.9.2), among patients (PT2.11.1) and among carers (Tech1.14.3); also through the websites of professional bodies, which are considered to be particularly reliable sources of information (PT2.11.2; PT1.16.3). A more comprehensive introduction and training in equipment might also lead to a greater level of uptake among therapy staff (PT2.9.1).

Where innovation is developed and appropriated successfully, this often occurs *ad hoc* (Tech1.9.3) and is based upon prior knowledge of problems and solutions, with dense information-sharing networks yielding a greater degree of innovative know-how (Tech1.9.2; Tech1.14.3). Such networks are informal and are maintained through face-to-face contact (PT1.16.3; Tech1.13.3) or web-based communication (Tech1.14.3). Perhaps partly as a result of this self-initiated information gathering, therapists are not always open to sales pitches (PT2.11.2), although targeting a specific problem might achieve better reception (PT2.11.3).

Knowledge of virtual reality in clinical practice

Each of the interviewees expressed an opinion about using virtual reality (VR) systems in their areas of practice, whether speculatively or based upon direct or indirect experience of the technology. Hence, opinions ranged from the positive to the negative, with concerns raised as to the appropriateness of the interface and engineers' understanding of clinical practice. Interestingly, one interview maintained that VR engineers do not always recognise the ways in which their system is of value to clinicians, perhaps resulting from poor communication between the two fields (OT2.7.4):

> *If you look at the research, the people who've done the research from the virtual environments angle hadn't picked up on things which I thought were really clinically significant, which someone working clinically would think of. For example there was one case where they mentioned in passing that the [patient],*

after he'd done the task, had a greater degree of wrist extension, which for us would be really important to know, it's one of the hardest things to achieve. (OT2.7.4)

Where VR systems received a negative response, this was for a range of reasons: that VR does not assist in limb strengthening (PT1.13.3); that VR does not allow the therapist to make physical contact with the patient (PT1.6.1) and cannot replace the therapist in this regard (PT1.6.2); that some existing VR systems do not provide a means to train in a functional task (PT1.1.3; PT1.5.1); that the visual abstraction of tasks in a virtual environment does not always help the patient (PT1.6.3) and that VR cannot always meet the levels of complexity required for patient assessments (OT3.16.1); that there is a lack of appropriate sensory feedback, especially haptic, which leads to undynamic motor retraining, especially in treating neurological conditions (PT1.5.2):

> *[With] VR you're not going to get any sensory feedback and what you feel is going to determine your motor output, so if I go and pick up a cup, and I feel the cup is hot, then I'm going to change how I pick up the cup, so my muscle activity will change as a direct result of what I'm feeling. If with VR you can't feel anything, then* [...] *– and also potentially if you're dealing with neurological difficulties – their systems aren't intact anyway.* (PT1.5.2)

More mixed responses pertained to the necessary conditions that must be satisfied for such a system to be successful, which included the individualized nature of therapists' requirements (PT1.16.4); the patient's level of physical and cognitive ability (PT1.4.4; NP1.5.3) and stage of recovery (PT1.6.3); that such a system is more appropriate to local, rather than global, impairments (NP1.6.2); that it should not take up space (PT1.16.4) or place extra demand on computing facilities (PT1.16.4); that appropriate training should be supplied (PT2.13.2); that a tangible user interface based upon items familiar to the patient would provide a suitable means of interaction (PT2.12.4); that, given the dynamism of therapy interventions, the interface should allow system alterations to be made during the treatment session (PT2.14.3) or across the therapy programme as a whole (OT3.14.3).

Many other responses were similarly speculative but they, too, provide valuable insights into therapists' requirements in this regard: that, given sufficient sensory feedback (PT1.4.1), VR might provide 'return home' and independence training (PT1.10.4) and that simulating a patient's home might aid their recovery through the provision of meaningful activities (PT1.1.3; PT1.9.1); that VR can be a suitable adjunct to street training, including with regard to vestibular training (PT1.14.2)[58], providing that the content is rich and spontaneous (OT3.10.2; OT3.15.2). Avatars were also thought of as being stable, controllable 'human' agents that could promote perception and communication in some circumstances (NP1.7.3); VR could provide errorless learning, especially for way-finding (OT3.15.1).

It was also observed that the patient's use of mental imagery and rehearsal might have a positive impact on recovery, especially in the return home (PT1.1.3; PT1.4.1; PT1.13.3) or in the need for 'role modelling' (NP1.7.1):

> *[We have been discussing] mental imagery and mental rehearsal in terms of promoting recovery of activity, so for example, if someone has an upper limb weakness and some sensory problems, there's some evidence to suggest that if you get someone to actually look at their hand, and really mentally try and engage, with what they're, so if you're trying to encourage them to, I don't know, pick up a cup, then if they're actually thinking about, I'm going to pick up the cup, which is why it's so important to have objects because it means that you immediately start that mental process rather than if you're just reaching into fresh air, there's no mental engagement in reaching into nothing. So I suppose I can sort of see VR in terms of someone mentally rehearsing movement, and mentally preparing their body to move, but obviously then you need the physical ability to do that.* (PT1.4.3)

> *[An avatar is] safer than interacting with a human being, because you haven't got that danger that that person is going to invade your personal space because they do have much larger areas of personal space. (NP1.7.3)*[59]

Some interviewees also commented on the relative appropriateness of common VR interfaces, with positive responses pertaining to the provision of natural and intuitive movement through datagloves and HMDs (PT2.13.1; PT2.13.2), as well as joysticks providing an interface highly similar to that of a motorised wheelchair – although navigation was found to be problematic in this regard (Tech1.4.2). It was also observed, however, that datagloves, HMDs and joysticks are not always appropriate to a patient's level of cognitive and physical ability (NP1.5.3; OT3.16.2; Tech1.4.2):

[58] Relating to balance, spatial awareness and navigation
[59] From a discussion of treating autistic patients

You'd have to have a certain level of cognitive ability in order to understand the complexity of what you're dealing with. It's actually quite a complex thing to put a helmet on or have a glove on and see that your hand here is doing something but that it's affecting what's going on on the screen. That's quite a difficult cognitive concept to grasp, and the same with the helmet, if you've got the helmet on, presumably you're seeing that inside the helmet, that again would be quite a difficult thing, so you'd have to have a certain level of cognitive ability to do that, so perhaps some of the better able patients might be able to handle that. (NP1.5.3)

I read a lot of papers about VR in kitchen work with OT and all along I'd been very dubious about that, you know, the whole idea of having a dataglove, and there's just a disconnection between what you're doing and the actual real task. It's a very different task, cognitively, and I just thought people aren't going to get that, and if they do, it's almost training them in something completely different. (Tech1.4.2)

It was thus observed that the simpler interfaces of non-immersive environments might be more appropriate to severer disabilities (NP1.6.1). HMDs might also cause claustrophobia (OT3.15.3; Tech1.4.2) and, when used in conjunction with datagloves, are prohibitively expensive (Tech1.4.2), although this view was based upon the relatively higher prices of the late 1990s.

In spite of these negative, qualified or speculative responses, many of the interviewees also affirmed that the technology is appropriate to their respective areas of practice, including its usefulness in achieving remote observation of a patient (OT3.9.2); its provision of variable environmental content, especially for street training (OT3.10.5; OT3.10.6); its provision of optical flow and other visual queues in gait and treadmill training (PT2.2.1; PT2.8.4), among other exercises (PT1.5.1); its value in training for space perception (PT1.5.1); its level of abstraction for functional training (PT1.5.1; PT1.10.4) as well as movement rehearsal (PT1.4.4); its value in adjoining a meaningful activity to a purposeful exercise (PT1.5.1; PT1.6.3)[60]; its value in strength training (PT1.10.4). PT1 intuited such a system:

If you were going to use VR and you could mock up something like their house at home or their bedroom or whatever, and you could give them tasks to navigate around ... you're kind of giving them an environment that's familiar to them and

[60] Meaningfulness and purposefulness are not synonymous in the clinical context

potentially using their effective upper limb in order to do that sort of private practice and giving them a task to do. […] There are reasons for when you're giving someone a task to do, so whereby, physios [often ask the patient to] pick up a comb or lift your arm up in the air, but actually that doesn't give someone a purpose or a target, and people's movement changes depending on whether they reach for fresh air or whether they reach for something, so to give someone a target of negotiating their way around a room would be different to just saying, 'Move a mouse on a table', because there's no purpose to doing that. So potentially, but again, you've got the sensory feedback of doing that, of using VR [as a means of] how somebody perceives themselves in that environment is different (PT1.9.1)

ITC in clinical practice

As VR for rehabilitation might be regarded as a system embedded in the broader information and communication technology (ICT) for healthcare context, the final area of questioning pertained to interviewees' usage and understanding of this in their fields of practice. A strong trend toward using ICT was described (OT1.10.7; OT1.11.3); each of the interviewees described using ICT on a daily basis for general administrative duties: report writing, communications, data storage and sharing, information gathering for clinical concerns and products, presentations, patient logs and caseload management (OT1.9.5; OT1.9.6; OT1.10.3; OT1.10.8; OT3.13.5; OT3.14.1; PT2.11.4; NP1.8.3; NP1.9.1; Tech1.12.1; Tech1.12.4; Tech1.13.1; Tech1.13.2).

The efficiency of ICT over traditional means of data storage was acknowledged (OT1.10.2), especially with regard to electronic patient notes (OT1.10.7). Similarly, the ease with which information could be gathered and disseminated was also outlined (OT1.9.6; OT1.10.4), although the variant quality of internet-based information was a cause for concern (OT1.10.2), as was the reliability of email (OT1.10.7) and telephone-based information such as NHS Direct (OT3.12.3). It was also observed that ICT systems with complicated interfaces were often abandoned (PT2.13.4) or required specialist skills (PT2.12.1). One interview also used ICT applications to create pictographic timetables and other diagrams by which patients with working memory impairments could organise their days (NP1.9.1).

Patient use of ICT

Many of the interviewees also described how their patients make use of ICT, which is common but not universal: it was observed that there is a generational divide in the levels of usage in this regard, with younger patients more confident, therefore more likely, to use PCs (OT1.12.3; NP1.11.2; Tech1.7.1), as Tech1 illustrates:

> *You've got a 70-year-old patient who had never used a computer in their life on top of teaching them how to use a single-switch scanning system, you've got, what is a computer, what is a document, what does 'click' mean? So we're saying, you can use this switch to simulate a mouse-click, and they go, I don't know what a mouse-click is anyway*. (Tech1.7.1)

Little or no use of PCs was also observed throughout patient groups comprising a range of age, social and clinical differentiators (OT1.12.2). It was observed that such pre-morbid factors and post-morbid levels of ability should be considered when implementing PCs for patient use in a clinical context (NP1.11.1; Tech1.7.1).

Access to information is also considered important to the patient's well-being, although this is not always recognised (OT1.12.6) and it is rare for patients to have sourced information independently (OT1.12.4); rarer still using the internet (OT1.11.4). Many therapists will thus encourage patients to source information about their conditions through charity websites (OT1.10.4).

ICT as a therapeutic tool

Where patients do use PCs, this might be to perform the activities of daily life (Tech1.7.1), or for hobbies (OT1.12.3), which can be regarded as therapeutically meaningful activities (OT1.12.4). The patient is sometimes taken to use PCs as a meaningful activity in a community setting, such as a library (OT3.1.4), or using standard administrative software:

> *I've got one patient who […] worked in marketing, and so I'll email him kind of cognitively challenging tasks for him to do, and give him timescales, so then I can actually say OK, I want you to get this back to me by such and such, so he's actually working on his time management, and memory, and having to put in the diary when I want it back and those kinds of things. I mentioned using things like Outlook Express with patients, and also we've got one patient we've done that with his family and friends, so that as a team of professionals and family working with him we can co-ordinate our visits, so we actually put our visits in to his diary so everyone can check that and he's got access to it.* (OT3.1.5)

PCs can thus be the focus of return-to-work training (OT3.13.5), which has particular value when the tasks of self-initiated (OT3.1.4); similarly, a standard handheld PC can provide a convenient means of facilitating working memory training (OT3.9.3). Tech1 outlined a particularly well-facilitated computer suite:

> *[Patients] can come into our computer room really for two main reasons, one is as part of their rehab programme, they'd be brought in by a therapist to work on memory skills, motor activity, that kind of thing, perceptual skills, cognitive skills, all that kind of stuff. They'll be doing kind of supervised sessions. But they can also use the computer room for their own leisure interests, surfing the internet, writing letters, playing games… and we use it very much as well as an assessment tool for working towards other technologies, so looking at how wheelchairs, but we were very dubious about someone's ability to drive, to use a joystick memory, starting with a joystick-type games, that kind of thing. Communication aids, we'll start off with a desktop computer and use the software on that before making a decision on an actual communication aid because they're much more expensive.(Tech1.3.3)*

The standard PC interface (keyboard, monitor and mouse) can sometimes be used as a means to achieve normal movement for some patients, such as fine motor training for hand function (PT1.8.3) or vestibular training (PT1.14.2)[61], but can also be adapted with large, strong handles to provide sensory feedback for myometric[62] assessment and training (PT1.10.3). PCs can thus help facilitate errorless learning (OT3.15.1).

User study analysis

Analysis of the user study against weighted objectives

The user data presented above offer valuable insights into the complexity and dynamism of brain injury therapy. Yet to be of use in designing a VR system which might serve as an adjunct to clinical practice, the data is now be subjected to a further level of analysis, conducted with reference to the pairwise comparison of design principles presented in Chapter Two, Problem Analysis. Through comparing the various design concerns yielded by the patient statement, this chart adduced weighted values of the design principles and thus a system of design priorities. These, to reiterate, include the need for user focus (w=5), clinical

[61] Complex and dynamic visual information is presented to the patient to help align visual and spatial functions

[62] The functional value of skeletal muscles

effectiveness (w=4), meaningfulness (w=3), marketability (w=2), adaptability to a range of clinical circumstances (w=1) and system variability within a treatment programme (w=1). The user study data is hence interpreted against each of these principles, in descending order of priority.

User focus

The user study data present a challenge to the principle of user focus in that there appears to be limited consensus among therapists as to the commonalities and discontinuities of their respective roles. Common routines are, however, apparent in that therapists will often, but not universally, begin their days with handover, among other communications, and thereafter attend to patients, whether in the treatment centre or in a community setting. Contact with patients is commonly a dynamic process, with programmes of therapy structured around cognitive or motor function goals that are altered as the patient progresses.

Further dynamism is necessitated by the disparity of the patient group, in which factors of age, gender, level of disability, pre-morbid tendencies, wealth and social standing each affects the processes and outcomes of clinical intervention. Goal-setting is similarly affected by these factors, considering especially the highly relative means by which patients are motivated, which might vary from the desire to return to work to the desire to sit up in bed, yet pose equally problematic challenges.

This general demand for clinical dynamism is also reflected in the management of patients during their transition through the care process, whether between acute and rehabilitative care or between clinical and community settings. In the latter case, however, the integrity of the service becomes far less consistent and often relies on informal networks of communication within the service and between the various agencies involved, with staff turnover also disrupting the service in this regard. Contact between patient and therapist might also break down partly as a result of this transience and remote monitoring would thus be beneficial in some circumstances; it has been suggested that communications technology could play a part in facilitating greater integrity throughout the care process.

Further evidence of the central importance of user focus for a system such as that proposed by the present study was gained through an observation of OT2 at work with two stroke patients. Although the nature of the evidence is beyond the scope of this interview-based study, the findings are of value and are presented in Appendix 6. Throughout this session the therapist, working with a nurse, demonstrated in practice the themes we had discussed. The therapeutic session thus embedded rehabilitative exercises in the activities of daily living (in this instance washing and dressing), while the elements within the environment (the sink, chairs, bed and a mirror) were employed for the maximum gain to the patients' functional performance and recovery.

The patients' were led through the exercises in such as way as to pose achievable challenges, while vocal support was offered at all times. Throughout the session, OT2 ensured that the patients' bodies were correctly aligned and some exercise thus involved direct and highly skilled manoeuvring, with special consideration given to the likelihood of pain. OT2 also demonstrated how the therapy process is dynamic in that knowledge and skill are brought to the fore as and when the patient offers evidence of functional progress. The patients' preferences were also considered – given especially that mood is an important factor in the success of therapy, and this can be affected by depression, frustration, a sense of hopelessness, compounded problems resulting from the stroke or other factors (such as MRSA); the nurse working with OT2 was thus particularly attentive to the patients' preferences, even including such things as selecting a preferred towel to use. In working with one patient, particularly intimate issues were discussed and dealt with as part of the therapy session.

Clinical effectiveness

The data revealed some parameters by which therapists maximise therapeutic interventions and measure clinical outcomes. As observed above, therapy will often be conducted according to goals actively negotiated between patient and therapist; these embed the functional tasks and direct manipulations by which normal and intuitive movement is restored to the greater degree. Goals might thus pertain to lifestyle aims (return to independent living, a hobby or work, and so on) or functional objectives (balance, muscle strength, wrist extension, and the like); an award system might also be established to encourage this behaviour. Goal-orientated task performance and fuller body integration thus engage the nervous system to a maximal capacity, thereby driving the recovery process at a deeper level.

In accordance with these methods, the therapeutic process involves a bespoke assessment and incorporation of the individual patient's requirements, desires and preferences, often including quite intimate concerns. The patient is often actively engaged or impelled, sometimes energetically, to participate in this process, which is regarded as having a positive impact on therapeutic outcomes. The continuation and self-initiation of exercises between formal therapy sessions is similarly regarded as being valuable by many therapists. Constraints on contact time can, however, deem this an improbable endeavour, as can the compounded clinical problems experienced by the patient such as poor insight, fatigue, depression, impaired perception and memory, as well as other factors such as lack of motivation, poor understanding of the therapy process and limited proclivity to goal-orientated behaviour.

The patient's environment is also of therapeutic concern with regard to levels of meaningfulness and complexity, as well as the quantitative changes resulting from the patient's condition (the need for the home to be reassessed and furniture to be adjusted, and so on). Furthermore, the hospital environment does not always allow cognitive or motor impairments to become apparent and is also unlikely to reflect the patient's long-term goals, for example return to work. The hospital environment might also promote negative responses from the patient, such as passivity to the care process and withdrawal from public life. The therapist thus endeavours to take the patient to a community setting such as a street, shop or library.

In facilitating a therapy programme, a range of equipment is normally be available to the therapist and patient, which is often utilised to leverage existing motor or cognitive function in support of the recovery process. Equipment thus includes prostheses such as adaptors for cutlery, walking sticks, bath boards, toilet frames and lifts and orthoses such as splints, weighted levers and walking harnesses for treadmill training. Patients with severe disabilities might also use powered wheelchairs or communication aids such as an adapted PC interface or blow tube. The therapist is often required to ensure that the equipment is appropriate to the patient's needs and abilities and that the patient is the using apparatus correctly, especially where errorless learning is being undertaken.

Meaningfulness

The manner in which patients engage in goal-setting for task performance, outlined above, illustrates how goals that are meaningful to the patient often benefit the recovery process. Meaningfulness thus pertains to a range of patient needs, whether individual, such as the lifestyle aims already described, or more universal objectives such as maintaining self-esteem or achieving self-realisation. In this sense, the hospital environment might limit the meaningfulness of activities, not least where the patient attaches particular meaning to the activities of work or domestic life. In enabling the patient to make and act upon choices about his or her environment, a mundane activity can thus become imbued with meaning, as the example of changing a television channel might illustrate.

Emergent in the user study data, and hence not included in the original pairwise analysis, is the distinction in task performance between meaningfulness and purposefulness. In this regard, a task might be purposeful in terms of clinical outcomes but entirely meaningless to the patient. Conversely, a task that is meaningful to the patient might have a limited or even negative impact on clinical outcomes, as the prevalent pre-morbid tendencies to anti-social or disruptive behaviour described by some interviewees might illustrate.

Marketability

Many of the user study data reveal the means by which an innovative technology might be introduced as an adjunct to clinical intervention, as well as the existing or potential problems associated with this. Although it was observed that therapists are generally knowledgeable about innovative technology and will usually be willing to find out about innovative equipment to further the effectiveness of their intervention, resources in this regard tend to be limited in relation to time, space, funding and technical skill. Lack of funding was of particular concern, although it was also maintained that equipment that benefits patient independence saves on the costs associated with hospital care.

Economic and social disparities within regions and populations might also affect the provision and uptake of equipment, which could be assumed to reflect in the uptake of innovative apparatus. In spite of such local problems, there does appear to be a paradigmatic shift towards innovation that has been formed through far-reaching government policy, not least for informational technologies. This has been engendered by a broader still requirement for integration of services for long-term patients and a general push toward patient choice, in both the care they receive and also, to a lesser degree, the equipment they use.

The patient is often engaged in choosing equipment from an authorised stock catalogue. Yet occasionally the therapist is encouraged to try out innovations as a result of advice from the patient or the patient's carers (who can have an instrumental role in the patient's successful use of equipment). Here, the innovations might have come to attention through the media or through peers, such as friends and neighbours. Negative media coverage might also dissuade patients from using certain innovations. Furthermore, the innovator will often need to gain the therapist's confidence; the formal networks of professional bodies and informal networks of professional peers seem to provide the more likely means to achieve this.

All equipment provision is associated with a certain level of bureaucracy, which increases according to the complexity and costliness of the apparatus. The involvement of agencies beyond the care service, more usually social services, also increases the demand on resources as extra communications, assessments and cost analyses must be made. Funding for equipment might also be derived from a variety of sources, whether public or charitable, and this too intensifies the bureaucratic process. Attitudes to costs also differ between these agencies, with care services apparently having the more generous attitude to equipment provision in this regard.

A gap in skills, knowledge and professional interest has also been observed within the engineering community, with engineers often having a poor understanding of therapists' needs, patients' limitations and the market value of equipment provision. Although this gap is usually to the disadvantage of the therapist and patient, one interviewee observed an instance in which engineers had not identified their system's value to a specific and particularly problematic clinical intervention. The various advantages and disadvantages of VR interfaces were also outlined by the interviewees, which similarly do not appear to be well understood by engineers.

Variability

As the therapeutic process is dynamic, as outlined above, so any equipment must respond to this. Equipment in rehabilitation is very often simple and robust. Where technologies are to be used, such as in gait analysis or gym training, the interface should allow for rapid system alterations without the need for specialist skills. Systems that do not fulfil this requirement are often abandoned, regardless of their potential clinical effectiveness.

Adaptability

The various therapeutic perspectives and contexts outlined above illustrate the breadth of rehabilitative interventions as well as the differing attitudes to the patient. Thus, as the care process is dynamic, so it is also complex and any equipment designed to ameliorate the recovery process should also be readily adaptable to the specific clinical context in which the therapy is being undertaken.

Service integration is also a problem among therapists and equipment that aims to meet each of their clinical needs should, as far as possible, be seamlessly transposable at the point of handover, while avoiding further disruption to the patient's transition through the care process. Furthermore, the disparities of the patient groups also necessitate a highly adaptable and readily operable system that minimises preclusion of users due to age, level of ability or other factors. Patients, moreover, are individuated by the therapeutic process and an innovative technology should also be responsive to the highly subjective means by which the patient is motivated.

This broad and detailed user study has served to outline many of the challenges to the design of a VR-based system for use in rehabilitation. Building upon these findings, the following chapters explore these issues through a a study of stakeholder perspectives (Part Two, below), an exercise in interaction modelling (Chapter Five), a practical pilot study (Chapter Six).

<u>Part Two: Stakeholder Perspectives</u>

Introduction

The interview data presented in Part One helped develop a picture of clinical practice, as well as the limitations and possible opportunities of appropriating VR might in this field. The findings provided some insight into how the technology must interface with the requirements of its target user group (the *market*) and also with the economic processes necessitated by its supplier (the *industry*). The assessment of the technology against these domains thus forms the basis of an innovation strategy, for which formal models have been devised (outlined below), and also reveals the means by which the technology could be implemented effectively and sustainably.

The pairwise analysis undertaken in Chapter Two, Problem Analysis, also revealed that marketability is as a key objective for the development of the technology. Marketability serves as a parameter both in achieving the sustainable development of the technology and also in demonstrating its effectiveness in the clinical treatment and practical management of patients. Marketability is not, however, intended to be synonymous with commercial profitability and the analysis presented below is set to differentiate between these factors. Although neurological rehabilitation does not appear to be a profitable area of enterprise, there are other economic pressure points in the field that require effective solutions, for which technology can play its part. These too are analysed as part of an innovation strategy.

Many of the market demands pertaining to the needs of therapists were, in this regard, outlined in Part One, above; this section continues the study by assessing the attractiveness of the market to which the technology is set to be 'sold', as well as the attractiveness of the industry by which the technology is set to be implemented.

In discussing technologies and health organisations, a great many abbreviations are used throughout the text. As a point of reference, these include:

ADL Activities of daily living
EAT Electronic Assistive Technology
ESD Early Supported Discharge
ICP Integrated Care Pathway
ICT Information and communication technology
IP Intellectual Property
NCRS National Care Records Service

NPfIT National Programme for IT in the National Health Service

NSF National Service Framework

PCT Primary Care Trust

VE Virtual environment

FAME is a company records service operated by Bureau van Dijk Electronic Publishing

Introduction: models for innovation

An innovative milieu

No single model can be devised to guarantee the innovative success of inventions, yet one survey of innovation among highly productive research facilities in the United States does reveal that innovation breakthroughs are born from creative milieu for which prime conditions are established (Stefik and Stefik, 2004). Thus, far from being a stable, linear process, it has been observed that innovation occurs within an 'ecology' of endeavour, involving many funding and research agencies and a variety of individual researchers, each with different backgrounds and perspectives. The ecology thus comprises collaborations between basic and applied research, with a third area of study seeking to further mine the source data. The market, too, might include many and variegated levels of stakeholder, whether in the private or public realm. The literature review of Chapter Three has revealed that these generally observed factors are certainly present, to varying degrees, in the field of virtual reality for rehabilitation.

The unevenness with which virtual reality for rehabilitation is developing thus appears to be consistent with the way in which innovation at its early stage occurs generally. Technological breakthroughs are, however, rare and are prone to internal constraints and conflicts within a corporation, not least in the conflict between a company's conservation of its existing core competences and the need to find and exploit new markets. There is, however, a pressing need pursue innovation as a principle, substantiated by the commonplace observation that, although the research might address existing problems in society or industry, successful technological breakthroughs, such as the light bulb, often create their own markets. Others, such as the motor car, have supplanted existing markets: the farm horse.

Stefik and Stefik have identified four different channels through which innovation can be driven (Stefik and Stefik, 2004a, which include developments at the theoretical level, freshly gleaned knowledge or inventions, new methods for observing phenomena and the pull factors of social or commercial needs. With regard to the present study, it might be maintained that the research stems from theories pertaining to the effect of environment and sensory stimulus upon neurological patients, the emerging data in the field of VR for rehabilitation (although this is somewhat inconsistent, as we have already observed) and the need for care providers to cope with the rising incidence of these conditions.

A model for assessing innovation

We noted above that innovation is not a predictable, linear process. Innovation thus necessitates failure, as ideas and models are devised, assessed and discarded. But failure also creates an irrecoverable cost which can cause obstacles to the creative process. As with any enterprise, it is thus expedient to assess the invention against the forces with which it must contend, whether commercial, social or otherwise.

The methods of assessment appropriated to the present study were originally designed by Mullins (2003), who maintains that any innovation can be assessed within a series of conceptual frameworks, or 'domains': market and industry at the micro and macro levels as well as the capabilities of the implementation team. As the 'market' comprises therapists and their clients at the micro level and the NHS at the macro level, so the 'industry' could be described as the technology creators and suppliers at the micro level and the Department of Health (as facilitator of funding and distribution channels) at the macro level. As the user study also revealed the means by which equipment is supplied to the therapist and client, this might also form a provisional model of the market demands that a supply team must meet.

The pre-plan business model presented below is thus arranged according these domains. Hence, the macro-level industry is described in terms of the emerging tendencies to innovation in health provision in the UK and the value attributed to information and communication technologies (ICTs) in this milieu. The industry at the macro-level might also comprise the National Service Framework (NSF) for Long-Term Care, also outlined below.

The industry at the micro-level is examined through the means by which healthcare innovation might be developed and distributed, being the newly established Regional Hubs and the NHS Institute. The practical means by which VR can be supplied to users are also described.

Regarding the market at the macro-level, the increasing prevalence of stroke is outlined as are the means by which the NHS is expected to cope with this. Advancing the themes emergent from the user study, the need for an integrated care process is also outlined. At the micro level of the market, the expediency of home-based care is examined in terms of both its clinical and economic value. Again advancing a theme of the user study, the technology is discussed in terms of its potential value in engendering or maximising 'social capital' as part of early supported discharge (ESD) and thus in the possibility of its supporting a social enterprise.

Analysis is based upon possible outcomes given existing data to develop a picture of the field. Such 'scenarios' help in preparing the innovator to adapt to any such outcome by analysing trends within set areas of concern: Society, Technology, Economy, Ecology and Politics. These have also been adopted by the Global Foresight and Innovation department at Arup, to form what they call the STEEP technique, also used for the scenario analysis, below[63]. Schwartz's fully extended technique involves discussion and debate among experts over a long period of time, but here only a basic format is adopted in order to identify the key 'drivers' of change as well as the environments in which those developments might occur.

The macro-level industry

Health and innovation in the UK

In distributing an innovative technology for health provision in the UK, it might be observed that the relationship of the independent sector to central government is problematic and prone to conflicting interests; reforms favourable to the independent sector have yet to be implemented satisfactorily (Lewis and Dixon, 2005). Although new amendments to social policy are intended to open the way for innovators (as outlined below), public perceptions of such reforms are somewhat variable (see for example Page [2004]). In this sense, the nature of health provision in the United Kingdom is in many ways a politicised concern, not least when one considers the 'modernising' agenda for public services that formed the basic policies of the post-1997 Labour government (Mandelson and Liddle, 1996). Though barely unique to post-war social policy, these decentralised, 'market orientated' reforms have granted increased opportunity for hospitals to opt out of central control – to become largely self-governing Foundation Trusts – and for independent care providers to supply treatments and other facilities in place of the public provider (Demopoulos, 2005).

The major reform to health provision in recent years has been The NHS Plan (Department of Health, 2000), which comprises a governmental commitment both to investment reforms and to integrating all areas of existing provision, including rehabilitation engineering (Department of Health, 2001). Although the government claims that the reforms will improve standards of care, expand service user choice, decrease waiting time for treatment and help secure more investment (reportedly an extra £40billion between 2003 and 2008), the reforms have their

[63] The scenario methods was devised originally by Schwartz (1996); Arup Foresight's "Drivers of Change 2006" flashcard set, which was also used in the present study, outlines the STEEP technique while providing data pertaining to the parameters

opponents, even within the present Cabinet. Opponents' concerns are that a 'two-tier' health service could emerge in which the quality of care varies across the nation (Butler, 2003). The departing Prime Minister has thus been observed by some as having retreated from what could be described as more aggressive essays in introducing privatised provision to community services (Dean, 2005). This development is perhaps suggestive of a resistance among the public to such reforms[64] and thus seems to render the role of the independent sector in public services evermore uncertain.

In spite of this uncertainty, however, there are other, clearer signals from less central quarters of the government that the independent sector is intended to play a role of increased prominence in the context of a devolved health service, outlined below. Political concerns aside, this potential opportunity is examined and evaluated in terms of the innovative implementation of virtual environments to post-brain injury rehabilitation.

Information and communication technologies (ICTs) in healthcare

Early in 2005, the then Health Secretary, John Reid, announced a major government investment over ten years into ICT provision in all areas of public health care, which appears to be a key opportunity for technological innovation. The National Programme for IT in the National Health Service (NPfIT) is intending to digitise the care process at every level of care and as such is the world's most expensive and far-reaching advance in civilian IT. The system has not developed without problems, however, and is due to cost twice the original estimate to implement (£12.4 billion by one estimate)[65].

While computerised data and diagnostic tools have been available to service *providers* for over a decade, the NPfIT now allows such technology to be developed and implemented for the benefit of health service *users*. Hence the client-focussed NHS Direct website regularly receives daily hits in the tens of thousands, while NHS Direct Interactive is now available through Sky TV to 7.5 million subscribers. A service-focussed search engine, NHS Gateway, is also on-line and there are numerous authoritative websites addressing niche concerns, for example *Teen Info on Cancer*. NHS clients can also be prompted to undertake rehabilitative activities through the NeuroPage pager service.

Further to these developments was a major study, published in 2004, that gauged the effectiveness, in terms of service usage and financial expenditure, of Virtual Outreach, a teleconferencing system that enables service providers to interact remotely with clients in

[64] The public sector trade union, UNISON, has, for example, launched a concerted campaign to oppose Foundation Trusts, with details provided in UNISON, 2003.
[65] This figure represents twice that of the original cost estimate (Doward, 2006)

various areas of care (Wallace et al, 2004). Similarly, the radically conceived HealthSpace[66] now allows a service user to access and track his or her medical records at will. The Department of Health is also sanctioning research to test a remote-controlled robot, 'Dr. Robbie', which has been designed to perform doctors' consultations – even reading client records, analysing test results and asking the patient questions about his or her condition (Andalo, 2005). Many other examples of innovations in health care exist, although such a survey is beyond the scope of present study.

Platforms for delivering informational technologies are also available to the patient in hospital. Recognising the value of supplying 'services that play an important part in [patients'] everyday lives'[67], without causing a financial burden to the hospital. Patientline has thus delivered a range of communication and entertainment services through a bedside device which includes a screen, telephone and handset control. Services include television (including Patientline's own channel, Hospital Vision), internet, radio, talking books, games and so on. Patientline also offers the opportunity for the patient to access information about his or her condition and medical record. The cost is met by the patient and patient's family with services purchased through a phonecard system (currently £2-10 per day for use of the services; telephone calls are charged at premium rate. Free television is supplied to children under 16 all day). Around five million patients use the 75,000 systems currently installed each year and the company, according to one report, is due to have broken even after seven years of operations (Wray, 2006). Yet in spite of this apparent success, the company has been beset by problems, as outlined in *Assessing the Competition*, below.

To cite a further example from beyond the UK, the Finnish government has recently taken a leading role in piloting a major scheme to use IT for integrating health services. The Satakunta Macro Pilot project has sought to develop seamless care and service chains through using electonic services to their maximum potential. The scheme was piloted in the city of Pori (population 76,000), comprising also a sub-project to examine the integration of care of older people. It was intended to be subsequently rolled out nationwide.

Not disimilar to developments in the UK, the project comprises an interactive informational system for professionals which combined primary care, hospital and social service information; a public internet information system for services users and providers and auxiliary services to support independent living for people with special needs, (an electronic authentication system, delivered through an identity card, allows access to data). The pilot was deemed successful, not

66 https://www.healthspace.nhs.uk/
67 See Patientline's website http://www.patientline.co.uk/overview.htm

least in the sub-project that examined care integration for older people (Huijbers, 2004) but unfortunately outcome data appear not to have been provided.

National Service Framework (NSF) for Long-Term Care

The implementation of information technology in healthcare, whether brought about by NPfIT or otherwise, is so far-reaching initiatives in health provision itself have been engendered by its development. Of relevance to the present study is the National Service Framework (NSF) for Long-Term Care, launched in March 2005 by the then Parliamentary Under-Secretary of State for Health, Stephen Ladyman. NSFs serve as Cabinet-level blueprints for reducing disparities in health and social care services.

The NSF for Long-Term Care in particular is thus set to demonstrate how, over the next 10 years, services for long-term neurological conditions can be improved in all areas of care provision. Its chief aims are to maintain independence and quality of life among the target population; to reduce the need for hospital or high-intensity care and to allocate investment to integrative 'community settings' and/or in a client's own home – a key objective also outlined in a care policy document of January 2005 (Department of Health, 2005). A further concern is the growing burden on the care provider; the estimation being that, by 2050, four times the present number of people will require long-term support.

Stephen Ladyman's speech to mark the launch of the NSF for Long-Term care, this 'radical reform' as he described it, was full of provocative language to signal the urgency of the problem as well as the manner in which the government expects a solution to be sought.

> *"I want to see councils challenging and competing with each other to come up with new solutions, to be at the cutting edge of development… This has to be competition that supports development and the spread of state-of-the-art technology that benefits the people who need it sooner rather than later… Innovations used creatively have the potential to transform the lives of individuals"* (Department of Health, 2005a).

In achieving the reforms demanded by the NSF, the government regards dynamic and forward-looking technology innovation as comprising a major strategic advance: "The stark truth is that innovative solutions are not just desirable but essential and we need to see leaps of imagination, not plodding steps" (Department of Health, 2005). The first rounds of funding were made available early in 2006 as the Department of Health allocated £60 million to Partnerships for

Older People Projects, to be distributed in the main to voluntary partner organisations. Recipients of the investment are required to develop creative approaches to support older people in following active and healthy lifestyles.

Telecare National Framework Agreement

In an early move towards implementing the ventures proposed in Stephen Ladyman's speech, the NHS Purchasing and Supply Agency issued the first announcement in June 2006 of the initial tendered partnerships that are set to provide a range of 'telecare' services to those in home-based long-term care[68]. 'Telecare' refers to a set of technologies and processes that comprise the remote delivery of health and social services directly to the end-user through ICT. Telecare is thus set to maximise current trends in ICT take-up: as of spring 2006, 65% of households in the UK own a personal computer, while 57% have internet access (40% of internet connections are broadband); between 48-71% of all internet users access online content at least five days per week (depending on geography and wealth distribution) (Office of National Statistics, 2007); around 60% of European internet users have sought advice about health online [Briggs, 2006]. Yet, further to health information, telecare is set provide services such as *safety* and *personal* monitoring, including detecting problems in ADL performance and other functional activities (outlined in the literature review, Chapter Three), as well as the monitoring of electronic assistive technologies (EAT), whereby the home of a disabled person in made functionally controllable with manageable devices.

Telecare is intended in some quarters to prevent the unnecessary institutionalisation of patients in long-term care (Barlow and Venables, 2004), and to support the more rapid transfer from hospital to home. Yet its implementation appears to have been hampered by structural difficulties, arising in part from confusion over administrative and executive roles, over service ownership and funding, lack of clarity over delivery care processes and conflicting perspectives among health and social agencies (Barlow et al, 2005; Barlow et al, 2006).

The Telecare National Framework Agreement thus covers contractual guidelines for implementing equipment, installation, maintenance, monitoring and response services. Although the guideline may serve as a model for how such organisations might work with the Department of Health, the performance of these agencies has yet to be measured systematically. Their progress would nevertheless be worth monitoring in the coming months and years.

[68] The current partners include Docobo, Fold Telecare, Initial Attendo, Invicta, Just Checking, New Church Housing, Philips Medical, Possum Controls, ProWellness, RSL Steeper, SRS Technology, TBS GB, Tunstall Group, Wealden and Eastbourne Lifeline and Vivatec

Summary: the macro-level industry

In spite of the uncertainty of the relationship between the independent sector and the Department of Health, the industry is, in broad terms, very attractive to a technology enterprise. The 'pull' from the industry is driven by the abundance of government funding for ICT in healthcare; the existing and growing use of ICT for service users, for which a business model has been established; the tendency to market-orientated service provision, not least in the establishment of PCTs; the targeting of long-term clients (whose conditions often arise from brain injury) and the requirement for service integration in this regard. Furthermore, the government has offered an open invitation for innovators to posit solutions for these areas of concern and has also provided the means of channelling intellectual property through the Regional Hubs and the NHS Institute. While there appears to be current growth through tendered partnerships between the NHS and independent organisations, the nature of this relationship and the performance of the companies have yet to be measured.

The micro-level industry

Effective channels for Innovation: Regional Hubs and the NHS Institute

Further evidence of the government's new openness to innovation is the establishment in 2006 of regional Innovation Hubs and a central department, the NHS Institute for Learning, Skills and Innovation. Together the purpose of these bodies is in part to maximise intellectual property (relating to both products and processes) sourced within and beyond the NHS for the benefit of service users. Hence in 2004/2005 the nine Hubs, which cover all of England, provided pipelines for ideas to materialise in medical devices (49% of the new IP for that year), biotechnology and pharmaceuticals (8%), diagnostics (8%) and IT/training (28%), 'miscellaneous' (7%) (Department of Health, 2005b). The NHS Institute has an executive role in fostering innovation and leveraging IP for service provision by working closely with innovators and providing an 'effective entry point' for industry (Department of Health, 2005c]. At the time of writing, however, the overall success of these has yet to be measured.

Considering this evidence of a commitment to innovation, a key question for the present study is whether these policies and investments will have a lasting effect on the relationship between the independent sector and public health provision and whether a hypothetical yet secure business model might be designed that would sustain entrepreneurial growth. These issues are discussed throughout this chapter. The case for a business model for VR in clinical practice is also established with reference to the future of brain injury, both in expected morbidity and in care management.

Supplying VR equipment to users

The user study presented in Part One described how equipment that is not implemented effectively is often abandoned by therapists. It was also observed that funding and staffing resources do not often allow new apparatus to be brought in to the clinical environment. Where equipment is used, it is usually required to leverage existing function by providing simple and robust mechanisms. Equipment is usually implemented by a third-party supplier.

These existing practices do not seem to provide an effective model as to the means by which virtual reality systems might be implemented. The user study also revealed that virtual reality appears to be regarded as being a highly specialised technology and therapists often surmise that they do not understand it sufficiently for use in their area of practice (although the study also suggests that the technology is in fact understood sufficiently well to commence professional training). VR is also believed to be expensive and time consuming and entirely dissimilar to the simple, robust apparatus usually utilised for clinical treatments.

Regarding VR technology as a stand-alone unit which is intended to be 'wheeled out' to the treatment area, all of these assertions might indeed be apposite. The challenge therefore is to regard the technology not in this capacity, but as an entirely modifiable and transposable system which can be implemented centrally and delivered dynamically whenever, wherever and in whatever capacity is required.

In this sense, the implementation team must comprise a cohesive organisation of clinical and technical experts, as well as the means to deliver the interface to the patient. The technical platform for such a system must also be delivered, although as digital penetration increases, this might be delivered through platforms that the client is likely to already possess, or which are easy to implement (such as broadband internet or digital television).

Summary: the micro-level industry

It has been observed that the government is commencing in the provision of regional hubs through which innovators channel inventions into public health provision and that the NHS Institute is intended to leverage this IP by working with innovators and providing an 'effective entry point' for industry. Yet it was also observed that the overall success of these ventures has yet to be measured against their lasting effect on the relationship between the independent sector and public health provision.

The macro-level market

How will the NHS cope with the rising incidence of stroke?

That the incidence of stroke is set to increase is certain and based upon strong evidence. Hence Malmgren et al (1989) have predicted that incidence of first-time stroke will increase 30% in England and Wales by 2023, in part attributable to an ageing population. Yet where many major reports have underlined the grave importance of hospital-based stroke units, for example (Langhorne et al, 1993), this increasing demand on resources has led to alternatives to extended hospital stays being sought, including the implementation of early supported discharge (ESD). Following acute care, ESD allows the patient to return to a 'community setting' (commonly home or work), yet remains integrated in the care process for post-acute rehabilitation. This approach has apparently led to positive results in patients achieving independence and engaging in purposeful activities (Young, 1994; Langhorne et al, 2005), although benefits to recovery after stroke and to financial cost might be limited, as outlined below.

Integrating the care process

Health management concerns regarding caseload, patient throughput, quality of service and risk management have been addressed in recent years through a set of evidence-based, multidisciplinary guidelines for practice known as integrated care pathways (ICPs), which might also comprise an ESD scheme (McSherry, 2003). The guidelines are intended to serve as management tools to map the care process in order to streamline it, thus returning the value to the patient by avoiding duplicated or superfluous interventions. To illustrate the system with a simple example pertinent to the present study, a specialist stroke nurse has reported on her team's collation of their patients' attitudes to the care received, the range of services used, the extent to which they were used and the subsequent integration of those services which offered greatest value to the patient (Griffiths, 2003). Other health managers have sought to use the method to produce graphical representations of the care 'journey'[69].

The recently launched National Care Records Service (NCRS) is also expected, as part of the NPfIT, to drive the use of ICPs as information technology is further enlisted as a means to integrate the care process (Todd, 2004). In spite of this and other such enthusiasm for the potential value of ICT in an ICP (for example the home-hospital 'e-pathways' reported in Nies and Berman [2004]), limitations to the initiative have been observed. Such limitations include the inconsistency and untimeliness with which knowledge is captured and stored; the problems associated with interfacing local procedures with a global template; the costliness in staff time and energy as well as the cost of associated training for implementing such systems (Allen,

[69] The interested reader is directed to De Luc, 2001, for a concise introduction to such methods

2004; De Luc and Todd, 2003; Clarke, 2005). Electronic ICPs might appear, therefore, to require further development to reach widespread use in clinical practice.

Summary: the macro-level market

The future prevalence of stroke based upon current trends in health, the persistence of clients in long-term care, the increased pressure on services resulting from this and the requirement for care provision to be streamlined and better integrated each make this market highly attractive to technology entrepreneurs at the macro level. It is not, however, clear at this stage how the service will be streamlined and integrated, with problems existing associated with knowledge capture and storage and the conflict between local and global needs. The overall cost in terms of financial expenditure and staffing resources associated with such systems has similarly to be evaluated to a satisfactory degree.

The micro-level market

The findings of the user study

The user study presented in Part One revealed a wealth of data pertaining to the needs of the therapist and user, which help form a picture of the market at the micro level and are presented in brief as part of the user study analysis. To reiterate the major themes of the study's findings:

- The therapy process aims to restore normal and intuitive physical and cognitive function and is, in this regard, dynamic and bespoke to a client's needs
- The client group is very highly disparate in terms of factors including age, gender, severity of disability and social standing
- Therapy is very often built around functional and lifestyle goals which are highly subjective
- There is a pressing need for integration of the care process
- The is a pressing need for client involvement in the care process, not least in continuing exercises between therapy sessions
- There is a requirement for clients to interact with complex and dynamic environments that are imbued with meaning
- In introducing innovative equipment there is a need to win both client's and therapist's confidence
- In developing and implementing an innovative technology , there are problems associated with lack of funding as well as poor equipment take-up among therapists and clients due to limited skills and time for development

- Equipment provision always causes a rise in bureaucracy, which appears to increase in line with the expense or complexity of the apparatus
- Any system designed for use in therapy must be variable within a therapy programme and adaptability to a range of clinical requirements

Is home-based care financially expedient?

A cursory review of literature suggests that, as a rule of thumb, the cost of treating a stroke survivor, both as an inpatient and outpatient, is broadly in the region of £8,000 (roughly around £1.8 billion for all stroke patients in the UK each year. See Isard and Forbes, 1992; Langhorne and Dennis, 1998; McNamee et al, 1998; Coast et al, 1998; Netten and Curtis, 2003)[70] yet therapy-based rehabilitation accounts for a fraction of this (apparently as little as 1%). One report sets the total cost of post-stroke care (including social services) at around £62,000 per patient (The Stroke Association, 2006).

Young and Forster (1992) compared the costs of home-based to hospital-based physiotherapy and found financial savings were made in home-based therapy of around 50%. This finding is perhaps contrary to a further-reaching analysis made by Beech et al, 1999, who evaluated a fairly typical care package for elderly post-stroke patients (basing their figures on the data presented in Netten and Curtis, 2003[71]). Comparing in-patient with out-patient care programmes they found that, while the financial annual savings were only marginal (circa £630 per patient per annum)[72], other economic ‘savings’ were made in releasing beds and in caseload. Also, the authors of (Coast et al, 1998) found savings were made when comparing a full home-based to a full hospital-based care package (£776 per patient over three months)[73].

Roderick et al (2001), however, found that while a reduction in costs was found among elderly, home-based stroke patients, those patients were more likely to use social services, resulting in no real savings made to the public purse. One major review of literature regarding trials of ESD (Langhorne et al, 2005), also found savings offset by other costs, with the only real savings made in the care of severely disabled patients (although it remains questionable whether ESD is always beneficial to such patients). A further review of research involving home care for acquired brain injury patients maintained that savings might well be maximised if such a scheme were integrated into a vocational, return-to-work programme (Turner-Stokes, 2004).

[70] Costs adjusted to consider inflation but do not reflect any adjustment to treatment expenditure that might have been introduced since publication. Methods of cost analysis also vary through the literature.
[71] This reports the cost of caring for a stroke patient to be around £168 per bed per day
[72] The ESD group had lower inpatient costs per patient of £4862, compared to £6343 for the control group, but higher non-inpatient costs of £1938 compared to the control group’s £1089 (all per annum)
[73] Based upon a mean cost over three months of £3292 per hospital patient and £2516 for a home patient

The manner in which patients use the resources available to them might also be scrutinised in this context. Whereas over £100 million is spent on housing adaptations in the UK each year (Heywood, 2001), one study found that over 30% of the equipment supplied to patients at home is not used, apparently due, in part, to the patients' lack of involvement in the assessment process (Scherer and Gavin, 1996).

Is home-based care clinically expedient?

Regarding the clinical expediency of home-based care, much evidence suggests that the patient is not at any disadvantage due to early supported discharge. Baskett et al, 1999, for example, presented the evaluation of a full home-based care package for stroke patients in a major Australian city and found that regular home visits by clinical staff resulted in equivalent recovery outcomes in the patients at home as to those in hospital. Such apparent benefits might not however acknowledge other impacts subsequent to early patient discharge: Anderson et al, 2000, for example, presents evidence also sourced among stroke patients in Australia that, while patients themselves were apparently at no direct disadvantage, early discharge might be linked to the poorer mental health found by the researchers among caregivers; similar findings regarding burden upon the caregiver were also reported among an American population (Teng et al, 2003).

Roderick et al (2001) found that, while the patients at home were at no disadvantage in their physical rehabilitation, they were less socially engaged and their mental states were low after a six-month follow-up and suggest a mixed home/hospital scheme. Similarly, Thorsén et al (1999) found that disengaged patients recovered less well and thus recommended a mixed home/hospital scheme. Finally, a major corroborative review of the literature on randomised trials in this area of post-stroke pointed to a general benefit to recovery outcomes for home-based care but maintains that there are clinical limitations to such schemes (Outpatient Service Trialists, 2004). No such clinical limitations were reported in a further review (Langhorne et al, 2005), but here benefits to patient recovery were only recorded among subjects with moderate disability (initial Barthel index of >9).

In view of this evidence, we might maintain that, while the patient is at no direct disadvantage by continuing recovery at home, the success of ESD might be dependent on the patient's level of disability. Furthermore, the process should be integrated well into a clinically centred scheme (the impact on caregivers and public services should also be considered). Regarding economic costs, home-based care does not generally result in marked savings to financial expenditure (the savings tend to be marginal or offset by subsequent costs). However, such a scheme does appear to result in benefits to other clinical cost savings (including relief of beds and efficiency in caseload management).

Social capital and rehabilitation

Having identified the slight or marginal savings to financial expenditure, the apparent benefits to patient throughput and the possibility for engagement in a more meaningful environment that ESD might offer, a further 'cost' in the health economics of long-term care could also be evaluated as 'social capital'. This is a dynamic value that can be assigned to the level at which matters of trust and reciprocity are engendered by and within any social system. It was noted in Chapter One that stroke is evermore prevalent among the less affluent and that recovery from stroke is in part dependant on the patient's engagement in the care process. Given these tendencies and the possible extension of home-based care, the means by which engagement among less affluent stroke patients might be engendered and evaluated warrants further examination.[74]

The present research poses the question as to whether VEs as an ICT might play a role in adding social capital value to the problematic experience of the stroke patient at home. The 'sense of community' that underlies social capital might well depend upon the face-to-face flow of information among a densely networked population (Putnam, 1995), yet populations in the developed world, where social capital is low, seem to use communication technologies to an ever greater intensity (Chen et al, 2002).

A question remains, therefore, as to whether ICT is an expedient or a hindrance to creating social capital. The impact of communication technology on social interaction appears not to be well understood (Blanchard, 2004): although evidence does suggest that on-line interaction strengthens community bonds, which often cross over to the physical community (see Quan-Haase and Wellman [2004] for an overview of this issue), the level to which face-to-face social capital is gained as a result of extending the 'community' through such technology (email, internet, and so on) appears to be unclear (Wellman, 2001).

Could virtual environments help facilitate ESD programmes?

The review of literature presented in Chapter Three outlined the testing of several systems which aimed to connect a remote patient to a treatment centre (whether a hypothetical centre or otherwise). Each of these reports demonstrate the technological feasibility of delivering information between service provider and service user, for example (Lewis-Brooks, 2004;

[74] The interested reader is directed to Putnam and Goss, 2002; Hall, 1999 and 2002, for a discussion of this theme

Reinkensmeyer et al, 2002; Holden et al, 2005). Many other papers in this review outlined testing of such systems for their effectiveness in supplying or supplementing treatment programmes, with varying degrees of success, for example, (Merians et al, 2002; RKF+05; Crosbie et al, 2004a; Christiansen et al, 1998). The conclusion to that review might well help answer the question of the technology's suitability in facilitating ESD: the technology is generally usable and, on the surface, popular with patients.

That VEs (regarded as an ICT) are usable locally does not, however, translate to the success of their use globally, as the evidence regarding 'e-pathways', cited above, might suggest. It is also apparent that the additional burdens on staff and management resources engendered by the implementation of such systems might, in terms of cost resources, offset any intended amelioration of the care process. Furthermore, the use of such systems for home-based care is not well understood, with the impact in social capital remaining uncertain. The sharing of electronic information between home and hospital appears to remain untested, (although the circumstantial evidence cited in Nies and Berman [2004] seems to point to successful such projects, the results of these pilots do not, to date, appear to have been published).

In spite of the current uncertainty some enthusiasm and optimism for the use of ICT in health provision might be observed. The enquiry of the present chapter remains as to whether the entrepreneurial development of virtual reality technology has any purchase in the innovative milieu of health care in the UK. In this context, we might infer from the evidence presented above a 'pull' factor from the sector in the need to alleviate ever-increasing pressure on resources, while integrating the patient into the care process. A 'push' factor might also be observed in central government's provision for innovative applications for IT, yet with apparently sparse guidance as to how this ought to be allocated by local authorities.

We might maintain, therefore, that there is a pressing and ever-increasing problem in care provision to which a solution has been sought through innovative management practices and the provision of abundant funding for ICT. Moreover, given the apparent lack of governance in solving the problem, and the costs associated with any solution presented thus far, there appears to be no good reason as to why virtual reality technology should not be evaluated further as a viable tool for the facilitation of ICPs and ESD.

Towards telerehabilitation as a social enterprise

Economies come in three forms: those which seek to maximise profit to the benefit of corporate shareholders, those which are planned at the state level to effect redistribution of wealth and those which are formed through the mutual actions of people to address a social need. The last of these, the so-called ‘third system’ (Pearce, 2003) is the concern of the present study and comprises voluntary organisations and charities, including those charities that trade, fair trade companies and social businesses, as well as such informal or networked organisations as community enterprises, faith-based communities or even families.

Hence the social economy comprises those organisations of the ‘third system’ whose surplus value (whether financial, knowledge-based or other) is reinvested for the benefit of a social objective, such as alleviating unemployment, providing food or shelter, caring for the vulnerable or addressing ‘green’ issues. The British government appears to be taking particular interest in this area of the economy as it helps to overcome social problems, both directly and indirectly, and to facilitate positive change at the community level in those areas of responsibility often ascribed to the state, yet increasingly implemented through mutual community networks (Department of Trade and Industry, 2002); thus 95% of social enterprises are focused on ‘helping people’ (Department of Trade and Industry, 2005). Such social objectives include providing child and domiciliary care, public housing, public transport, leisure provision, recycling and refuse collection, among others[75].

What does this mean for healthcare?

Health care is not well represented among social enterprises in the UK, with rehabilitation not apparently undertaken by any except in vocational training for people with learning disabilities (Department of Trade and Industry, 2005b), which might be due to the arguably monopolistic role of the state in these areas (Kendal and Knapp, 2000). That is not to say, however, that health has little social capital value. It has already been noted as a key finding from the user study that there is a pressing need for care service clients to be engaged as fully as possible in the care process, whether in undertaking therapeutic exercises, self-initiating therapeutic exercises, identifying clinical goals, choosing equipment or in seeking to understand the nature of their condition. The care providers also have a need for their service to be integrated to a greater degree, and it was noted that the limitations of staff contact time with clients and the turnover of staff each have a negative impact on the engagement of client in this respect.

[75]To put the present discussion in context: there are around 15,000 social enterprises in the UK, comprising 1.2% of all enterprises nationally, with a particularly strong representation in areas of multiple urban depravation. The annual turnovers of social enterprises appear have a median average of £250,000. The sector as a whole has a turnover of approximately £18 billion a year and employs 775,000 people (470,000 paid; 300,000 unpaid). Around 82% of all turnover is sourced through sales and around 14% through grants and donations (Department of Trade and Industry, 2005a). Of the social enterprises which trade, 33% are involved in social care, 21% in community, social or personal services, 20% in housing, 15% in education and 3% in wholesale (Department of Trade and Industry, 2005b).

Michael Marmot also makes a compelling case that paucity of social engagement has a highly negative impact on overall health and life expectancy among a population, the impact becoming evermore deleterious with relative accord to the lowness of an individual's social standing (Marmot, 2004). His argument is that, during our early evolution as a species, social cooperation was necessitated as a means of securing food and nurturing young, thus of sustaining life. Our genetic disposal as a species to socially orientated behaviours thus means that our physiologies are sensitive to major disturbances in social interaction, which results in heightened levels of stress.

Marmot continues that, if an individual is low down in any sort of social hierarchy, then that person is less likely to engage in social networks, is subsequently more susceptible to the stress that can result from an isolated existence and, furthermore, gains diminished support in dealing with stressful situations. This in turn negatively affects that person's resistance to infection and disease itself then becomes a compounding source of stress. And so the downward spiral continues. The biological effects of social interaction have thus been demonstrated in studies of female macaques, where those females of low social standing are more likely to develop artherosclerosis (Shively, 2000); among a human populations, a link has similarly been determined between weak social interaction and a greater tendency to develop the common cold (Cohen et al, 1997).

Marmot's own research was based upon observing the health patterns across the hierarchy of all British civil servants working at Whitehall and demonstrated a gradient tendency for heart disease to increase as standing in the workplace diminished. 'Standing', in this sense, relates to the level of autonomy enjoyed by an individual in his or her professional role and also to both the formal levels of professional interaction with colleagues and to the tendency to belong to other, less formal organisations (Marmot et al, 1997). The 'cause' of these poor rates of health among civil servants lower down the Whitehall hierarchy, as well as the converse good health of their superiors, is perhaps attributable to a range of factors, but Marmot argues persuasively that social engagement engenders social support and that this plays a crucial role in overcoming the deleterious effects of stress in the workplace and other areas of life.

The tendency for the less affluent to enjoy less social support has been in a major survey of British citizens from across the social spectrum. Here, 26% of least affluent men reported inadequate social support, while only 10% of the most affluent reported the same problem. Women generally enjoy greater social support than men, but rates of affluence have the same relative effect on the paucity of social interaction with 15% among the least affluent women experiencing poor social support and only 5% among the most affluent experiencing this problem (Department of Health, 2000a).

As with other areas of the social economy, it might be maintained that social capital reveals its value in the areas where it has diminished to the greater degree and has led to deteriorated health (Berkman and Glass, 2000; Pearce, 2003a). We have already observed that stroke has higher incidence among the less affluent and especially among less affluent men. Social interaction, too, is more likely to be inadequate among men of low social standing and we have noted how that impacts on overall health. In this sense, the micro-level 'market' for a social enterprise that encourages greater engagement is large and apparently growing. Yet, given the very lack of social enterprise growth in this area, this presently difficult to quantify.

Summary: the micro-level market

If by 'micro-market' we can describe care provision in day-to-day practice, then the user study revealed a series of requirements which a VR innovation would address. There is furthermore a need to alleviate costs in care provision, both financial and in other economic costs such as caseload. Here, managers have sought alternatives to hospital-based care by assessing the effectiveness to recovery of rehabilitation in a community setting (usually home or workplace). In this regard, a VR system could help facilitate the care process while creating no extra burden in financial costs.

The user study also revealed that a pressing requirement among therapists is the engagement of the patient. Such engagement is of broader concern in the promotion of social capital, which has a directly positive impact on overall health among a population. We can thus suppose that VR as an ICT can similarly play a role in providing the means for this engagement to occur and therefore form the basis of a sustainable social enterprise; there appear to be such enterprises now emerging in health provision which may provide for how more user-focused measures might be implemented. One caveat is, however, that the way in which the use of ICT impacts on social capital is not well understood and might even have a negative impact in this regard.

Assessing the 'competition'

According to Michael Porter's Five Forces model for assessing a new business idea, or indeed an innovation, the entrepreneur would do well to survey the levels to which other companies or other organisations are set to exploit the emerging opportunities which are of interest to us (Porter, 1980). The risks associated with this competition might thus pertain to the threat of new entrants to the market who are able to offer a better product than our own or a product that might serve as an effective substitute for our own.

The review of literature presented in Chapter Three offered an overview of the other work being carried out in the field and it was noted in the summary that very little of the research satisfies the main areas of clinical concern with which such a system is expected to interface. The stronger studies presented in the literature review (such as Katz et al, 2004; Crosbie et al, 2004a; Merians et al, 2006; Adamovich et al, 2003, 2005), each have developed a system that is ostensibly ready for clinical trialling, although none of the research presented from the respective teams thus far suggests that any are ready to advance a marketable product.

Perhaps due to this lack of development, virtual reality as a product for health care appears to remain an entirely speculative enterprise. Yet the need for greater integration in the care process has been successfully demonstrated and also that ICT might provide a means of achieving this. In order to establish a model for a company that could deliver a virtual reality based system, a model for a successful company delivering ICT in healthcare might be gainfully sought.

An independent provider within the health service

We noted above that one such company, Patientline, has already taken the lead in supplying patients with bedside communication and entertainment systems and that this might serve as provisional a model for how such a company might deliver virtual reality systems. Yet Patientline has struggled to perform effectively as a company. Revenues per terminal have fluctuated by more than 5% (BBC, 2005) and the company has been investigated by the telecommunications regulator, Ofcom, over their billing rates. Although cleared of charges of exorbitant charging, the high rates were found to be the result the apparent obliqueness of health care provision in the UK or, as the Ofcom report put it, of ‘a complex web of government policy and agreements made between the providers, the NHS and individual NHS trusts’ (Ofcom, 2006).

In spite of steady rise in turnover, with the company’s FAME report revealing how revenues have increased steadily from around £1.5 million in 2000 to almost £50 million in 2005, Patientline’s overall performance has come to reflect the complexity and uncertainty of the public health sector (although not always unfavourably). Hence, the company’s losses have decreased rather unevenly since 2000 while the profit margin has yet to reflect a point of breakeven; accordingly, their share price has fluctuated by around 40% (due in part to the Ofcom investigation [Wray, 2006]) but to date appears to be rising. In spite of this unevenness in growth, the company now appears to have stabilised and might well prove a source of competition, if treated in this regard, or indeed a stable, if powerful, partner for launching such an innovation.

A new social enterprise for health provision

We noted above that, as part of the Government's attempt to modernise the public services, a more market-orientated model for health service provision is being developed. In spite of public resistance and of limitations to this process, it has engendered a new model for regarding the service user, which encourages greater participation in the planning, design, delivery and undertaking of the care process, and is often referred to as being a 'citizenship' model (Mills, 2005). It has already been noted in the user study of Part One of this chapter, above, how this engagement can benefit the patient and thus how therapists will often encourage this involvement. The model is now also intended to extend to the community level by supplying a means for patients and carers to have a formal 'voice' in the care process and by avoiding barriers that hinder mutual (that is, member-led) 'third system' organisations from becoming involved in the care provision in this regard, as a recent White Paper signals (Department of Health, 2006). This paper thus reveals the intention for such mutual societies is to offer more responsive and dynamically resourced care, in which the service user plays an active part.

The first of such mutually owned, 'third system' health providers is currently being developed (Lewis, 2006), and is due to launch in 2007. East London Integrated Care (Elic) is intended to support local GPs undertake their newly assigned responsibilities as 'practice-based commissioners' – meaning that they are able to execute decisions about the distribution of resources. Elic will also provide care directly, starting with ear, nose and throat treatments, which can be undertaken by a GP with specialist skills rather than a hospital consultant. Overseen by a members' council with 10 professional representatives and one representative of patients' interests, and general practice staff in charge of care services, Elic is intended to make use of the skills already available in the community. Any financial surpluses are intended to be reinvested for the benefit of local patients.

Concluding remarks: into the chasm?

In presenting a framework strategy for innovation, I examined how virtual environments as an innovative technology must at once interface with the requirements of its target user group (the *market*) and also with the economic processes necessitated by its supplier (the *industry*). The research and funding ecology in which such innovation can be encouraged were also outlined and it was observed that the field of virtual environments for healthcare fits this broad and open model. In evaluating the innovation against more formal, economically derived parameters, however, the picture becomes more complex and the outcomes less certain. Similarly, the relationship between the independent sector and the public health provider in the UK is far from clear, in spite of the government's efforts to open the way for innovators.

The key findings of this strategy framework can now be summarised. Regarding the industry at the macro-level, there is a strong 'pull' from the abundance of government funding for ICT in healthcare as well as the existing and growing use of ICT for service users, for which a business model has been established. There also appears to be a growing tendency to market-orientated service provision among health providers, not least in the establishment of PCTs, although these are subject to intense public scepticism, as reflected in a major public sector union campaign. The government has also targeted long-term clients in providing integrated care (whose conditions often arise from brain injury), and there is a pressing requirement for service integration and patient engagement in this regard. Furthermore, the government has offered an open invitation for innovators to posit solutions for these areas of concern and has also provided the means of channelling intellectual property through the Regional Hubs and the NHS Institute.

Regarding the industry at the micro-level, it has been observed that the government is commencing in the provision of regional hubs through which innovators channel inventions into public health provision and that NHS Institute is intended to leverage this IP by working with innovators and providing an 'effective entry point' for industry. Yet it was also observed that the overall success of these ventures has yet to be measured against their lasting effect on the relationship between the independent sector and public health provision.

In attempting to devise a model for how VR could be used in clinical practice, two models were posited. The first a simple, static model based upon constant demand and the second a more dynamic model based upon uneven demand. The latter of these two revealed a more compelling case for a sellable product that could provide the therapeutic adjunct while reducing the cost of hospital-based care (assuming that here the equipment would be used in a community setting). This latter model would, however, create demand upon the supplier in that more units would need to be sold to maintain the competitive pricing.

Regarding market at the macro-level, there will continue to be pressing need for innovative interventions. This observation is based upon the projected prevalence of stroke based upon current trends in health, the persistence of clients in long-term care, the increased pressure on services resulting from this and the requirement for care provision to be streamlined and better integrated. It is not, however, clear at this stage how the service will be streamlined and integrated, with problems existing associated with knowledge capture and storage and the conflict between local and global needs. The overall cost in terms of financial expenditure and staffing resources associated with such systems has similarly to be evaluated to a satisfactory degree.

Finally, in evaluating the market at the micro-level a series of requirements was revealed which a VR innovation could address, which are based upon the findings of the user study, above. There is furthermore a need to alleviate costs in care provision, both financial and in other economic costs such as caseload. Here, managers have sought alternatives to hospital-based care by assessing the effectiveness of rehabilitation in community settings (usually home or workplace) and have demonstrated a possible advantage in the patient engaging in environments or activities that more meaningful than those of a hospital. In this regard, a VR system could help facilitate the care process while creating no extra burden upon financial expenditure (it might even be possible to reduce costs in this regard).

The user study also revealed that a pressing factor in therapists ensuring positive therapeutic outcomes is the full engagement of the patient in every area of their rehabilitation. Such engagement is also of broader social concern in the promotion of social capital, which has a directly positive impact on overall health among a population. We can thus suppose that VR as an ICT technology can similarly play a role in providing the means for this engagement to occur and therefore form the basis of a sustainable social enterprise; there appear to be such enterprises now emerging in health provision, which may provide examples of the means by which more user-focused measures might be implemented. One caveat is, however, that the way in which the use of ICT impacts on social capital is not well understood and might even have a negative impact in this regard.

Yet, in spite of these promising and intriguing results, the field of virtual reality as a technology for health care appears to consist of entirely speculative or academic pilot studies, with very few business models apparently available. The first such model is based upon a company that provides communication and entertainment to the patient at his or her bedside. Yet here the company, Patientline, has struggled to capitalise its revenue, partially as a result of investigation from the telecommunications regulator. In the field of social enterprise, rehabilitation is very much under-represented, yet the first mutually owned, ‘third system’ health provider is currently being developed and was due to be extended across London’s East End in 2007. The success of this would well be worth investigating, as would the possible opportunities the enterprise might afford the innovator.

Barriers to technology diffusion

In his widely adopted analysis of the processes of technology innovation, Geoff Moore revealed a typical diffusion curve comprising a small number 'visionary' adopters at the early stages of development, growing to a greater number of early adopters as the technology matures (see Moore, 2002). Early adopters comprise those pragmatists who will adopt a technology that they can see provides a clear benefit to their practice. Yet this process of maturation appears to depend on what Rogers has called the 'change agent' (Rogers, 1983), those original 'visionaries' who might well effect further diffusion of the technology, if only they were not so focused on the *newness* of emerging products.

A serious caveat to this development is in the persistent shortfall in technology outcomes that leads to the innovation process falling into a 'chasm' of under-use, under-development and under-resourcing. The goal for a developing technology such as VR in rehabilitation is, in part, to creatively engage the change agents in a longer term programme (getting over the chasm) whereby they might influence the 'early majority' of future users. Moore's and Rogers' patterns seems to fit the current picture of VR in rehabilitation in the UK. Where those studies undertaken at the Universities of Haifa and Ulster and at Rutgers University and Hong Kong Polytechnic University might comprise the visionary developers of Moore's curve, so there appears to be a gap in reaching the early majority: those clinicians who recognise the intrinsic value of the technology to their practice.

As the literature review revealed a series of practicable systems, so the barriers to diffusion do not appear to be wholly technical. While issues with innovation management within the NHS might pose a barrier to adoption, the culture here is likely to change, as outlined above. Instead I offer the suggestion that it is the lack of a robust theoretical framework that is set to prevent wider adoption of the technology. Hence, the *intrinsic* value of VR has yet to be fully substantiated against the requirements of its end-users (as outlined in Chapter One of the present study). However, the growing interest in motor imagery (relating to complex conceptualisation of environmental stimuli in the formation of motor engrams) might well play a significant role in encouraging the adoption of this technology. For example, Castiello et al (2004) build upon the lead author's work elsewhere into the role of motor imagery in reaching and grasping function (Castiello, 2005) by presenting research into the intrinsic value of using VR in therapy interventions for the treatment of spatial neglect. A similar example is the work undertaken at the University of Ulster, where mental imagery is being examined alongside VR systems (see Crosbie et al, 2004). I expect to see more literature pertaining to motor imagery emerge in the coming years, and believe that this will help drive the wider adoption of VR in the rehabilitation field.

Chapter Five – Interaction models

General Introduction

Stefik and Stefik (2004c) have argued that innovation occurs as a confluence of the existing needs of clients and what technologists can feasibly deliver. The present study has thus revealed what is *possible*, by way of the review of literature presented in Chapter Three and what is *needed* by way of the user study presented in Chapter Four.

Throughout the preceding chapters, a picture has been built up of what a virtual reality system must deliver if it is to be an effective adjunct to clinical rehabilitation. Thus the review of literature offered a systematic appraisal of the research field through which those research projects that represent the state of the art were revealed. This also revealed problems extant throughout this field of research, not least in the general failing to supply adaptability and variability in the system design. The analysis of the user study against weighted objectives similarly revealed therapists' key requirements with respect to a system design.

Having surveyed the field in some details, this chapter might be regarded as a return to the design challenge. It thus serves partially as a continuation of Chapter Two, Problem Analysis, with the additional benefit of the practical knowledge gained from the review and user study.

System patterns are thus presented which offer general yet practicable 'templates' for a system. Considering the problems of delivering such a system, the intention here is not to propose concrete designs but rather to provide illustrative patterns which can be adapted to any platform (a brief sample of possible programming code is also provided)[76]. The templates are thus intended to be generically useful to therapists and engineers, yet remain adaptable to any given clinical context as well as the changing requirements of any given patient.

Key findings of the literature review and user study

By way of an approach to the analysis, the major findings of both the literature review and user study can be amalgamated and summarised.

[76] The C++ code is supplied as a readily extendable object-oriented (OO) language.

Figure 5.1 Key findings of the literature review and user study

User focus	Clinical effectiveness	Marketability
Outcome measurements of a technology for clinical practice must relate to clinical measurement*s*	Treatment is embedded in an ADL through several dimensions, including use of domestic equipment (the sink for thumb alignment)	The technology must interface with clinical practice
The system can only be deemed usable if its acceptability to the therapist and patient has been evaluated	Manoeuvring the patient is serial and highly interactive	Therapists are generally knowledgeable about innovative technology and will usually be willing to find out about innovative equipment to further the effectiveness of their intervention
No research into virtual environments in rehabilitation has yet to develop a system which could be adapted to the specific needs of a particular user	The therapist interacts intimately with the patient's movements, considering also problems with pain and lack of sensory feedback	Lack of funding is of particular concern in equipment acquisition
There appear to be differences of opinion among therapists as to the commonalities and discontinuities of their respective roles.	The patient's body must be correctly aligned, including at rest	Equipment that benefits client independence saves on the costs associated with hospital care
Many therapists begin their days with handover, among other communications, and thereafter attend to clients, whether in the treatment centre or in a community setting.	Patient's do not always understand instructions for further exercises	Economic and social disparities within regions and populations might effect the provision and uptake of equipment
Contact with clients is commonly a dynamic process, with programmes of therapy structured around cognitive or motor function goals that are altered as the client progresses.	Therapy is often conducted according to goals actively negotiated between client and therapist	There appears to be a paradigmatic shift in government policy towards innovation, not least for informational technologies
The client group is highly disparate in terms of age, gender, level of disability, pre-morbid tendencies, wealth and social standing	These embed the functional tasks and direct manipulations by which normal and intuitive movement is restored	There is a broad requirement for integration of services for long-term clients
Clinical disparities in the sample population have an effect in outcome measurements which ought to be included in the analysis	Some goals pertain to lifestyle aims (return to independent living, a hobby or work, and so on)	There is a general push toward patient choice is care provision
Goal-setting is similarly affected by these factors, considering especially the highly relative means by which clients are motivated	Other goals pertain to functional objectives (balance, muscle strength, wrist extension, and the like)	The client is often engaged in choosing equipment from an authorised stock catalogue
Management of patients through the care journey, including various clinical contexts, is a dynamic process	Goal-orientated task performance and fuller body integration might engage the nervous system to a maximal capacity, thereby driving the recovery process at a deeper level	The therapist is occasionally encouraged to try out innovations as a result of advice from the client or the patient's carers
Service integration often relies on informal networks of communication within the service and between various agencies	Therapy involves a bespoke assessment and incorporation of the individual client's requirements, desires and preferences, often including quite intimate concerns	Innovations might have come to attention through the media or through peer recommendations Negative media coverage might dissuade clients from using certain innovations
Contact between client and therapist might break down partly as a result of this transience	The client is often actively engaged or impelled to participate in this process	The innovator will need to gain the therapist's confidence; the formal networks of professional bodies and informal networks of professional peers seem to provide the more likely means to achieve this
The patient's preferences are acknowledged throughout the treatment process	The client's continuation and self-initiation of exercises between formal therapy sessions is similarly regarded as being valuable by many therapists	All equipment provision is associated with a certain level of bureaucracy, which increases according to the complexity and costliness of the apparatus
A patient must be filled with confidence, even when challenged by the treatment process	The engagement of patients in their own therapy can be limited by time and by the patient's physical and emotional limitations, as well as his or her proclivity to goal-orientated behaviour	The involvement of agencies beyond the care service (such as social services or charitable funding bodies) increases the demand on resources as extra communications, assessments and cost analyses must be made
Patients respond differently to the treatment and have very subjective motivations	The client's environment is of therapeutic concern with regard to levels of meaningfulness and complexity, as well as the quantitative changes resulting from the client's condition (the need for the home to be reassessed and furniture to be adjusted, and so on)	Attitudes to costs differ between various agencies
A patient's condition and environment might affect their mood and motivation	The hospital environment does not always allow cognitive or motor	Gaps in skills, knowledge and professional interest has been observed

User focus	Clinical effectiveness	Marketability
	impairments to become apparent and is also unlikely to reflect the client's long-term goals, for example return to work	within the engineering community, with engineers often having a poor understanding of therapists' needs, clients' limitations and the market value of equipment provision
	The hospital environment might also promote negative responses from the client, such as passivity to the care process and withdrawal from public life.	A range of unseen factors impact on the recovery process which ought to be considered and precluded in the design of a system
	The therapist often endeavours to take the client to a community setting such as a street, shop or library	No research into the use of VEs for rehabilitation has precluded other factors that might effect clinical outcome from the research
	A range of equipment is normally available to the therapist and client, which is often utilised to leverage existing motor or cognitive function in support of the recovery process	No research projects in VR for rehabilitation have developed systems that are directly marketable to clinicians
	Equipment might includes prostheses such as adaptors for cutlery, walking sticks, bath boards, toilet frames and lifts and orthoses such as splints, weighted levers and walking harnesses for treadmill training	
	Clients with severe disabilities might also use powered wheelchairs or communication aids such as an adapted PC interface or blow tube	
	The therapist is often required to ensure that the equipment is appropriate the client's needs and abilities and that the client is the using apparatus correctly, especially where errorless learning is being undertaken	
	The consequences of patients using 'risky' virtual environments are not well understood	

Adaptability	Meaningfulness	Variability
Equipment designed to ameliorate the recovery process should be readily adaptable to the specific clinical context in which the therapy is being undertaken	Meaningfulness pertains to a range of client needs, whether individual, such as the lifestyle aims already described, or more universal objectives such as maintaining self-esteem or achieving self-realisation.	The treatment process is both contingent and dynamic
Equipment should ideally be seamlessly transposable at the point of handover between clinical contexts	The hospital environment might limit the meaningfulness of activities, not least where the client attaches particular meaning to the activities of work or domestic life.	Equipment must respond to this to the dynamism of the therapy process
The disparities of the client groups necessitate a highly adaptable and readily operable system that minimises preclusion of users due to age, level of ability or other factors	In enabling the client to make and act upon choices about his or her environment, a mundane activity can thus become imbued with meaning	Equipment in rehabilitation is very often simple and robust
Clients are individuated by the therapeutic process and an innovative technology should also be responsive to the highly subjective means by which the client is motivated	A task might be purposeful in terms of clinical outcomes but entirely meaningless to the client.	Simplicity in system design tends to result in clearer methods and outcomes
Most systems developed for research in VR for rehabilitation have been basically adaptable yet this transfer of basic operability has not been shown to translate other areas of clinical concern	A task that is meaningful to the client might have a limited or even negative impact on clinical outcomes	Interfaces for technologies used in, for example, gait analysis or gym training should allow for rapid system alterations without the need for specialist skills
	There is a tendency among VR researches to fall short in developing systems that are clinically effective and meaningful to the user	Systems that do not fulfil this requirement are often abandoned, regardless of their potential clinical effectiveness

Adaptability	Meaningfulness	Variability
		No research projects in VR for rehabilitation have developed systems that are directly variable to the changing requirements of the therapeutic process

Part One: System analysis with object-oriented modelling

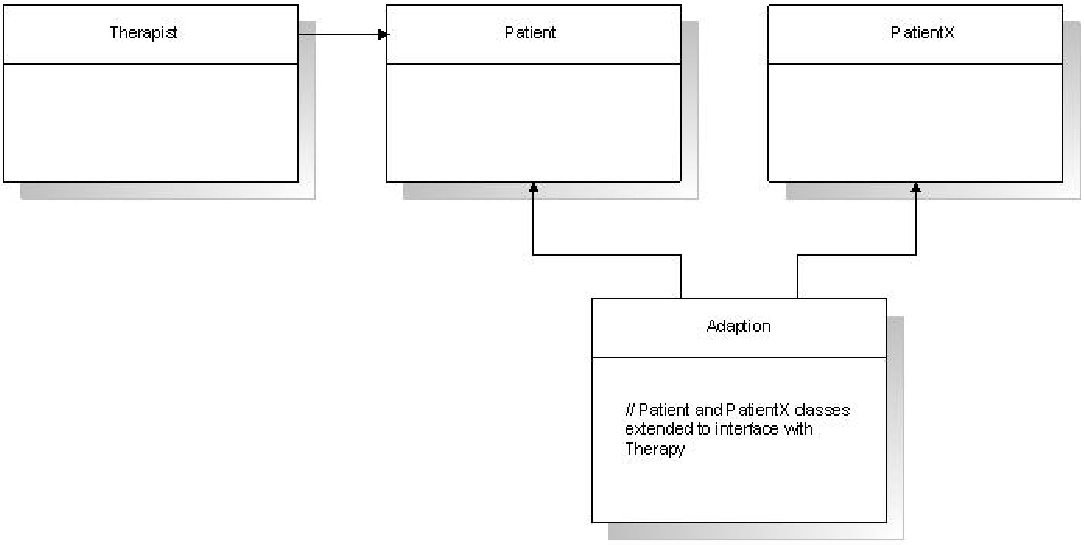
Introduction

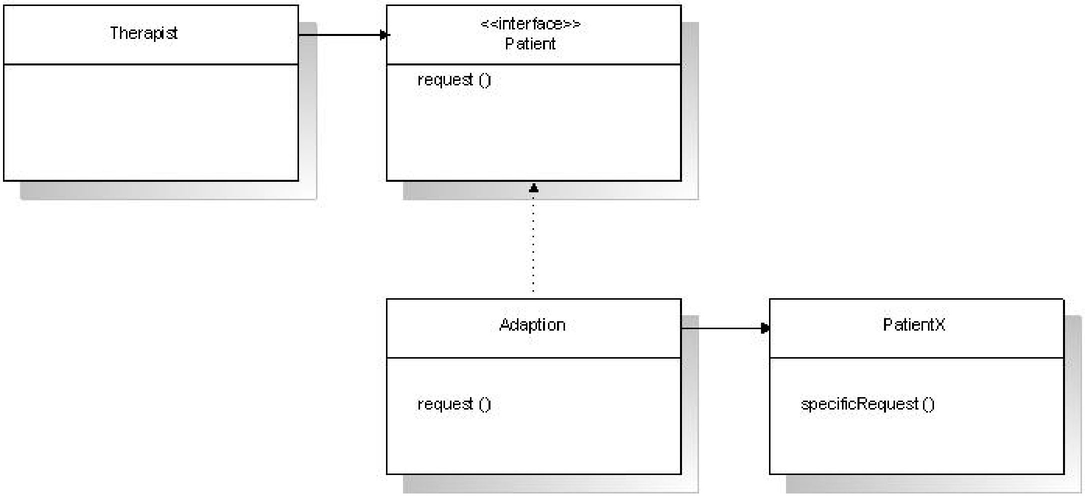
The client statement (presented in Chapter One), requested that a system be delivered that could be non-tangible (that is, remain a design). The lists of design parameters, offered in the section above, demonstrate the considerable complexity of designing a system for use in stroke rehabilitation. Yet patterns might be designed that allow for any of these parameters to be accommodated without the need for implementing a near-infinitely extendable system. The first of such patterns is adapted from object-oriented modelling (the second from game design), in which the requirements are not yet known but certain conditions are probable[77].

The basic principal of design patterns is that the elements of a system can be cast as extendable variables. Hence a generic 'Patient' class will naturally possess all the attributes (variables) of all patients, while the class 'PatientX' will extend the Patient class, yet be assigned the variables of the specific patient being treated. *Figure 5.2* illustrates this basic principle. In addition to the system requirement for an extendable, generic Patient class, it also requires the allowance for particular clinical modes and perspectives as commonly used by therapists (for example the Bobath and Carr and Shepherd approaches; see Chapter One for a brief outline of these), as *Figure 5.3* illustrates.

[77] The patterns here have been adapted from Freeman, 2004, the authors of which adapted their designs from Gamma et al, 1995, which have become industry standards since their publication.

Figure 5.2. The Patient class is extended to specific patients as an adapter pattern





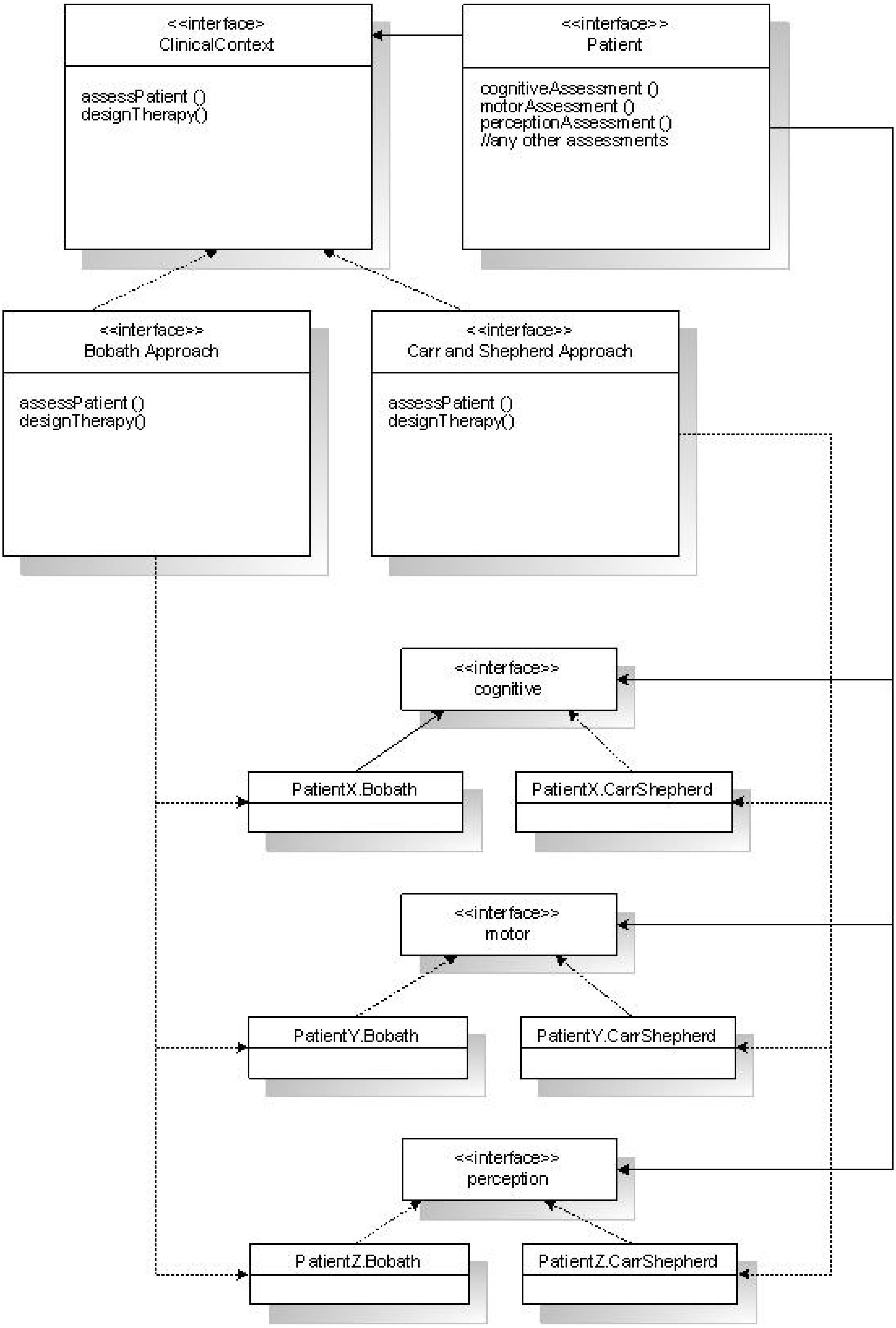


Figure 5.3. Abstract factory model of several patients being assessed and treated through two major clinical approaches

Although the purpose of this chapter is to present models of systems, rather than the details of operational efficiencies, a sample of code is given here to illustrate how a pattern such as that shown in *Figure 5.4* might be implemented:

Figure 5.4 Sample code for a possible system implementation

```
// sample factory pattern code in c++
Class Therapy {
        Public:
        Patient* AssessPatient ( );
Virtual Patient* ClientContext ( ) const
          { return new Patient; }
Virtual CogAssess* CognitiveAssessment
          ( int n) const { return new CogAssess (n); }
// repeat for motor and perceptive assessments…

// Assess patient
Patient* Therapy :: AssessPatient ( ) {
  Patient* aPatient = ClinicalContext ( );
        cogAssess* cog1 = CognitiveReport (1);
        cogAssess* cog2 = CognitiveReport (2);
        // more cognitive reports…

        aPatient-> cogDesignTherapy(cog1);
        aPatient-> cogDesignTherapy(cog2)
        // design more cognitive therapies

        cog1-> UndertakeTherapy(Tasks ( ) );
        cog2-> UndertakeTherapy(Tasks ( ) );
        // more therapy tasks
        return aPatient;
  }
}
```

```
// Sample product interfaces – various clinical contexts
 class BobathTherapy : public Therapy {
        public:
        BobathTherapy ( );
        Virtual CogAssess* CognitiveAssessment ( ) const
        { return new BobathCogAssesment; }

        // repeat for motor and perceptual assessments…
};

Class CarrShepherd : public Therapy {
        public:
        // as Bobath methods…

};
```

The various perspectives and contexts of the therapy programme might also pose problems in implemented a system, as *Figure 5.3* illustrates. Yet here, too, design patterns provide an efficient means of allowing the system to switch in the form of a state machine, *Figure 5.6*, with control made available to the therapist through a façade pattern*, Figure 5.5*.

Figure 5.5. Switching between clinical concerns and contexts

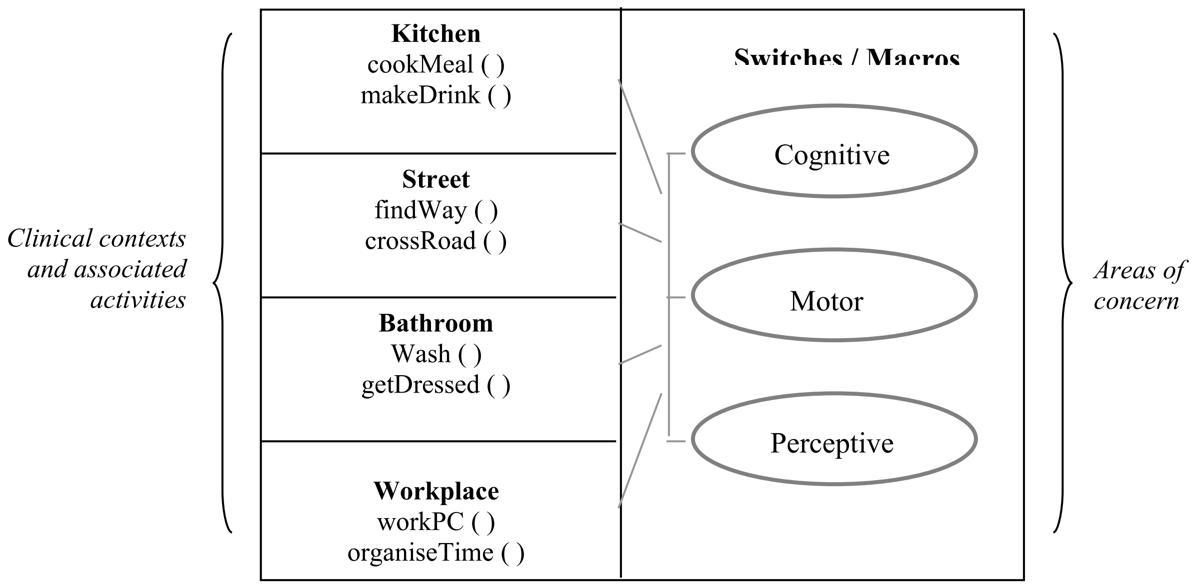
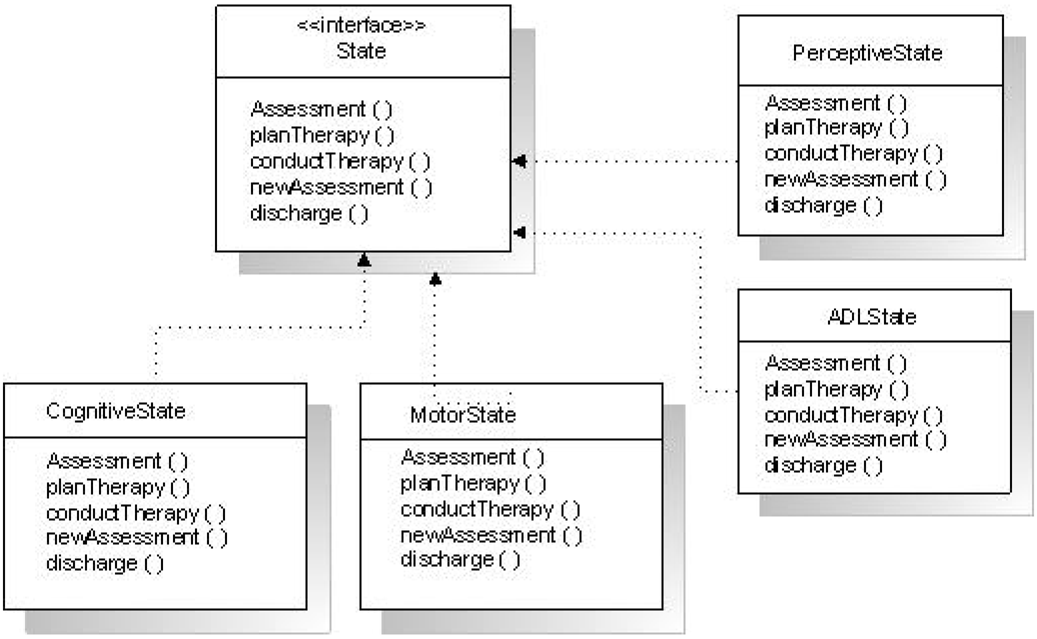


Figure 5.6. The therapy programme as a state machine



The state machine thus anticipates how the patient will move through the various modes of rehabilitation, with various clinical requirements being addressed as discrete variables within these states. Such numerous states might be difficult to manage, yet here a design pattern can be implemented that serves to offer a point of overall control, this is the amalgamated pattern, as shown in *Figure 5.7*.

The entire therapy system might thus be delivered through a dynamic combination of the patterns presented above, among other patterns, and thus operate on the model of a compound pattern, as *Figure 5.8* illustrates. Here, the system control also allows the many area of clinical concern to be addressed in a non-linear fashion.

Figure 5.7. Supplying simple control with an amalgamated pattern

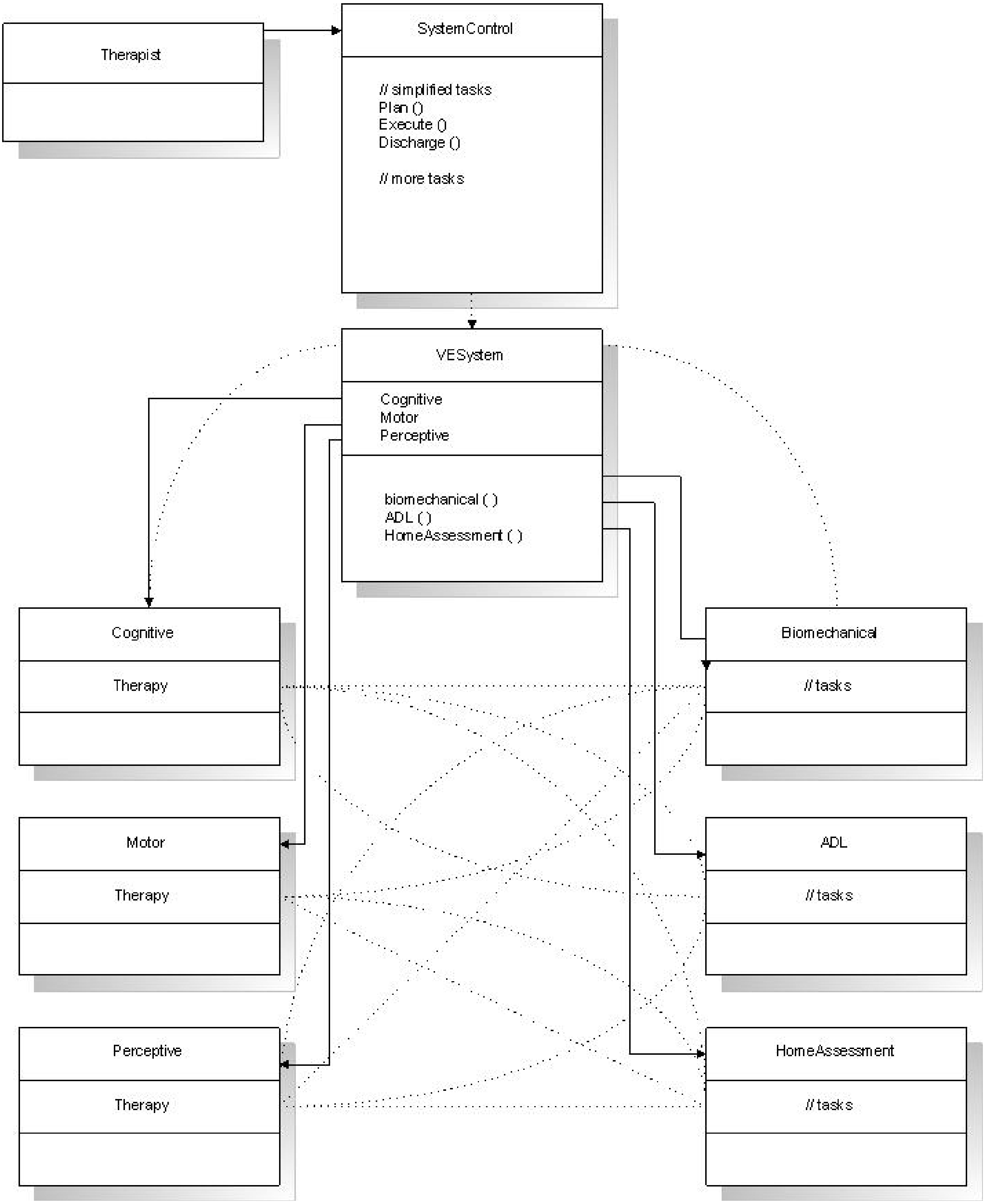
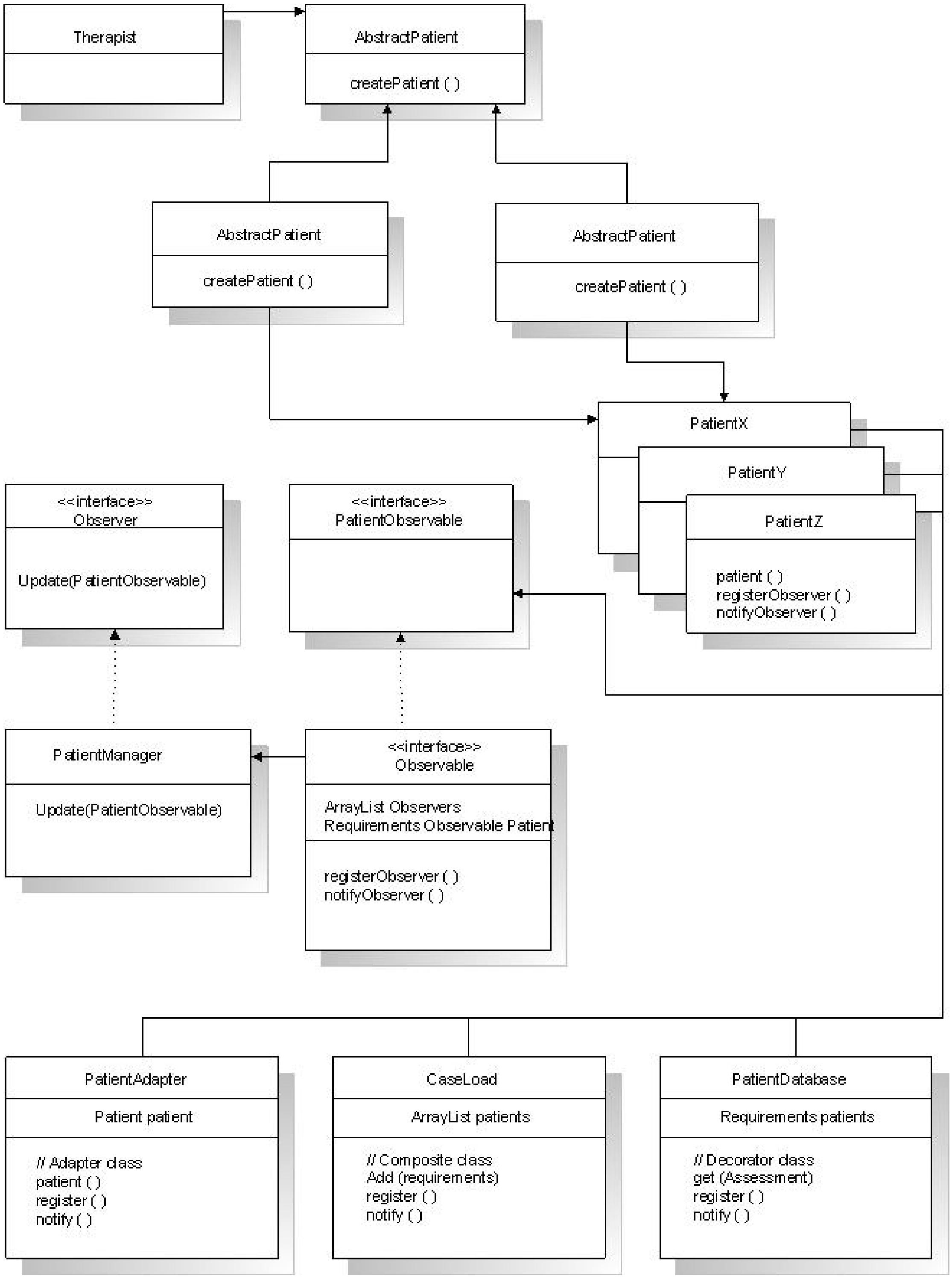


Figure 5.8. The entire system as a compound pattern



Part Two: models of optimal spatial usage

The aim of this section is to address the basic problem of infinity, introduced in Chapter One, including the problem of degrees of freedom and of the infinity of material objects, symbolic generation and broader existential themes experienced by the subject. The intention is to show that the means of overcoming this problem may be found in identifying the point of 'crisis' through which the theoretically general becomes the practicably specific.

The selection of material goods for the therapeutic process ascribes otherwise meaningless objects with values that are specific to the circumstances in which the patient undertakes the therapy. This theme is explored in greater detail in Chapter One, Part Three, where key themes are outlined pertaining to the manner by which people live with material products; how meaning can be ascribed to objects; how interacting with objects impacts on the body; how the body exists in a meaningful physical space and finally how that space is constructed from a dynamic process of subject-object relations. The intention here is to provide a basic model for how such a 'sphere' of life might be simulated in a way that is beneficial to the therapy process.

Usable Space

Given the concern outlined by Imrie, among others, of developing 'usable space' over formal architecture, a novel approach to designing the domestic spaces of people with disabilities might be proposed; this approach might also embed many of the concerns outlined throughout this chapter. In a user-centred model, it might thus be proposed that the human body behaves in 'circular' motions – implying the cyclical, biomechanical descriptors that extend from the basic pivotal axes of movement – yet the physical space of the home is normally 'square', with 'negative' space being occupied by utility in the home (for example, kitchen equipment, living room furniture or storage space). *Figure 5.9*, illustrates this idea, where the square represents the parameters of the space, pivotal movement axes form circular patterns of total movement, and the grey zone represents the negative space given over to utility.

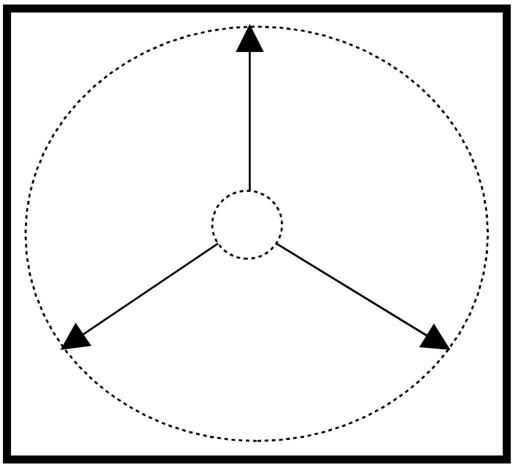
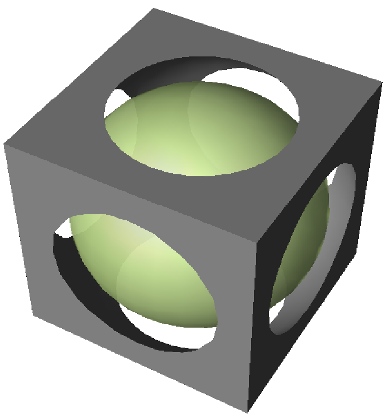


Figure 5.9. A reduced zonal model of behaviour of within a domestic space, including greyed-out space designated for utilities

As part of a standard clinical assessment, VEs might also offer a means for the therapist or technician to assess the spatial requirements of the patient, not least on their return home. Here, a conceptual model is offered in which 'meaningful' human activity, as defined in the user study, is represented by a sphere and the physical environment of the patient's home is represented by a cube. The model below, *Figure 5.10,* represents a situation in which the requirements of the patient have been planned sensitively with regard to the space allowed.

Figure 5.10. Balancing meaningful activity and utility



In a virtual reality system that has been implemented for use in stroke rehabilitation, the simulation of the patient's own domestic environment could, in this way, embed both the means for therapy to take place and for the home's existential facility to be augmented. Thus as the 'self' might be regarded as a being *emergent* through social and physical transactions within its surroundings, so the virtual 'system' through which 'imagined' transactions take place might also be regarded as being *emergent*. Hence, although the physical parameters of the home might be disabling, a virtual system implemented in this space might offer the chance to maximise the facility of the domestic sphere by providing the opportunity for further transactions that, although 'imagined', are nevertheless based upon corporeal functionality.

As the user study revealed that the therapeutic process changes dynamically over time as the patient's recovery progresses, so I am able to describe the patient's circumstances as being the crisis that exists as the proximal point of confluence along a vertical axis of *what* the patient requires (recovery) and a horizontal axis of *where* the patient needs to be (community setting), as *Figure 5.11* shows:

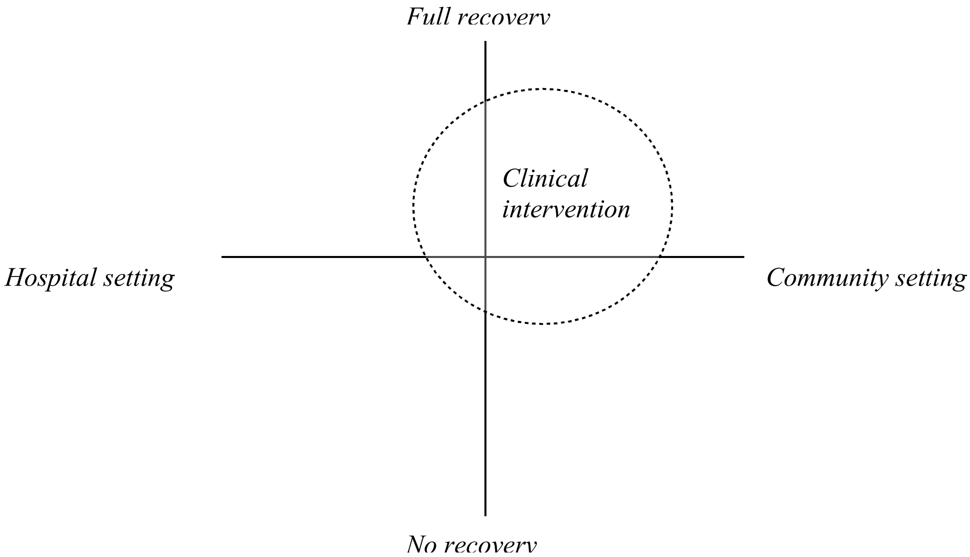


Figure 5.11. The proximal confluence of a patient's requirements

In identifying the proximal zone that encompasses clinical intervention, the intention is to populate this area with both objects and goals that might represent the means of achieving positive clinical outcomes. This theme forms the discussion of Chapter One, Part Three, which outlines and evaluates the ways in which meanings are ascribed to some objects yet not others; the impact that interacting with such objects might have upon the body; the social zoning that anthropologists have described as 'habitus' (see, for example, Bourdieu, 1977); the place of commodities in such zones and the ways in which disability might affect interaction.

Part Three: Achieving engagement through gameplay

Introduction

Developing a system that is at once generally usable by all patients yet that also meets the requirements of the individual is a challenging exercise, given especially the highly subjective ways in which patients are engaged and motivated (as evidenced in the user study of Chapter Four). Even where such a generic-specific system might be established, a further problem presents itself in the need for variability as the patient's requirements change as the rehabilitation process progresses.

In attempting to overcome these problems in design, I have elected to adopt some of the techniques and strategies developed in the field of gameplay. Play – as distinct from the more technical game theory – appears to be universal in all human behaviour, an argument articulated expertly by Huizinga (1955). It appears that most juvenile animals require play to learn and develop to adulthood (Bateson, 2000; Bekoff and Byers, 1998), and that human play serves the essential purpose of establishing and maintaining communally embedded selfhood (Sutton-Smith, 1997). Building on this general value, Salen and Zimmerman developed a series of game systems that are intended to engage the players with meaningful activities, while providing scalability in gameplay levels as well as a means of cybernetic modification, as they maintain:

> Meaningful play *in a game emerges from the relationship between player action and system outcome; it is the process by which a player takes action within the designed system of a game and the system responds to the action. The* meaning *of an action in a game resides in the relationship between action and outcome* [original emphases] *(*Salen and Zimmerman, 2004).

Such a system that is based on engagement, interaction, exchange, discernible output and modification might also refer to rehabilitation. Hence, 'meaningfulness' in therapy could be fostered 'descriptively' in that the actions of the patient have an effect within the system (leading to modifications that are integrated in to the fabric of the system as a whole), while the patient is able to discern those modifications through a feedback mechanism. In this way, the therapy process could interface well various stages and modes of game design and this possibility is explored below by developing several of the game designs offered by Salen and Zimmerman.

A game is a *system* that comprises hierarchically nested frames that each embed the following elements: *objects* (the things controlled), *attributes* (the state of play), *internal relationships* (social, psychological and emotional communications) and an *environment* (the many and broad contexts and sub-cultures surrounding a game). Some games are closed systems in that they have no relationship with the outside world (such as the board game go[78]) while others are open systems in that be their nature they include elements of the surrounding environment (such as horse racing). A strategy game such as chess appears to mix internal relations (movement constraints) with external phenomena (hierarchical political alliances).

All games are *interactive*, in that the elements within the system have reciprocal relationships with one another[79] and the players experience explicit, effective and cyclical 'agency' within the terms of the game[80]. Rules are also an essential part of any game by limiting players' actions through fixed, binding, repeatable structures for play. As well as such operational structures, rules are also constitutive, in that they form the logical system through which the game is operable.

Types of games are many and varied yet Salen and Zimmerman's review reveal some commonalities: games have rules that limit players' activities; they involve conflict or contest; they are goal- or outcome- orientated; they are artificial systems; they are uncertain; they create special social groupings; they require the players to adopt a 'lusory' attitude (which is perhaps synonymous in this regard with Csikszentmihalyi's description of the 'autotelic personality', discussed earlier [Salen and Zimmerman, 2004a]). Computer games add information, automation and the possibility for networked play to these qualities. They also increase the possibilities for behaviourally nonlinear 'emergence' in play: behaviours start to interact recursively within the bounds of the game and the gameplay becomes disconnected from its basic rules and objects. Such emergent behaviour might thus allow for greater levels of meaningfulness in the gameplay where, as John Holland surmises, the whole becomes greater than the sum of its parts (Holland, 1998).

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[78] Curiously, Go is only classical game that has, to date, defied successful simulation
[79] These summations were made initially by Littlejohn (2002)
[80] Ideas first offered by Cameron, 1995, Crawford, 2002

Games and rehabilitation

Gameplay and rehabilitation appear to have specific commonalities (Rizzo, 2006). As with the 'rehabilitation way of thinking' (as described in Chapter Four), so a game must also establish a cognitive or attitudinal frame, or mode, in which the special activities are to take place. In such a mode, activities and elements become imbued with novel meanings (as discussed in earlier with reference to semantic exchange in rehabilitation). Challenge is also a necessary component both of successful gameplay and rehabilitation in achieving activities that induce neither boredom nor anxiety and which impel the participant to strive towards a goal (a theme outlined in the discussion of 'flow', above). Feedback is similarly a key element in both areas of activity, both in reward and in regulate performance.

In Chapter One, Introduction and Background, the theme of transfer was introduced, with reference to one experiment that had sought to identify the effect of ecological validity on the transfer of training from a VR task to a real world task. The earlier section of this chapter also comprises an attempt to evaluate the intrinsic properties of VR, yet here ecological validity was not so much a sensory allowance but a set of more generalised existential phenomena pertaining to the centrality of 'dwelling', of which sensory feedback is a component, yet which also comprises motor activity, semantic and material exchange, the construction of selfhood, and so on.

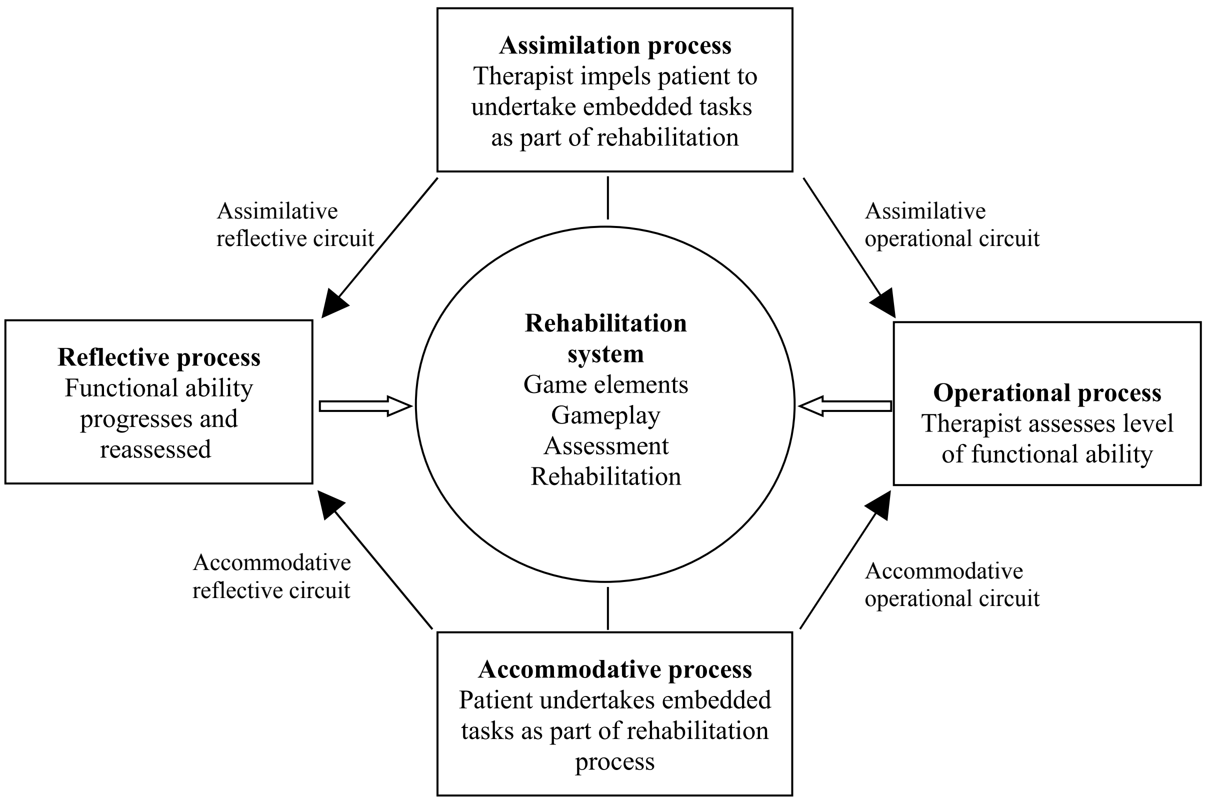
More complex descriptions of transfer as it relates to gameplay thus reflect this non-reductive model of ecological validity, thereby presenting a potentially useful model that approximates the complexities of rehabilitation. Hence, Fritz (2005) has outlined a set of hierarchical schemata for transfer that pertain to the *fact level* (knowledge of the world, such as that gleaned from reference books); the *script level* (sequential models for performance such as menus, bus timetables or particularly effecting storylines that might provide the basis for a real life decision); the *print level* (rudimentary and transferable action sequences with little contextual grounding such as pushing, throwing, catching); the *metaphorical level* (semantic transfers from one element to another, such as that identifiable in the phrase, 'He is as old as the hills'); the *sociodynamic level* (the game-specific actions that transfer to goals within the context of the game, such as conquer, domination, destruction).

In playing games, Fritz also offers useful models of forms of transfer between the gaming frame and the real world. Thus we might identify problem-solving transfer, emotional transfer, action-oriented transfer or moral transfer. More complex and potentially problematic modes of transfer have also been identified, among them are associative and reality-structuring transfer, in which real world and game become suffused. Considering these, Fritz offers a valuable model for gameplay transfer, which is apparently based on Piagetian principles (as outlined in brief in the section *Existential and functional space: the home and disability*, above). In this sense, the transfer of the various modes (whether script or metaphorical and so on) is the result of a process of assimilation and accommodation of stimuli, in which operational processes (sensory-motor and perceptual, and so on) are in a dynamic relations with reflective processes (feedback, re-evaluation, correction, and so on). His model has been adapted to the present study and provides the initial model for a possible game design.

Game models

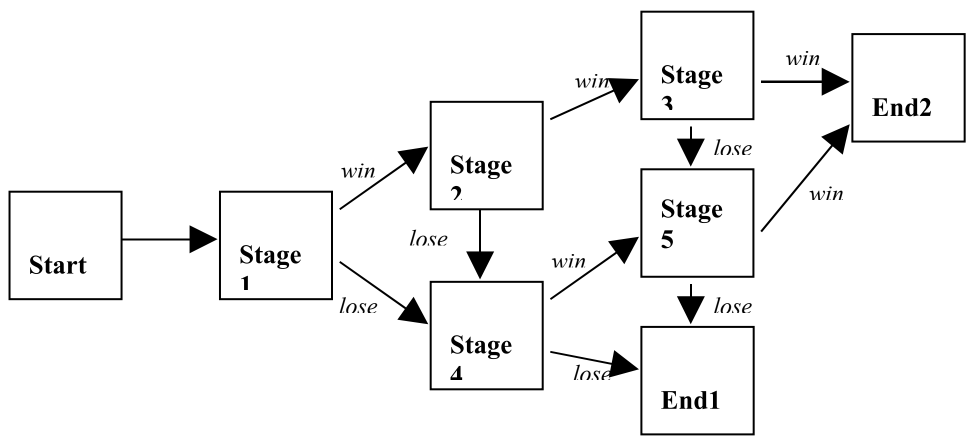
In devising a model of gameplay that might be embedded in a VR rehabilitation system, and thence lead to emergent behaviours, an initial model might be devised based upon the complex model of transfer, outlined above. *Figure 5.12* thus illustrates this model.

Figure 5.12 Rehabilitation as game-like system of assimilation and accommodation of schemata from and to the real world, adapted from Fritz (2005)



The gameplay of rehabilitation might also be modelled along classic gaming patterns, comprising decisions that lead to the succeeding stage or the end of the game, as *Figure 5.13* illustrates. At every stage of the game the circuits of reflective and operational assimilation and accommodation are in play. Thus where transfer is often regarded as a concern solely of physical or cognitive ability, this model might serve to illustrate how gaming patterns could provide a far richer transfer of training through many and various modes.

Figure 5.13. Gameplay in rehabilitation based upon a classic gameplay decision sequence



While remaining sensitive to the emotional vulnerability that many stroke victims experience, that basic pattern of this decision tree might well be a suitable model for posing challenges, goals and possible paths through the rehabilitation process. The stages of this game might thus comprise the activities of daily living (ADL), with winning and losing contingent on accomplishing tasks within the parameters of the therapy programme. Such variables might thus include, for example:

// keyFunctions
Hand-eye coordination
Upper Limb function
Spatial navigation
// more…
// keyRequirements
Nourishment
Warmth
Social life
// more….

A game of the activities of daily living might also be based on gaming goals and win/lose paths:

Stage1: getUp (go to Stage2) / stayBed (go to Stage4)
Stage2: getDressed (go to Stage3 / dontGetDressed (go to Stage4)
Stage3: visitShops (End) / dontVisitShops (go to Stage5)
Stage4: makeDrink (go to Stage5) / dontMakeDrink (End2)
Stage5: doHobby / dontDoHobby (End2)

In devising a similarly 'serious game', Crawford (2002) has invented a formula in which the values of variables are affected by an operator that pervades gameplay. Such an operator might thus be included in a rehabilitation game as a value of taskAttendence, which might decrease if the participant neglects to play the game; this might also serve as a register as to the level of patient engagement:

getDressed = taskAttendence
taskAttendence = (keyFunction + keyRequirement)*patientActivity

Concluding remarks

This section has proposed that gaming models might be introduced to the rehabilitation process to maximise interaction with the VR system and to allow the patient to behave as an active agent within the modalities of gameplay. This might also allow the patient to use the system independently (perhaps in a community setting) while providing the physical and behavioural constraints that are often necessary in therapy. Gameplay might also serve to make up an 'autotelic' deficit or, more simply, help to motivate and engage an otherwise passive.

Chapter Six – Testing User Responses to Simulated Domestic Environments: a Pilot Study

Introduction

Chapters Two, Three and Four have outlined many of the requirements of post-stroke therapy and the possibilities for a VR-based technology adjunct to these practices. The value of such a technology might result from the possibility that VR can offer the patient simulations of objects which have some meaning and thus help engage him or her in the care process. A limitation to the technology was also found in that clinical outcomes might also be affected by the patient's proclivity to goal-orientated behaviour.

The purpose of the current chapter is to present the findings of a simple pilot study which aimed to test both these arguments. It is proposed that a certain level of engagement in the task performance might be measured by equating this with levels of immersion in the environment, and that this might be achieved through simulating their own domestic environments. Level of immersion has been gauged as a measure of 'presence', which can perhaps be enumerated either through questionnaires, through brain scanning or through sympathetic physiological responses such as galvanic skin response (GSR).

Each of these methods have however been criticised by various authors for problems in ecological validity (such as in the *post hoc* nature of completing a questionnaire), in equipment use (brain scanning equipment might impair movement in the user) and in readings that are highly open to interpretation (such as GSR) (see for example Slater, 2004). While recognising the practical and empirical problems in each of these methods, three were chosen which would help gain some comparable data of the user's levels of immersion and therefore of possible task engagement: an adapted Task Specific Feedback Questionnaire (TSFQ), an Immersive Tendency Questionnaire (ITQ)[81] and GSR scanning. The levels of impairment of each of the subjects were also measured with a standard Motricity Index, where the greater level of impairment is reflected in the lower percentage score[82].

In recruiting subjects for the system testing, it was proposed that, considering both the highly novel nature of the technology and that the technique does not appear to have been explored elsewhere, a small sample population would be appropriate to the testing, with analysis

[81] Initially designed by Kizony et al (2003) and based upon earlier work by Witmer and Singer (1998), the questionnaires were altered slightly in tone and to include questions pertaining to the specific field of research (see Appendix 7)
[82] See Acknowledgements, for further details of this exercise

conducted on a case-by-case basis (summarised in *Figure 6.1*, below). This method would allow data to be interpreted against subject-specific qualities, with the intention of providing material for further research and discussion.

Recruitment of live subjects also necessitated formal ethical approval though an NHS sanctioned ethics committee. It was found that the ethics committee to which a proposal was initially submitted was unwilling to approve such studies that were not undertaken with the guidance of professionally trained therapists and in a formal therapy setting. The current pilot study was thus undertaken as an extension of research in the use of VR as an adjunct to stroke therapy that has been pursued by physiotherapy staff at the Department of Rehabilitation, University of Ulster, and through Queens University Belfast Royal Group of Hospitals Trust, whose research had achieved a sufficiently high scoring in the review of literature, presented in Chapter Three. Ethical approval was thus granted through the Office for Research Ethics Committees in Northern Ireland (ORECNI).

Working collaboratively in this respect brought about a constraint in system development, whereupon the ORECNI application pertained to the use of an established, approved system. Hence, the pilot study reported here should be read not as the testing of an entirely novel system, but as that of the novel development of a given system. It is hoped that the findings pertaining to this development would be applicable to other VR systems wherein matters of interface expediency have been further evaluated.

The study: an overview

Three subjects were recruited to the study, each of whom had suffered a stroke no less than two years previously and exhibited a range of impairments (scorings for which are supplied below). Selection criteria included the ability to live independently of a treatment centre yet experience some level of hemiplegia to one upper limb as a result of their stroke, as *Figure 6.1*, below, outlines. Level of disability has, this regard, been linked to diminished control over rehabilitative VR systems (Crosbie et al, 2006), a factor which also affected the design of the system described here.

Each of the subjects were asked to supply digital images of their kitchens and also of objects which represented a meaningful activity – not however including watching television or listening to the radio as the level of motor activity involved in these tasks would not normally suffice for the sorts of therapeutic exercises undertaken by the department in which the research was being undertaken. In the event, only two of the subjects provided images which represented meaningful activity but this was deemed to provide a possible indicator of personality type (a personality which might not attach meaning to any one particular activity); the subject who had not supplied the activity image was thus not pressed to do so. The subjects were invited to attend the laboratory separately in order to undertake the tasks.

	Subject A	**Subject B**	**Subject C**
Age and gender	77 year-old male	45 year-old male	62 year-old female
Time of stroke	5 years ago	3.5 years ago	6 years ago
Nature of disability	Left upper limb hemiplegia	Right upper limb hemiplegia	Left upper limb hemiplegia
MI score	73%	34%	46%
Approx. GSR range (ohms, min. to max.)	250-2000	1500-4000	1800-2600
Immersive tendencies (summary)	prone to becoming quite immersed in a range of consecutive tasks; becomes fairly involved in narratives and responds with some emotion to others' situations; good at blocking out distractions when involved in an enjoyable activity; can be disturbed easily; often loses track of time.	fairly prone to getting involved in projects assigned to him by an instructor; switches tasks from one in which he is involved to another very easily; becomes involved with narratives; less likely to respond to stories emotionally; quite good at blocking out distractions when involved activities, whether or not the task is enjoyable.	prone to getting extremely involved in projects assigned to her by an instructor; switches tasks from one to another quite easily; high emotional response to news stories; high empathy for others including fictional characters and events; prone to being distracted from tasks, but can concentrate well if undisturbed.

Figure 6.1. Summary of pilot study subjects

The images, presented in the sections below, were used to create simulations of elements of their kitchen environments. As this study required comparisons to be made between familiar environments and unfamiliar environments, singular elements of the kitchens (the kitchen units) were selected for simulation and these were presented together in what was intended to be a fairly neutral space (an empty, greyish utility space) though a head-mounted display (HMD). In order to introduce a degree of randomisation to the study, smaller objects from the digital images were also selected and simulated (such as kettle, television, toaster, and so on) and these were dispersed across the kitchen units in such a way as to present to the subjects familiar objects in unfamiliar settings. The two 'meaningful' objects were similarly simulated and dispersed in unfamiliar settings. *Figure 6.2(a-c),* below, provides a screenshot of the environment, as seen by the subjects.

Figures 6.2(a-c). Screenshots of the simulated kitchen units and smaller domestic objects

Figure 6.2(a)

Figure 6.2(b)

Figure 6.2(c)

As the subjects' levels of upper limb motor disability were not known prior to their arrival at the laboratory it was deemed that normal VR input/output hardware (datagloves, and so on) might be inappropriate to the subjects' levels of motor control. As the task to be undertaken was simply to navigate around the environment and make notes of the scene before them, the subjects were thus required to indicate their desired direction to the investigator through basic hand gestures using their affected limb (forward, backward, left right), with some verbal assistance given if this means of navigation appeared to presenting problems in task performance.

It might be argued that such a technique would complicate the outcomes of the experiment by confusing what is the result of the VR activity and what is the result of the subjects' communications with the investigator. Yet the sensitivity in feedback afforded by most VR hardware does not appear to be well suited to the gross movements commonly performed by many stroke patients (including each of the three subjects recruited for the present study). This 'mixed reality' means of navigation was thus deemed to be the more effective means of input in its allowing the subjects a means of navigation that considered and supported their impairment and that was not prone to system misreading. This approach also appeared to allow the subjects to focus on the task of navigation, without navigation being complicated by the possible sensitivities of standard VR equipment; one of the subjects also required direct physical assistance from the physiotherapist who was present at each of the tests, yet this similarly appeared to have allowed a greater level of focus on the task. Yet in spite of the successful use of such a technique in this instance, it is however acknowledged that further work ought to be undertaken to demonstrate conclusively the validity of this assertion.

As each of the subjects were required to navigate around the environment, they were allowed a brief training session during which they were able to become accustomed to the means of navigation by signalling their desired direction around the neutral, greyish utility room. Upon being shown the room with the kitchen elements included, the subjects were also asked to choose a kitchen that appeared familiar to them and one that appeared unfamiliar. They were also each requested to choose one smaller object that was familiar and one that was unfamiliar. A final cognitive exercise was undertaking in turning to a blank part of the VE and recalling as many objects as possible. The exercise as a whole (excluding training) lasted for 10-15 minutes in each case.

While these tasks in the VE were being undertaken, GSR readings were taken from the skin surface of subjects' unaffected hand. This data was read as being a gross indicator of the subjects' relative level of cortical arousal in performing the tasks, which might relate to levels of presence and possibly therefore to task engagement (Slater et al, 2003; Riva et al, 2004). The GSR data was then compared to the results of the Motricity Indices[83], the TSFQs and ITQs and subsequently to the comments made by the subjects through a brief, semi-structured interview following the exercise. A case-based, qualitative narrative was thus established, presented below.

Case One: Subject A

Personal details and disability

Subject A is a 77 year-old male. He had suffered a stroke (CT scan showed nil of note) five years previously, causing a left hemiplegia. The current level of disability to his left upper limb, as measured with a Motricity Index (including pinch grip, elbow flexion and shoulder abduction) is 73%, reflecting moderate disability. The physiotherapist present commented on the good progress that *Subject A* had made in regaining motor function during the previous year in spite of the general 'underuse' of his affected limb.

[83] See Sánchez-Blanc et al (1999) for an overview of this technique

Subject A had supplied an image of his kitchen environment (shown in *Figure 6.3*., below) and also taken a photograph of his bowls, reflecting a meaningful activity (*Figure 6.4*).

Figure 6.3. Subject A's kitchen

Immersive Tendencies

The Immersive Tendency Questionnaire revealed that *Subject A* felt, at that moment, well and mentally alert (although he did not give full marks to either criteria); he felt fairly physically fit and had been concerned with personal problems quite a lot over the past 48 hours.

Subject A feels prone to getting extremely involved in projects assigned to him by an instructor; he switches tasks from one in which he is involved to another fairly easily. *Subject A* watches soap operas and docudramas a lot and he responds to news stories emotionally with moderate frequency and becomes deeply involved with films and TV drama fairly easily, often becoming involved with the characters in the storyline and has quite often gets excited by chase and fight scenes, yet he does not very frequently get involved in a film to the extent that he is not aware of what is going on around him, and less so that others cannot gain his attention. He is not prone to being scared by what he watches on television or in films and has never felt apprehensive or fearful after watching a scary film. *Subject A* will sometimes not go on a carnival or fairground ride because it feels too scary.

In general, *Subject A* feels that he is quite good at blocking out distractions when involved in an activity, but is disturbed easily when performing a task. If the task is enjoyable he can concentrate on it very well; conversely he concentrates with some difficulty if the task is disagreeable. *Subject A* also feels that he often gets so involved in a video game that he feels that he is inside the game (although he also states that he never plays video games, so this result is ambiguous) and this is true to a greater extent when watching a sporting event. When playing a sport or game, or indeed in undertaking any activity, *Subject A* very often loses track of time. He also feels that when daydreaming, he is sometimes not quite aware of what is going on around him; his sleeping dreams are often so real that he occasionally feels disorientated when he wakes.

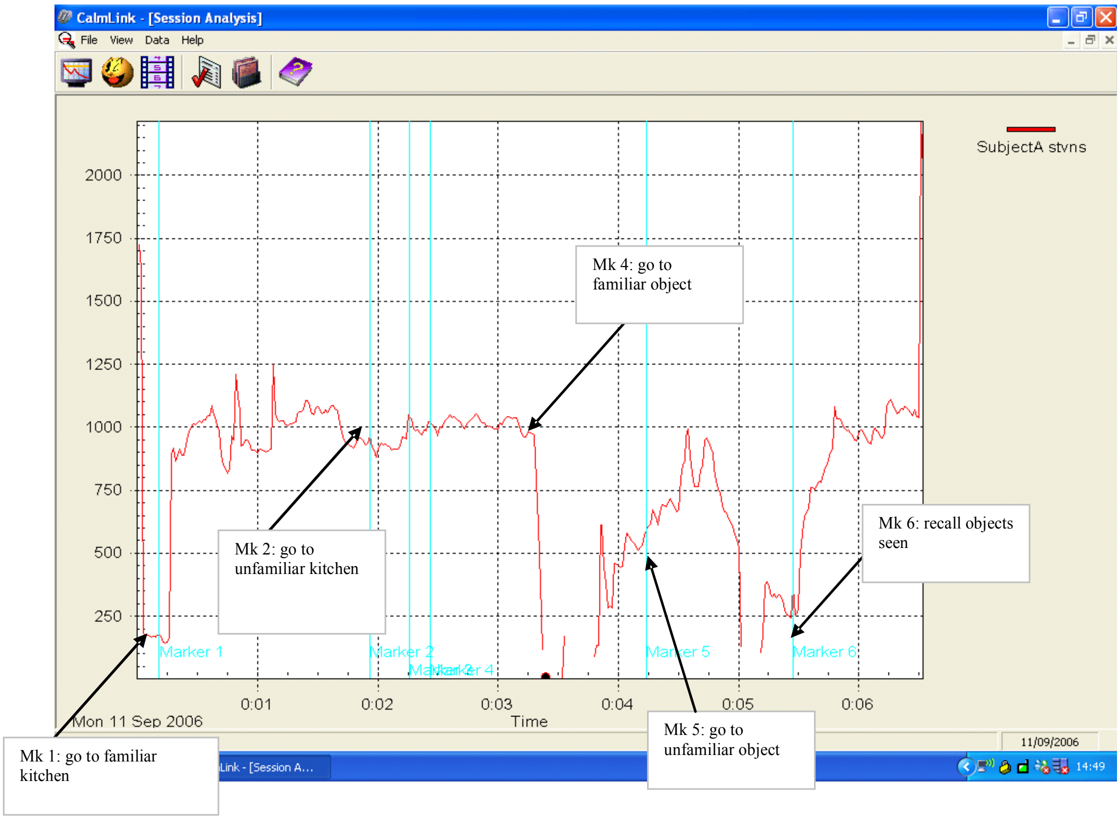
Figure 6.4. Image representing Subject A*'s meaningful activity: Crown Green Bowling*

To summarise the major findings of the ITQ, it would appear that *Subject A* is overall prone to becoming quite immersed in a range of consecutive tasks. His television watching behaviour perhaps suggests that he becomes fairly involved in narratives and responds with some emotion to others' situations or activities; he achieves greater empathy when watching a sporting event. This emotion is not carried beyond the televisual experience. *Subject A* similarly seems to be good at blocking out distractions when involved in an enjoyable activity, but can be disturbed easily, especially if the task is less enjoyable. When in undertaking any activity, not least in playing a sport or game, *Subject A* very often loses track of time.

Task performance and GSR results

Subject A undertook the navigation and recollection exercises described in the overview, above. The Task Specific Questionnaire reveals that *Subject A* felt that the environment was fairly interesting/enjoyable; that he had a strong sense of being in and control of the environment; that he was overall successful at the tasks and that the system feedback was highly understandable. *Subject A* also records that some elements in the environment felt very much like those in his own home and also that other elements in the environment felt quite unlike his own home. This response might well be affected by *Subject A*'s general tendency to become immersed in activities, as outlined in the analysis above.

Figure 6.5. GSR readings relating to Subject A*'s task performance*



The GSR reading shows reveals some inconsistency between *Subject A*'s questionnaire feedback and his sympathetic (physiological) reaction to the tasks and environment. The GSR feedback chart shown in *Figure 6.5* demarcates the periods in which certain activities were being undertaken. Hence, the period prior to Marker 1 (shown as Mk 1) being set represents *Subject A*'s GSR response to exploring the environment in the first instance, which reveals a marked cessation in emotional arousal with GSR readings dropping from 1750 ohms to around 150 (perhaps also reflecting *Subject A*'s tendency to immersion). Marker 1 itself represents the moment when the investigator requested *Subject A* to move towards the kitchen that felt most familiar. This caused a general and sustained increase in arousal, with GSR levels remaining constantly raised around the 1000 mark. This level was also sustained throughout the next task (which Marker 2 represents), being navigating to a kitchen that feels less familiar (Marker 3 was placed aberrantly).

Marker 4 represents the commencement of a new task, being choosing and navigating to a small object that felt familiar. Here *Subject A* chose the bowls, which were the objects he had marked out as representing a meaningful activity. Interestingly, identifying the bowls is marked by a sudden drop in GSR levels (from around 1000 to around 0). Marker 5 represents the moment when the investigator requests *Subject A* to choose and navigate towards an unfamiliar object. Throughout the course of performing this task the GSR level rises unevenly to peak at its former level of 1000 ohms before dropping once more to around the 250 ohm mark. Here, however, *Subject A* had actually misconstrued the instruction[84] and returned to the familiar bowls.

Marker 6 represents a final task of recalling as many objects as possible while looking at a blank area of the VE. Here, *Subject A* recalled six of the nine objects, while GSR readings reveal that the listening to his instruction induced a general rise in the level of arousal, while performing the task caused the level to settle fairly unevenly at around 1000. Removing the HMD equipment and returning to the offline environment caused a very sharp increase in GSR levels.

The post-exercise interview revealed that *Subject A* experienced no trouble in identifying the content of the VE. He identified his own kitchen immediately (the vividness of the colours being a particularly strong visual cue in this regard). Curiously however, Subject A reveals that the object that appeared most familiar was the kettle placed upon the familiar kitchen unit (being 'more or less' similar to his own electric kettle, although the shape was somewhat different). *Subject A* offers some explanation as to the confusion: the bowls were not at first familiar (they lacked sufficient detail) but upon recognition they gained greater salience ('I'm something of an addict', he says of bowling).

Discussion

Subject A generally achieved a relatively low level of arousal while using the VE. This is perhaps related to his general tendency to become immersed in tasks, even in spite of his dwelling on personal problems to a fair degree in the previous 48 hours. The major finding of this study appears however to be the marked drop in GSR levels as *Subject A* chose and navigated toward the bowls that represent his meaningful activity. In spite of misconstruing the instruction, *Subject A*'s return to the bowls resulted in the same drop to a minimal level of arousal. It might be suggested that it is the meaningfulness of these objects that relates to *Subject A*'s achievement of a lower level of arousal and perhaps therefore to a greater level of immersion. This theme warrants further investigation.

[84] The assistant to the investigator commented that the vocal instruction seemed sufficiently clear

Case Two: Subject B

Personal details and disability

Subject B is male and aged 45. He had suffered a stroke 3.5 years previously and experiences hemiplegia of the right upper limb (no further details were available). The level of disability to his right upper limb, as measured with a Motricity Index (including pinch grip, elbow flexion and shoulder abduction) is 34%, reflecting a high level of disability. The physiotherapist present was compelled to physically assist *Subject B* in performing the navigation tasks, which also necessitated *Subject B* providing vocal signals as to his intended direction.

Subject B had supplied an image of his kitchen environment (shown in *Figure 6.6*, below) yet had not supplied an image which reflected a meaningful activity. Although it later emerged that *Subject B* was in fact a keen video game player (for which he might have supplied a representative image) this omission was assumed to be a possible indicator of *Subject B*'s personality type and thus considered as a factor is assessing his task performance.

Figure 6.6. Subject B's kitchen

Immersive Tendencies

The Immersive Tendency Questionnaire revealed that *Subject B* felt, at that moment, very well and very mentally alert; he felt fairly physically fit and had dwelt only to a small degree on personal problems over the past 48 hours.

Subject B feels fairly prone to getting extremely involved in projects assigned to him by an instructor; he switches tasks from one in which he is involved to another very easily. *Subject B* watches soap operas and docudramas a lot, he also reads for pleasure around two books a month and particularly likes spy novels. He seldom responds to news stories emotionally and becomes deeply involved with films and TV drama fairly easily. He never becomes involved with the characters in the storyline and occasionally gets excited by chase and fight scenes. He occasionally gets so involved in a film or book that he is not aware of what is going on around him, and this sometimes means that others cannot gain his attention. He never gets scared by what he watches on television or in films and has never felt apprehensive or fearful after watching a scary film. Subject B has never avoided a carnival or fairground ride because it feels too scary.

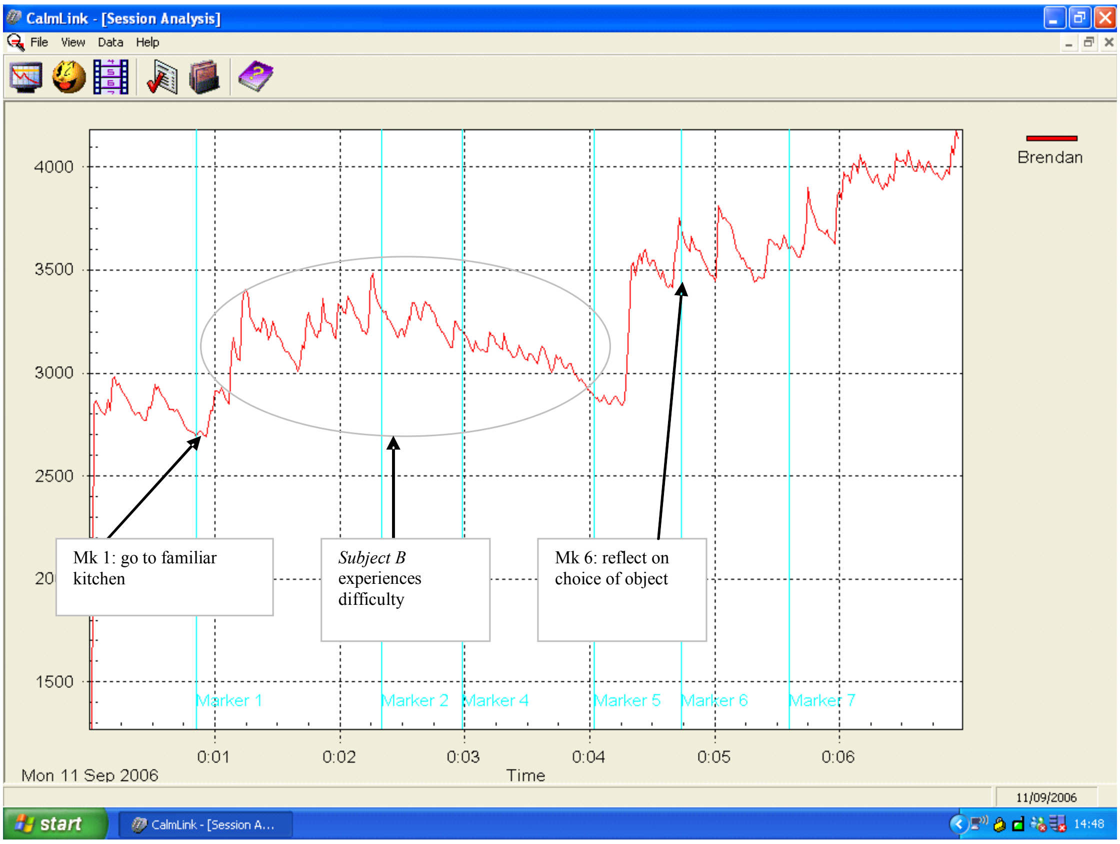
In general, *Subject B* feels that he is quite good at blocking out distractions when involved in an activity, and is not easily disturbed when performing a task. If the task is enjoyable he can concentrate on it very well and quite well even if the task is disagreeable. *Subject B* plays video games very regularly but never gets so involved in a video game that he feels that he is inside the game; he is also unlikely to feel as though he is one of the players when watching a sporting event. When playing a sport or game, or indeed in undertaking any activity, *Subject B* occasionally loses track of time. He is never unaware of what is going on around him when daydreaming and has never felt disorientated when waking from a sleeping dream.

To summarise the major findings of the ITQ, *Subject B* seems fairly prone to getting involved in projects assigned to him by an instructor and switches tasks from one in which he is involved to another very easily. *Subject B*'s television, reading and game playing habits suggests he becomes involved with narratives of some complexity but is less likely to respond emotionally with the stories, characters and action scenes; the same appears to be true of his emotional response to the news. *Subject B* seems to be quite good at blocking out distractions when involved in other activities, whether the task is enjoyable or not.

Task performance and GSR results

Subject B undertook the navigation and recollection exercises described in the overview, above. The Task Specific Questionnaire reveals that *Subject B* felt that the environment was fairly interesting/enjoyable but that he did not have a strong sense of being in the environment; yet his sense of control over the environment was a little greater. He felt that he was fairly successful at performing the tasks and that the system feedback was fairly understandable. *Subject B* records that few elements in the environment felt like those in his own home but also that few of the other elements in the environment felt unlike those in his own home. This equivocal response might be regarded with reference to *Subject B*'s generally low level of emotional response to books, television and films that the ITQ revealed. *Subject B* thus appears to be less prone to becoming immersed in a VE. *Subject B* had also neglected to forward an image that reflected a meaningful activity, which might also affect his response to the VE.

Figure 6.7. GSR readings relating to Subject B's task performance



The GSR reading reveals a sharp rise in arousal upon first encountering the VE (as shown in *Figure 6.7*), which stabilises unevenly around a relatively high 2800-3000 ohms prior to the first task being initiated. Marker 1 thus marks the point were the investigator requests of *Subject B* to navigate the more familiar environment (it later emerged that this instruction was misconstrued by *Subject B* who then searched for the most *un*familiar kitchen). The GSR readings overall rise to between 3000-3500 ohms, perhaps reflecting both the lack of particular salience in any kitchens and also the higher level of disability experienced by *Subject B*. Here, *Subject B* misconstrued the instruction and navigated to the kitchen that felt most unfamiliar. *Subject B* was then asked to reflect on his choice for a moment for further discussion (outlined below), which is reflected in the decline in arousal prior to Marker 6.

Marker 6 marks the point where Subject B was requested to navigate to the small object that felt most familiar and a sharp rise in arousal can be observed, rising rapidly to around 3600 ohms. *Subject B* once again made a similar mistake as above in navigating to an object that was unfamiliar (the trowel); which is perhaps reflected in the high state of arousal. Marker 7 marks the point where Subject B was asked to recall small objects from the VE, marked by a further rise in arousal to a peak of 4000 ohms (rising a little further still as the HMD was removed).

The post-exercise interview revealed that *Subject B* had indeed misconstrued much of the instruction[85], although he also maintained that he had little trouble in completing the tasks. In this regard, *Subject B* did navigate successfully to the kitchen he found most unfamiliar. Upon being asked which was the more familiar kitchen he identified *Subject C*'s (of which he says, 'Not familiar, but as near as damn it'). Regarding the simulation of his own kitchen, *Subject B* did notice that the kitchen had a Belfast sink, which he recognised as being similar to his own, but this did not translate to a sense of familiarity during this experiment. *Subject B* was not forthcoming on why this was the case.

Discussion

Subject B generally experienced a relatively high level of emotional arousal while using the VE, which rose throughout the exercise. This might be regarded against his general tendency not to become immersed in tasks. The major findings of this study appear to be firstly the sharp rise in emotional arousal while *Subject B* was choosing a kitchen that felt most unfamiliar, yet while not responding particularly strongly to any of them (as revealed in the ITQ). The second major finding appears to be the overall increase in arousal as the exercise continued. I would suggest that is appears that, in spite of *Subject B*'s confidence that he had performed the tasks successfully and that he enjoyed/was interested in using the system, he was in fact experiencing some difficulty in using the environment and was far from becoming immersed in the experience. Also, given the fact that the VE contained no element that represented an activity that was meaningful to *Subject B*, this might also have reflected the general lack of salience in the environmental content.

Case Three: Subject C

Personal details and disability

Subject C is a 62 year-old female. She had suffered a lesion to the basal ganglia six years previously, causing complete paralysis to her left upper limb. The current level of disability to her left upper limb, as measured with a Motricity Index (including pinch grip, elbow flexion and shoulder abduction) is 46%, reflecting a fairly high level of disability. *Subject C* had supplied an image of her kitchen environment (shown in *Figure 6.8.*, below) and an image of her garden to represent her meaningful activity of gardening (*Figure 6.9*).

[85] The assistant to the investigator commented that the vocal instruction seemed sufficiently clear

Immersive Tendencies

The Immersive Tendency Questionnaire revealed that *Subject C* felt, at that moment, fairly well generally and very mentally alert; she felt fairly physically fit and had dwelt to a small degree on personal problems over the past 48 hours.

Figure 6.8. Subject C*'s kitchen*

Subject C feels somewhat prone to getting extremely involved in projects assigned to her by an instructor; she switches tasks from one in which she is involved to another quite easily. *Subject C* frequently watches soap operas and docudramas, she also reads for pleasure around one book a month and particularly likes historical novels. She always responds to news stories emotionally and becomes deeply involved with films and TV drama fairly easily. She frequently becomes involved with the characters in the storyline and quite often gets excited by chase and fight scenes. She seldom gets so involved in a film or book that she is not aware of what is going on around her, and this sometimes means that others cannot gain her attention. She quite often gets scared by what she watches on television or in films and has sometimes felt apprehensive or fearful after watching a scary film. Subject C has never avoided a carnival or fairground ride because it feels too scary.

In general, *Subject C* feels that she is not too good at blocking out distractions when involved in an activity, and is easily disturbed when performing a task. If the task is enjoyable, however, she can concentrate on it very well and fairly well even if the task is disagreeable. When watching a sporting event, *Subject C* has never felt as though she is one of the players (she has either never played or had this experience when playing a video game). When playing a sport or game *Subject C* seldom loses track of time, but this is occasionally true when performing other types of tasks. She is very occasionally unaware of what is going on around her when daydreaming and has never felt disorientated when waking from a sleeping dream.

Figure 6.9. Image representing gardening as being Subject C*'s meaningful activity*

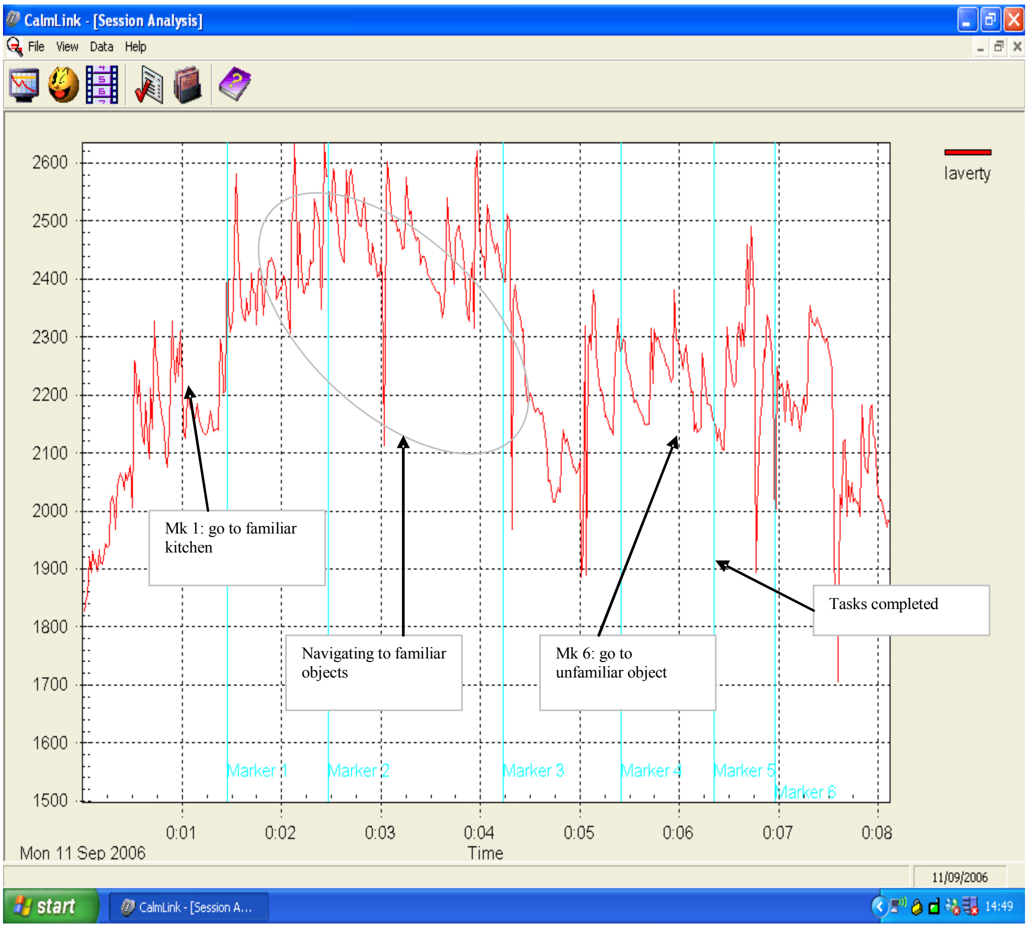
To summarise the major findings of the ITQ, *Subject C* seems somewhat prone to getting extremely involved in projects assigned to him by an instructor and switches tasks from one in which he is involved to another quite easily. *Subject C's* very emotional response to news stories suggests that she might achieve high empathy to others and this is true, although to a slightly lesser degree, with regard to fictional characters and events. This is not true of viewing a sporting event. *Subject C* is prone to being distracted from tasks, but can concentrate well if undisturbed, whether the task is enjoyable or not, and sometimes loses track of time when doing so.

Task performance and GSR results

Subject C undertook the navigation and recollection exercises described in the overview, above. The Task Specific Questionnaire reveals that *Subject C* felt that the environment was very interesting/enjoyable and that she had a strong sense of being in and having control of the environment. She felt that she was highly successful at performing the tasks and that the system feedback was highly understandable. *Subject C* records that some elements in the environment felt quite a lot like those in her own home and other elements in the environment felt very much unlike those in her own home. Such strong reactions to the environment might reflect Subject C's tendency to becoming immersed in tasks and perhaps also in VEs.

Subject C's GSR reading, shown in *Figure 6.10*, reveals an ostensibly unstable response to performing the tasks that nevertheless remains within a fairly limited range (1700-2600 ohms). A general rise in arousal is shown prior to performing the first task of navigating to a familiar kitchen (after Marker 1). Navigating to an unfamiliar kitchen causes a further rise and then sudden drop in arousal after Marker 2 (the drop reflects the completion of the task). The overall state of arousal drops slightly while *Subject C* navigates to a small object that feels familiar (flower pots), and peaks again upon being asked to reflect on this for a moment (for later discussion). Marker 6 marks the point where *Subject C* is asked to navigate to a small object that is unfamiliar (bowls), resulting in a slight rise in arousal. The arousal then drops quite suddenly as *Subject C* recalls the small objects she has seen while looking at a neutral wall in the VE.

Figure 6.10. GSR readings relating to Subject C*'s task performance*



Discussion

In spite of the variable readout, *Subject C* evinced emotional arousal at a generally low level. This did however rise throughout the exercise and there appears to be some correspondence high arousal and unfamiliarity of objects (although this requires further investigation). The interview revealed the quite high sensitivity of *Subject C*'s responses, which go some way to explaining the varied rates of the GSR feedback. Thus, while *Subject C* made a clear identification of her own kitchen, she seemed somewhat troubled by the television that had been placed there ('That must be a health hazard, having a TV there' she says of it). When choosing the least familiar kitchen, *Subject C* was aware this was only unit that had neither a hob nor a sink (the vivid blue tiles were also salient). Subject C also commented on her hesitation prior to navigating toward the small object most familiar to her (flower pots) in remarking that although she 'loves gardening', she would not have these objects in her kitchen. Such sensitive and considered responses might reflect *Subject C*'s tendency to respond emotionally to news and to be immersed in tasks, while also being easily distracted from them. This mixed response to tasks in general appears to be reflected in this GSR reading, perhaps also correlating to a variable tendency to be immersed in a VE.

General discussion

Previous chapters have revealed the need for engagement in the therapy process in achieving the rehabilitation of the activities of life. This chapter is intended to be an exploration of this possibility through a pilot study. Three subjects were recruited for the study and each were requested to supply digital images of their kitchen and of an object that held or represented some meaning to them (in the event only two of the subjects supplied an image of a meaningful object). These images formed the means to create a virtual simulation of the subject's kitchens, with a range of objects dispersed throughout.

Upon arrival at the laboratory, the subjects were each assessed for disability and given an immersive tendencies questionnaire to fill out. They where then invited to take part in a series of navigation and recollection exercises while using the VE, after which they took part in a short interview and filled out a Task Specific Feedback Questionnaire.

Considering and comparing all of this data, some suggestive results were found. While *Subjects A* and *C* were the individuals more likely to become immersed in an experience, they were also the most sensitive to the environmental content of the VEs (reflected in an apparent rise in emotional arousal when navigation toward an unfamiliar kitchen or object). These two individuals had also supplied images of meaningful objects and the virtual representations of these objects had particular salience. *Subject B* had not supplied an image of a meaningful object and appeared overall equivocal about the relative familiarity of the kitchens and smaller objects he experienced in the VE. His ITQ also revealed that he is perhaps less likely to respond emotionally to either news or media, although fairly likely to become immersed in a task. So although *Subject B* might become immersed in a VE, this might not be revealed in an emotional reading. Subject B also experienced the greater level of disability to his upper limb and this might affect his level of engagement with the VE tasks.

The major finding of this study is that greater familiarity and especially the meaningfulness of objects appears to be reflected in relatively low levels of emotional arousal. I would suggest that this is equivalent to higher levels of immersion and thus perhaps also of task engagement, although the personal tendencies of the system users does appear to impact on these outcomes. I would recommend that this experiment now be repeated with a larger sample population, including also a control group of users less likely to become immersed or for whom no one activity in particular has strongly salient meaning. Given a longer period of time in which to conduct such an experiment, it might also be pertinent to introduce a measure of performance outcomes, not least in the subjects' changing conditions, as described by Zahn and Ottenbacher (2001), as well attitudes to activities, such as the Canadian Occupational Performance Measure[86].

[86] http://www.caot.ca/copm/index.htm for further information about this technique [last accessed December 2007]

Chapter Seven – Summary and Recommendations

General Introduction

This final chapter is intended to bring together the findings of Chapters Two to Eight in order to provide an overview of the research as a whole, including a critical repost to Rizzo and Kim's conjectures (Rizzo and Kim, 2005), (initially outlined in Chapter One, Introduction and Background). It was observed in the literature review of Chapter Three that virtual of reality as an adjunct for post-stroke rehabilitation is not well understood and remains at an exploratory level (as evidenced in the nature of much of the research as being small-scale pilot studies). It is hoped however that the research presented in this thesis should provide a contribution to the field by offering considered and substantiated recommendations as to the direction of further study and also to possible enterprise in the clinical field.

Summary of findings

The introductory chapter offered sources of preliminary work to which the subsequent field of study was set to respond: a client statement based upon the broad observations and intentions of the clinicians with whom I was working and a summary of an authoritative SWOT analysis conducted by Rizzo and Kim (2005). Here the authors maintained that virtual reality might provide variable and realistic environments while supplying suitable performance feedback for either error-free or trial-and-error rehabilitative training. Yet the authors also outlined serious challenges to the delivery of such a system, including interface design, immaturity of the engineering process, lack of consensus among engineers and the cost of equipment. The inappropriate administration of the technology might also result in harm to the patient, and subvert the perceived relationship between therapist and patient.

A key problem in the design of such a technology was identified as being that of infinity: in human movement, in material objects, in symbolic generation and in existential life themes. It is posited that VR might provide one way of alleviating this problem. Hence, Chapter One comprised an outline of the intrinsic and incommutable values that the technology might provide to clinical outcome in its capacity to transform abstracted sensory information into naturalistic physiological responses. This encompassed a broader and somewhat problematic enquiry as to the nature of mind in relation to body and the role that 'commodities' – not least those of the domestic environment – play in the generation of selfhood. A further proposal was that gameplay might provide a stable yet flexible (or, rather, 'emergent') framework in which VR-based therapeutic tasks might be executed.

The review of literature presented in Chapter Three revealed that Rizzo and Kim's analysis is broadly accurate in that the technology is superficially ready for further clinical trials with regard to its technical capacities, to patient acceptance and with apparent benefits to the post-brain injury recovery process. The review also revealed how the authors' concerns as to the weaknesses and threats relating to the technology also appear to be accurate in that the technology's role in the recovery process is not well understood. There furthermore appears to be a persistent gap in communication between engineers and clinicians that the user study presented in Chapter Four sought to address.

In conducting an analysis of the client statement, Chapter Two, Problem Analysis, presented a series of system requirements and functions, design concerns and outcome metrics. From these metrics a pairwise analysis was conducted which provided a series of objectives that were weighted in such a way as to provide a convenient 'rule of thumb' for evaluating the technology, comprising (in descending order of weight) user focus, clinical effectiveness, meaningfulness, marketability, variability and adaptability.

The review of related work also revealed that simplicity in system design tends to result in clearer methods and outcomes; that outcome measurements of the system must ultimately relate to clinical concerns and interface well with these; that the system can only be deemed usable if its acceptability to the therapist and patient has been evaluated. It was thus posited that the challenge for engineers is to establish a VR system that is at once bespoke to therapeutic methods and integral to clinical intervention as a whole. This was thus shown to necessitate adaptability to various contexts and variability to the changing clinical requirements maintained as design concerns.

Chapter Four presented the findings of a user study, based upon a series of interviews with experts in the field of neurological rehabilitation (each practice at a senior level and many worked in treatment centres of national or international importance). As a loosely adapted grounded theory method was used to analyse the interviews, so these findings were subsequently summarised against the weighted objectives outlined above.

Hence it was observed that, regarding user focus, there appears to be limited consensus among therapists as to the commonalities and discontinuities of their respective roles, yet that contact with clients is commonly a dynamic process, with programmes of therapy structured around cognitive or motor function goals that are altered as the patient progresses. It was also observed that the patient group is highly disparate in terms of age, gender, level of disability, pre-morbid tendencies, wealth and social standing that each affects the processes and outcomes of clinical intervention. Goal-setting is similarly affected by these factors, considering especially the highly relative means by which patients are motivated. There also appear to be general problems in focusing on the patients needs as he or she moves between the various departments involved in the care process.

With regard to clinical effectiveness, it was found that therapy will often be conducted according to goals actively negotiated between client and therapist and that these embed the functional tasks and direct manipulations by which normal and intuitive movement is restored. Goals might thus pertain to lifestyle aims or to functional objectives. Goal-orientated task performance and fuller body integration thus engage the nervous system to a maximal capacity, thereby driving the recovery process at a deeper level. The therapeutic process thus involves a bespoke and inclusive assessment and incorporation of the individual client's requirements, proclivities and preferences, often including quite intimate concerns. The continuation and self-initiation of exercises between formal therapy sessions was also regarded as being of value among some therapists, yet limitations in contact time and the compounded clinical problems experienced by the patient often mean this is difficult to pursue.

The meaningfulness and complexity of the patient's environment was also shown to be of concern among therapists, yet the hospital environment was considered among some to be insufficient both in allowing cognitive or motor impairments to become apparent and in reflecting the client's long-term goals. It was also observed that the hospital environment might promote such negative responses in the patient as passivity to the care process and withdrawal from public life. Therapists thus often endeavour to take the client to community settings. A range of equipment is normally available to the therapist and patient, which tends to be prostheses and orthoses that are usually intended to leverage existing motor or cognitive function. The therapist is normally required to ensure that the equipment is appropriate the patient's requirements and abilities and that the patient is the using apparatus correctly.

The user study also revealed that therapeutic tasks and goals should be meaningful to the patient if they are to be effective. Meaningfulness thus pertains to a range of patient needs, whether they are individual or more universal objectives. It was further observed that the hospital environment might thus limit the meaningfulness of activities, not least where the client attaches particular meaning to the activities of work or domestic life. The user study also revealed the distinction in task performance between meaningfulness and purposefulness whereby a task might be purposeful in terms of clinical outcomes but entirely meaningless to the client. Some therapists would endeavour to avoid this.

Drawing on the concerns among therapists about delivering engaging activities to the patient, it was proposed that engagement might be achieved by supplying simulations of those objects that represent 'meaning' to the patient. This proposal formed the basis of the practical study outlined in Chapter Six, which provided anecdotal evidence that interaction with meaningful items result lower levels of cortical arousal, which has been identified as reflecting greater levels of immersion and thus perhaps engagement in the task. It was thus recommended that this experiment should be repeated with a larger sample population, including also a control group of those users who have been deemed less likely to become immersed or who might not attach particular meaning to any one particular activity. Further evidence for the value of meaningful objects might also be gained in evaluating subjects' changing attitudes to activities.

A further purpose of the user study was to source data that would support an enquiry into the marketability of the proposed system. Hence it was observed that the therapists interviewed are generally knowledgeable about innovative technology but that resources in this regard tend to be limited with regard to time, space, funding and technical skill, as well as to the subsequent increase in bureaucracy. It was also found that economic and social disparities within regions and populations might affect the uptake of innovative apparatus. Yet there does appear to be a general shift towards innovation, not least in support of services for patients in long-term care.

Some of the therapists interviewed also outlined a perceived gap in skills, knowledge and professional interest among the engineering community as to therapists' needs, patients' limitations and the market value of equipment provision. This appears to be a persistent disadvantage to clinicians and engineers alike.

As the therapy is a dynamic and individuated process, so any equipment must respond to these factors by allowing system variability during any one treatment session and adaptability throughout the therapy process as a whole. Technologies that do not fulfil this requirement appear to have been abandoned.

Considering the problems with technology take-up inferred from the user study observations, the second part of Chapter Four presented the findings of further research pertaining to the marketability of the proposed system. Thus the means by which the technology should interface with the requirements of the target user group (the *market*) and the economic processes necessitated by its supplier (the *industry*) where examined. The key findings of this strategy framework were the observations of a strong 'pull' from the abundance of government funding for innovative applications of information communication technology (ICT) in healthcare, as well as the increased use of ICT among service users. In establishing a technology through the means of the independent sector, there appears to be a growing tendency to market-orientated service provision among health providers, not least in the establishment of (primary care trusts) PCTs, (although this appears to be subject to opposition from the major public sector workers' union). The government has also targeted long-term clients in providing integrated care for the increasing incidence of stroke. There appears to be a pressing requirement for service integration and patient engagement in this regard. It was also observed that the government appears to be supporting innovations through the NHS Institute and through regional hubs of this, yet the effectiveness of these ventures has yet to be measured against their lasting impact on the relationship between the independent sector and public health provision.

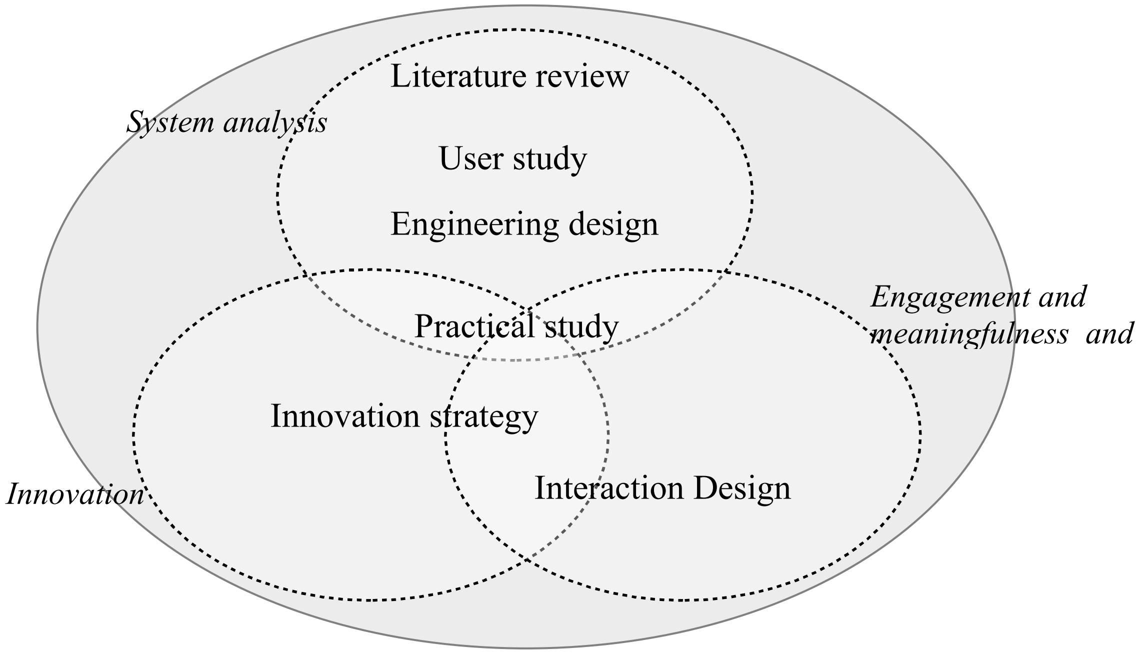
As managers have sought alternatives to hospital-based care by assessing the effectiveness of rehabilitation in community settings, so there appears to be a possible advantage to a patient engaging in environments or activities which are more meaningful than those of a hospital. In this regard, a VR system could help facilitate the care process while creating no extra burden upon financial expenditure. This possibility warrants further examination.

Patient connectedness and engagement was thus shown to be of clinical concern, in these factors have a directly positive impact on overall health among a population. Given this observation, it was posited that VR can help provide the means for this engagement to occur and thereby form the basis of a sustainable social enterprise. The impact of ICT usage on social capital is not however well understood and further research in this area is necessary.

VR might be delivered on a telecare platform, allowing the patient to undertake therapy sessions remote from the treatment centre. Hence Chapter Five provided a series of possible interaction models that might accommodate clinical parameters and deliver formal therapy protocols and processes to the patient. A clinical 'zone' was also devised which might serve as tool determine the proximal confluence of a patient's requirements along temporal and spatial axes, and hence a region of clinical effectiveness.

Drawing the various areas of this thesis together, we find that a more holistic aspect of the research emerges, illustrated in *Figure 7.1*.

Figure 7.1 An overview of the research



Here the major areas of concern are shown as being system analysis, innovation and meaningfulness and engagement. The last area encompasses the themes outlined in the practical work (an attempt to demonstrate how virtual environments might provide meaningful content), in the innovation strategy (which outlined the transferable value of integrating and engaging the patient in the care process) and in the interaction design (an attempt to identify the intrinsic value of the technology). With respect to these themes, it was in this area that the real value of the technology was found.

In comparing this evaluation of meaningfulness and engagement to the work already undertaken elsewhere in the field, it seems that a deeper understanding of the technology, including of its precise role in the recovery process, is generally lacking. The initial discussion the theoretical background to this application of the technology was thus provided in Chapter One, while the pilot study presented in Chapter Six attempted to address the apparent lack of 'meaningfulness' among projects in the literature.

Hence, in developing themes and areas of enquiry from the fields of philosophy, anthropology and neuropsychology, it was proposed that the ‘x-factor’ comprised the intentional drive by which what is sensed is dynamically transformed into what is perceived, and that subsequent motor responses might thus be secured to produce a successful skill-learning programme. Hence, the objects of everyday life that become commodified inalienably through the normal processes of social interaction come to bear the requisite affordance to the stroke patient so as to promote meaningfulness and engagement in the activity. It was also shown that a subject's powers of imagination (or, rather, visualisation) could be maximised by way of a VR system. Imagined objects and activities might thus transfer to actual sensory-motor recovery through newly discovered neural processes (the mirror neuron system). Yet the value of what is sensed in the context of sensory-motor recovery appears to be contingent on the subjective salience that such 'percepts' afford to the patient. Hence, the true value of the technology is not in presenting generic environmental content (as appears throughout the literature) but in providing objects and associated activities that are directly of the patient's choosing.

Recommendations

Part One: concluding remarks

Stopping the wastage

The field of study presented in this thesis was prompted by a client statement, from which a set of metrics was derived (see *Figure 2.6*). Many of these metrics were addressed through the literature review and user study, while others were approached through the practical pilot study. Other major parts of the thesis also focussed on the parameters of 'possible channels of distribution', 'appropriation to the various needs of clinicians' and 'meaningful and perhaps motivating'. Analysis was also offered as to possible system designs that would meet the parameters set in the client statement.

However, shortfalls in the design and implementation of VR in rehabilitation appear to remain, was well expressed by one of the interviewees for the user study:

> *…the people who've done the research from the virtual environments angle hadn't picked up on things which I thought were really clinically significant* (OT2.7.4)

There hence appears to be a persistent gap in knowledge among engineers as to both the needs of clinicians and their patients and of the fundamental value of the technology. This gap appears to account for very significant wastage in the technology's value. Overcoming this wastage is discussed as a key recommendation, below.

The analysis presented throughout this study has revealed a picture of a technology that, through engaging capacities of the human brain that have only recently been discovered, is close to achieving its potential of delivering complex, meaningful content to stroke patients for whom the sensory and perceptual affordances of the environment might provide a powerfully effective method of achieving a fuller recovery of their sensory-motor and cognitive functions. Furthermore, as ICT is set to play an increasingly more integral role in the lives of patients and care providers, so future generations of stroke patients could readily access the means of rehabilitation in any context that might benefit their recovery.

Yet for virtual reality to be adopted as a general tool for rehabilitation, it is not only the question of meaningfulness that must be addressed. The potential value of the technology in promoting patient engagement in the recovery process was outlined in Chapter Four, Part Two. Hence, the channels for innovation that are intended to deliver novel, bespoke solutions to therapists and patients alike must be made open to inventors and engineers in the independent sector; in this capacity, the effectiveness of the relatively new NHS Institute (comprising NHS Innovation) has yet to be demonstrated satisfactorily.

Engineers, too, must address a series of problematic shortfalls in the manner by which such a system might be delivered to the patient. While hardware problems currently remain an obstacle to effective implementation in some areas, (not least in the inappropriateness of standard means of VR input), it is here assumed that these are not insuperable. The greater hindrance to development now appears to be the general lack of understanding among engineers of therapists' highly diverse practices, as well as the myriad disparity of patients' individual circumstances, requirements and desires. The task at hand therefore is to continue in building the means of communication between engineer, therapist and patient in order to return the value of the endeavour to the stroke victims of the future.

Part Two: a proposal for further research

A design-led ethnographic longitudinal study of NeuroVR

Throughout this study, the ways and means by which neuro-rehabilitation clinicians can use virtual reality (VR) to deliver meaningful and stimulating simulations to the patient have been examined. At various stages there have been recommendation for further research. These pertain in the main issues of meaningfulness, engagement and flow, while issues of service integration and patient mobility were also shown to be of outstanding concern among clinicians.

The recent launch of NeuroVR[87] marked an important development in this application of the technology, and this final recommendation outlines one such study that might address these further research concerns.

Figure 7.2 Screenshot of NeuroVR

NeuroVR software allows clinicians to work in a technically non-expert capacity to model bespoke environments according to the requirements of their patients. The key technical improvement of upon existing VR systems is a collaborative facility that allows clinicians to publicly share scripts and models and to communicate interactively about their patients' conditions. NeuroVR currently includes a library of generic environments that are frequently of clinical concern, such as the office environment shown in *Figure 7.2*, it is expected that the database of models will grow in the coming years, providing clinicians with a rich VR resource. In anticipation of this, I aim to discover how clinicians might adapt the software *in situ* to the needs of the patient. I propose that an ethnographic study of a *bespoke* adaptation of the system being used *in situ* could help further our understanding of VR in neuro-rehabilitation. The key research questions are:

1. Does NeuroVR serve to benefit the mobilities of clinician and patient?
2. Does NeuroVR help achieve professional vision of the patient's requirements
3. Can NeuroVR help accommodate a client's individual proclivities?
4. What are the means by which a NeuroVR system can be adapted *in situ* to client's requirements?

[87]Authored by Prof. Giuseppe Riva and his colleagues at Istituo Auxologico Italiano, Milan. Officially launched at Virtual Rehabilitation 2007 in Venice

Transfer and mobility

The user study of Chapter Four revealed how transferring a patient between settings poses care and management challenges to the clinician, which are currently met through verbal and written correspondence among the various agencies (e.g. with social services). NeuroVR might play a role in transfer by offering maps and models of the patient's community environment (e.g. home or work), or of the treatment facilities to which the patient is being transferred. Such models might also serve an important *inductive* role in preparing the patient for the next stage of therapy, a matter which has yet to be addressed anywhere in the VR literature.

In facilitating transfer, neuro-rehabilitation clinicians are often required to work remote to the treatment centre. Hence NeuroVR is also intended to be delivered on a mobile platform, allowing clinicians to refer to models and maps remotely. The technology might thus help clinicians achieve a 'professional vision' of the patient's requirements in the field.

The mobile use of a mapping system has been the subject of an *in situ* ethnographic study of landscape architects developing their vision of a terrain, comparing given data with their sensory experience (Büscher, 2006). This method provides an apposite model for examining the use of NeuroVR among clinicians in achieving their professional vision of patient's requirements against their material and functional domains.

Methods and analysis

The project will respond to the research questions, presented in the Abstract, above and comprise three major parts (anticipated time period given in brackets):

1. Development of a bespoke PC-based system upon the NeuroVR platform
2. Ethnographic study among the subjects. To reflect a typical transfer scenario, the study will examine the communications of three subjects pertaining to one patient: a physiotherapist, an occupational therapist and a social worker. The subjects will initially be interviewed about normal transfer procedures. Subsequently their communications while using the NeuroVR system over the full period of intervention will be videoed. The recordings will be analysed *in minutae* with the aim of revealing behavioural signals as they might change throughout their collaboration. Analysis will be based on a grounded theory model, in relation to the previous interview material.
3. Publication of results, including textual and pictographic analysis. Following Büscher's model, textual analysis will be presented along with

stills from the video bearing and enunciated 'subtitles' of the subjects' communications.

This study would help further our understanding of how VR might play an integral role in the rehabilitation of stroke victims. As the field as a whole appears to evolving year upon year, so the various areas of research and, increasingly, of product development must continue to ensure that technology protocols interface suitably with demands of policy makers, clinicians and their patients. The patients of the future will be evermore familiar and comfortable with using virtual environments. I hope, therefore, that this study anticipates some of these coming trends and helps encourage the convergence of endeavours that are necessary for the successful establishment of VR in the clinical domain.

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Appendix 2 – Literature review scores

At an early stage in the research, a scoring system was devised that might select out those papers of most relevance and use to the present study. As the research progressed, the focus became more on addressing the gaps in the field as a whole, rather than the merits of exemplary studies. Although this system was abandoned in the research, the themes against which they has been scored may continue to be of use elsewhere. Hence they are presented below.

The scoring system used in the analysis was designed to select those papers that are of particular value to the present study. It is acknowledged that industry-standard scoring systems exist (such as Cochrane, PeDro and OTseeker[88]), but that these are not well applied to a field as immature as that under examination here (see Weiss and Ring, 2007, for a discussion of this). The papers are reviewed according to the criteria (weighted objectives) established in the preceding chapter. As the quality of the papers appears to vary very widely, an additional criteria was established to select out the minority of papers that satisfied sound research methods. Greater scores were given to the weighted objectives devised in Chapter Two; a study could score up to five points for fulfilling the objectives of user focus and four for clinical effectiveness, and so on. In this part of the scoring, the criteria of 'meaningfulness' relates to the relevance of the virtual environment content to the system user.

A further area of scoring is set to gauge the quality of the research overall. Hence, one point is given where a paper has satisfied the criteria of sound research, including the use of measurable outcomes, of randomised trials and of considering or precluding factors which might affect outcomes to the thoroughness by which the system being tested was used by the subjects (such as the length and number of training sessions).

The table below thus shows that the studies which have received the highest overall results are those which gained scores in the objectives of greater weight (user-focussed, clinically effective and meaningful) while also using suitable and consistent outcome measurements and analysis. This is not to suggest that these are the best papers in field by any universally generally accepted criteria, but that they reflect well the concerns of the client statement presented above. Each has something to offer the present study, but it is acknowledged that there are serious limitation in some of the work selected here.

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[88] See, for example, CRD: http://www.york.ac.uk/inst/crd/report4.htm
PEDro: http://www.ptjournal.org/cgi/content/full/83/8/713
and the
OTseeker adaptation of PEDro http://www.otseeker.com, which would provide an apposite review scale as the field matures

Totals of scoring for each study

	Broeren et al, 2004	Jang et al, 2005	Merians et al, 2006	Viau et al, 2004	Crosbie et al, 2004a	Kizony et al, 2003, 2004	Christiansen et al, 1998	Pridmore et al, 2004; Edmans et al, 2004	Harrison et al, 2002	Pugnetti et al, 2005	Davies et al, 2002	Lam et al, 2004, 2006	Katz et al, 2005	Rand et al, 2007	Lewis-Brooks et al, 2004	Reinkensmeyer et al, 2002	Holden et al, 2005, 2007	**Total by objective**	**Total as % of HPS***
Weighted objectives																			
User-focused	2	3	4	3	4	3	3	3	4	2	0	4	4	4	2	2	3	**15**	**14**
Clinically effective	3	3	3	3	3	3	1	1	2	2	0	3	4	3	0	2	3	**12**	**14**
Meaningful	1	0	1	2	2	2	0	1	2	0	2	3	2	3	0	0	0	**5**	**8**
Marketable	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	**1**	**2**
Variable	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
Adaptable	1	1	1	0	0	1	0	1	1	1	0	0	0	0	0	0	0	**0**	**0**
Research methods																			
Measurable outcomes	1	1	1	1	1	1	1	0	1	0	0	1	1	1	0	1	1	**4**	**19**
Randomised trial	1	1	0	1	1	0	0	0	0	0	0	1	1	1	0	0	0	**2**	**10**
Other factors excluded	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
Thorough use/training	0	0	1	0	0	0	1	0	0	0	0	1	1	0	0	1	1	**3**	**14**
Total study score	**11**	**10**	**12**	**11**	**11**	**10**	**6**	**6**	**10**	**5**	**2**	**14**	**13**	**13**	**2**	**6**	**8**		
Ttl approx. % of HPS*	**48**	**43**	**52**	**48**	**48**	**43**	**26**	**26**	**43**	**22**	**8.7**	**61**	**57**	**57**	**8.7**	**26**	**35**		

*Highest Possible Score

Regarding the weighted objectives and research methods across the field as a whole, most of the studies considered the needs of the user (for which scores were awarded to the user focus objective). None, however, achieved the full mark of 5 as none developed systems which could be adapted to the specific needs of a particular user. Many similarly achieved scores for being clinically effective and meaningful to the user, if in a very limited capacity. None of the studies reported on systems that were directly marketable to clinicians or variable to the changing requirements of the therapeutic process. Only some were deemed partially adaptable in the sense that the systems were tested among a disparate sample group, but none of these studies had successfully differentiated the impact of the system on the specific users. This transfer of basic operability might not however translate to effectiveness in other areas of clinical concern.

Most of the paper used measurable outcomes, whether clinical or statistical, but to various degrees of effectiveness and sometimes without rigorous analysis. Most of the sample populations were also satisfactory according to the parameters of the study (given that most were pilot studies, the samples tended to be small) but the researchers did not tend to require subjects to train to a sufficiently intensity to generate meaningful data. Only a few of the studies randomised their trials by including control groups and fewer still actively precluded or considered any extraneous factors which might have affected the outcomes.

Appendix 3 – Details of the User Study Interviewees

Presented below are further details of the interviewees regarding their backgrounds and levels of expertise. Observations are also provided regarding the circumstances in which the interviews were conducted.

Interview with OT3

OT3 is Senior 1 Occupational Therapist (Clinical Specialist in Cognitive Rehabilitation at [large metropolitan hospital]. OT3's patients are usually traumatic brain injury patients that tend to be younger, mostly 16-24 year-old males. There are often victims of road accidents and also assault (blows to the head and strangulation). For two days a week OT3 is also tasked with implementing the National Service Framework (NSF) for long-term care and has elected to evaluate and attempt to improve the care pathway as well as integrating the assessment process (one assessment, rather than many). OT3 is very much aware of policy trends and can reflect easily on negotiating the demands of government with good clinical practice.

The interview took place in OT3'a rather cluttered office. OT3 was having a quiet morning and talked openly about [his/her] broad clinical experience. OT3's tone is quiet and even-tempered and he/she paused occasionally to receive the next question.

Interview with NP1

NP1 is Senior Neuropsychologist at [national-level brain and spine injury hospital]. The interview was conduced in NP1'a assessment room, which fairly bare and windowless office. I sensed a certain caution as NP1 started the interview (perhaps due to lack of familiarity with the technology I had mentioned) but he/she soon relaxed and even offered a little more time from a busy schedule. NP1 is pursuing an MSc in Applied Neuropsychology (retrospective to his/her clinical experience for the purposes of career advancement).

Interview with PT2

PT2 is currently a Research Assistant/PhD candidate and a former Senior 1 Physiotherapist with around 6 years' professional experience in both community and post-brain injury acute rehabilitation, including at [national-level brain injury hospital]. I first met PT2 when giving a presentation about my research for the [Hospital] staff in April 2003.

The interview was conducted in the Orthoses Room of the [Hospital], surrounded by cardboard boxes jammed with all manner of prostheses and orthoses for upper and lower limbs. PT2 was talkative and able to expound on his/her own and others' experience of clinical practice, although his/her energy appeared to diminish a little half-way into the interview. PT2's experience is unusual in that for four years he/she worked as a Senior Phsyiotherapist at the [Hospital]'s Acute Brain Injury Unit in a highly integrated team (with an OT and speech therapist) and thus developed knowledge of his/her colleagues' perspectives and goals. PT2 is currently beginning the second year of a three-year PhD but is having on-going problems with the equipment being evaluating. Although this seemed to affect her attention a little during the interview, PT2 nevertheless provided a great deal of valuable information about his/her clinical experience.

Interview with Tech1

Tech1 is the [assistive technology group] Co-ordinator at [national-level neuro-disability hospital]. [Assistive technology group] is the Electronic Assistive Technology (EAT) Service at the [Hospital]. It is comprised of a multi-disciplinary team who provide assessment and provision of EAT equipment for patients and residents within the hospital, as well as for people with disabilities living in the community or at other hospitals or units. [Assistive technology group] is remarkably well serviced, with an engineering department capable of creating bespoke assistive technologies. The hospital has a national and international profile and is highly specialised. Patients have often arrived there after a fight with authorities for funding.

The interview took place in the hospital canteen. Tech1 was fairly forthcoming but his opinions weren't strongly held, except on matters of government policy. Although contact with clinical staff is part of [his/her] job, I sensed a certain distance or strain on those professional relationships, especially given a high turnover of therapists compared to the relative longevity of engineers and equipment administrators. I also met [Tech1's colleague] – unusually, a qualified assistive technology co-ordinator who seemed to share a similar sense of separateness to both the clinical staff and the IT department.

Interview with OT1

OT1 is Senior II Occupational Therapist at [large metropolitan hospital]. The Community Rehabilitation Team in which [he/she] works deals with a patient group experiencing a range of conditions and requirements in a densely populated metropolitan area that is remarkably disparate in terms of income, standard of living and even 'social standing'. Much of their work revolves around visiting patients at home. OT1 has been an OT for five years, having worked in a number of treatment centres across London and with all manner of patient groups. [He/she] is currently a Senior II OT and is shortly to take a 3-month career break[89].

[89] OT1 was invited back to work for the hospital upon his return, which he accepted

Having gained a distinction in a one-year graduate-level course in medical anthropology, OT1 is very able to reflect and expand upon [his/her] own role and is very aware of the broader institutional and social context of his professional activities. OT1 was having a quiet morning doing some admin. Although diligent, OT1 also regards [his/her] job with some humour. The interview was conducted in a small, fairly bare assessment room at the hospital, prior to a staff meeting at 12.30pm which OT1 was due to attend; I had also been invited to this to give a short presentation.

Interview with PT1

PT1 is Senior 1 Physiotherapist at the Acute Brain Injury Unit of the [national-level brain injury hospital]. The interview was conducted in the hospital staff café. In spite of PT1's insistence that she new little about VR he/she had remarkable insight into the advantages and disadvantages of its application to his/her field of work. The therapy staff at the [Hospital] work as a very integrated team and PT1 is highly aware of the needs of OTs and his/her clinical relationship to them, perhaps to an unusually high degree. PT1 is highly articulate able to reflect at length on his/her experience.

Interview with OT2

OT2 is Senior 1 Occupational Therapist for stroke rehabilitation at [metropolitan university hospital]. The interview was conducted on a bright and icy morning in a windowless ward office (boxes of files on the floor, work-related printouts on the notice board). For the two hours prior to the interview I had observed OT2 undertaking 'washing and dressing' assessments with two patients: a lengthy and apparently tiring process in which the rehabilitation method is embedded in an ADL. Throughout the observation I was noting the value of the therapist's skill and knowledge and how this might or might not be automated (see Part Two, below).

OT2 is also pursuing an MSc in Applied Neuropsychology and is thus more aware than many in this field of specialised practices. He/she was keen to talk about his/her clinical skills but not so much about use of equipment, and so on.

Appendix 4 – Special Considerations for Designing a VE System for Use by Children

A possible application for the use of VR in neurological rehabilitation is as a tool for the treating children with brain injury. This field is beyond the present area of study but an interview with two children's occupational therapists revealed details that highlight the very different ways in which they work with this patient population.

The OTs interviews deal with children with all manner of motor and cognitive impairments resulting from head injury or brain disease (commonly cerebral palsy, brain tumour, epilepsy, or young men involved in traffic accidents). Their task is often to support their patients as they engage in normal life at school or among friends. Many of their patients are also from disadvantaged backgrounds and they sometimes find that their clinical role offers a stabilising influence in their lives. This can cause problems where the clinical environment or the special school provides an enclosed environment which does not expose the patient to the normal 'rough and tumble' of life. It was maintained that working in community settings is highly beneficial to the recovery process.

There is a significant disparity in the age among their patients, with age groups being highly variegated in terms of their clinical or lifestyle needs. Particular clinical problems are sometimes associated with specific age-groups. Adolescents, for example, are sometimes too self-conscious to use the requisite equipment in public places such as in school. Infants are usually highly active but often inarticulate and this can pose a problem in focusing on their individual requirements, even in basic activities of daily life such as toileting.

Among every age group setting suitable rewards is a key means of motivation, often based on a preferred hobby (although use of computers is not encouraged as this does not employ the requisite range of motor skills). Hence cooking, gardening, crafts and model-making are suitable reward activities that can also be carried over into normal life. Children might also become stubborn about their own way of doing things, and this is something the therapists try to accommodate. Children's hobbies are occasionally beneficial to the recovery process but given the levels of disadvantage they often experience, their horizons and interests are often limited.

The OT interviewed who works with pre-school children maintained that VR would not be suitable for her patients as the key concern here is for them to work with normal life, rather than the sensory abstractions of the virtual environments; this is especially true of working with infants from disadvantaged backgrounds whose experience of normal life might be limited. Using a VR system might also not disclose problems the patient might be facing in normal life. VR interfaces are also deemed unsuitable for this age group.

Among adolescents there is some variation between the requirements of boys and girls (although patients are usually male among this age group). Firstly, girls and boys develop differently both physically and mentally. Girls seem to prefer sedentary activities, whereas boys tend towards sporting activities: trampolining is often utilised as a therapeutic activity as a means to achieve sensory integration, as an activity that all can enjoy and also as a sociable and cohesive activity that encourages mutual responsibility for maintaining safety. Cooking is enjoyed universally, which involves creating something (this embedding a range of skills) and achieving instant gratification, whether in providing a gift (as girls tend toward) or in eating (as boys usually prefer). The OTs interviewed maintained that this gratification is something a virtual environment could not deliver although they were open to the idea of a computer game that could aid recovery.

A key finding of this interview was in the fundamental difference between children's therapy and adults': children's is often organised in groups, whereas adults is usually one-to-one. Hence, while OTs try to match children in personality, children's groups are very mixed in terms of conditions and requirements, so as one child's strengths might complement another's deficit. This might also encourage social interaction, especially in preparation for the social life of adolescence.

Appendix 5 – Interview Transcript Referenced, Annotated and Summarised

Para.Ref	Area	Major themes	Emergent themes	Specific point
NP1.1.2	scene	Assessment of client	Care process is transitional	Therapy as trial and error process
NP1.1.2	scene	Client group	Age differences	Children to elderly
NP1.1.2	scene	Client group	Goals reflect client's abilities and needs	Strong difference intervention between learning disability and head injury
NP1.1.2	scene	Client group	Multi-disciplinary background	Client group split between mental health and head injury
NP1.1.2	scene	Therapeutic perspective	Goals reflect client's abilities and needs	Therapy is highly individualised
NP1.2.2	work	Assessment of client	Environment, therapeutic...	Environmental distractions removed for assessment
NP1.2.2	work	Client focus	Information provided to client	Information provided selectively to avoid overload
NP1.2.2	work	Environment, difficulties of...	Environment, inappropriate…	Environmental distractions led to poor attention
NP1.2.3	work	Client engagement	Environment, client's...	Regarding environmental details helps memory recovery in task performance
NP1.2.3	work	Client engagement	Goal-orientated behaviour	Client asked to speak the activities undertaken to engage all senses
NP1.2.3	work	Client focus	Overcoming client's resistance to therapy	Client must be assured even basic equipment should be used
NP1.2.3	E & I	Equipment provision, factors in…	Technology reflects clients' needs	Diaries used for ADLs in working memory
NP1.5.3	E & I	Knowledge of VR	Interface, problems of	Cognitive ability might affect understanding of equipment
NP1.5.3	E & I	Knowledge of VR	Technology reflects clients' needs	Cognitive ability must be assessed before VR is used
NP1.6.1	E & I	Knowledge of VR	Interface, appropriate to	Non-immersive VR might be more appropriate
NP1.6.2	E & I	Knowledge of VR	Technology reflects clients' needs	VR more appropriate to localised brain injury problems
NP1.7.1	work	Contact with clients	Technology reflects clients' needs	VR as an supplement to human contact
NP1.7.1	E & I	Knowledge of VR	Interface, appropriate to	VR can provide 'role model' for behaviour
NP1.7.2	E & I	Motivation, providers…	Interface, appropriate to	Sensory feedback provides reward system
NP1.7.3	E & I	Knowledge of VR	Interface, appropriate to	VR avatars offer 'stable' human interaction
NP1.7.4	E & I	Knowledge of VR	Interface, appropriate to	VR avatars offer 'controllable' human interaction
NP1.8.1	scene	Catchment	Level of expertise	National and international catchment
NP1.8.3	ICT	Provider use of ICT	Level of use	Heavy use of PC
NP1.9.1	ICT	Provider use of ICT	Range of use	Admin, etc. But also creating diagrams for clients
NP1.9.2	E & I	Client focus	Imagery and rehearsal	Diagrams reflect client's preference for task sequences
NP1.9.2	E & I	Therapeutic perspective	Imagery and rehearsal	Images as diagrams reduce cognitive overload in working memory
NP1.9.2	E & I	Therapeutic perspective	Imagery and rehearsal	Diagrams create pictographic reference for ADL performance in working memory
NP1.10.1	work	Client focus	Information provided to client	Information provided discretely to avoid overload in working memory
NP1.10.1	work	Contact with clients	Information provided to client	Communication delivered sequentially to avoid overload in working memory
NP1.10.3	E & I	Equipment provision, factors in…	Client's support network	Family members help client switch on mobile phone alarm as prompt
NP1.10.3	E & I	Equipment provision, factors in…	Interface, problems of	Mobile used for prompts but client not understanding how to turn on
NP1.11.1	ICT	Client use of ICT	Level of use	PCs very useful for clients with appropriate ability
NP1.11.1	ICT	Motivation, providers…	Client use of technology	PCs help attentions and motivation
NP1.11.1	ICT	Motivation, providers…	Client use of technology	PC prompts lead to better motivation
NP1.11.2	ICT	Client use of ICT	Age differences	Younger clients more likely to use PCs
NP1.11.2	ICT	Client use of ICT	Age differences	Older patients confused by PCs
NP1.11.3	work	Goal-setting	Client leads goal-setting	Internally generated' goals more powerful for motivation
OT1.1.1	scene	Routine	Little or no routine	Case-by-case
OT1.1.2	scene	Daily routine	Routines change throughout the day	Morning routines involve checking correspondence
OT1.2.1	scene	Caseload management	Dynamic caseload planning	12-18 clients; 2-5 home visits daily
OT1.2.1	scene	Caseload management	Geography can be a barrier to providing care	Visits are planned dynamically
OT1.2.2	scene	Catchment	Densely populated urban area	Urban area takes longer to traverse
OT1.2.4	scene	Caseload management	Densely populated urban area	Therapists reach clients by foot or bus
OT1.2.7	E & I	Equipment provision, means of	Therapist rarely carries equipment	Therapist occasionally carries item in a rucksack
OT1.3.1	E & I	Equipment provision, means of	Nature of items carried	Occasionally a stick carried by therapy assistant
OT1.3.1	E & I	Equipment provision, means of	Third party usually delivers equipment	Bulk is a problem for carriage
OT1.3.2	work	Rehab at home	Level of contact with client depends on assessment	Contact tends to be weekly unless a need for monitoring
OT1.3.2	scene	Weekly routine	Level of contact with client depends on assessment	Contact tends to be weekly unless a need for monitoring

Para.Ref	Area	Major themes	Emergent themes	Specific point
OT1.3.3	work	Rehab at home	Intervening in client problems	Rehab sometimes necessary after premature discharge
OT1.3.3	work	Rehab at home	Return to normality	Rehab addresses ADLs and daily routines
OT1.3.4	scene	Level of expertise	Knowledge of client	General knowledge of condition leads to forward planning
OT1.3.5	scene	Level of expertise	Environment, client's...	View that homes are not normally suited to client's needs
OT1.3.6	scene	Service integration	Environment, client's...	Client's support network regarded
OT1.3.6	scene	Service integration	Environment, client's...	Other services used by client are regarded
OT1.3.6	scene	Service integration	Knowledge of client	Carers supply information about home environment
OT1.3.6	scene	Service integration	Knowledge of client	Client's medical history regarded
OT1.4.1	scene	Client group	Long-term care	65%-75% in long-term care
OT1.4.1	scene	Client group	Time since leaving hospital	25%-35% recent hospital leavers
OT1.4.2	scene	Service integration	National Service Framework	Service remains fragmented
OT1.4.2	scene	Service integration	National Service Framework	Urgent need for service integration
OT1.4.3	scene	Service integration	Extended care network	GPs, hospital staff, therapists, social workers part of referral system
OT1.4.4	scene	Client engagement	Extended care network	Client often has carer who provides much of support
OT1.4.4	scene	Client engagement	Home rehab is cooperative	Client might be vulnerable/frail but permission still necessary
OT1.4.5	scene	Client group	Many clients are stroke victims	Fewer clients are head-injury
OT1.5.1	E & I	Equipment provision, means of	Third party usually delivers equipment	Third party stores equipment in warehouse
OT1.5.3	E & I	Equipment provision, factors in…	Therapist must ensure risk minimisation	Client often expected to use equipment independently
OT1.5.3	E & I	Equipment provision, factors in…	Time and expertise are factors in installing equipment	Usually simple and quick to install
OT1.5.3	E & I	Equipment provision, means of	Client's preferences	Client's body measurements taken for adaptations
OT1.5.3	E & I	Equipment provision, range of…	Environment, client's…	Domestic adaptations, the sofa-raise
OT1.5.6	E & I	Equipment provision, factors in…	Time, expertise and helpfulness are factors	Usually simple and quick to install
OT1.5.6	E & I	Equipment provision, range of…	Environment, client's…	Domestic adaptations, bath board
OT1.5.6	E & I	Equipment provision, range of…	Environment, client's…	Domestic adaptations, the bed lever
OT1.5.6	E & I	Equipment provision, range of…	Environment, client's…	Domestic adaptations, toilet transfer frame
OT1.5.6	E & I	Limitations of resources	Cost of equipment	Specialised adaptations cost around £500
OT1.5.6	work	Rehab at home	Equipment use as an ADL	Equipment installation involves a full ADL assessment
OT1.5.6	work	Rehab at home	Interface, appropriate to…	Simple equipment maximises existing function
OT1.6.1	work	Client engagement	Client use of equipment	Clients encouraged to make decision about equipment
OT1.6.1	work	Client engagement	Client use of equipment	Clients encouraged to use equipment as means of engagement
OT1.6.1	work	Client engagement	Interface, appropriate to…	Simple equipment maximises existing function
OT1.6.2	work	Client engagement	Client use of equipment	Client training is brief
OT1.6.2	E & I	Equipment provision, means of	Client use of equipment	Basics need to be explained; eg, battery recharging, etc
OT1.6.2	E & I	Equipment provision, means of	Client use of equipment	Equipment installation depends on client feedback
OT1.6.3	work	Equipment provision, means of	Client's support network	Family is enlisted to help in equipment use
OT1.7.2	work	Equipment provision, means of	Client's support network	Social services enlisted to help in equipment use
OT1.7.3	work	Client engagement	Client choice, extent of	Direct Payments are made to client from Dept of Health
OT1.7.3	work	Client engagement	Client choice, limits of	Choice of provider is made from an approved catalogue
OT1.7.3	scene	Client group	Client group is disparate	Social disparity impacts on care provision
OT1.7.3	scene	Client group	Wealth disparity	Wealthy clients employ 24-hour carers
OT1.7.3	work	Goal-setting	Client use of equipment	Equipment choice and use is a way of engaging the client
OT1.7.7	work	Client engagement	Client choice, extent of	Equipment choice and use is a way of avoiding passivity
OT1.7.7	E & I	Client engagement	Client choice, limits of	Client choice does not extend to equipment
OT1.7.7	E & I	Client engagement	Client choice, limits of	Equipment choice is made from a stock catalogue
OT1.7.7	E & I	Client engagement	Client preferences are considered	Client's point of view is established when choosing equipment
OT1.7.7	E & I	Client engagement	Extended care network	Other people are consulted in the equipment choosing process
OT1.7.7	E & I	Client engagement	Networks for information, informal	Client's friends sometimes recommend equipment
OT1.7.7	E & I	Equipment provision, factors in…	Waiting list for major adaptations	Waiting list for new showers
OT1.7.7	E & I	Equipment provision, means of	Client choice, limits of	Care provider makes final decision
OT1.7.7	E & I	Equipment provision, means of	Client choice, limits of	Choice sometimes over budget or not necessary
OT1.7.7	E & I	Equipment provision, means of	Client choice, limits of	Client's choice not always good
OT1.8.1	scene	Client group	Social disparity affects care provision	Major adaptations are means tested
OT1.8.1	scene	Equipment provision, factors in…	Complexity of community rehab	Need for equipment authorisation causes delay

Para.Ref	Area	Major themes	Emergent themes	Specific point
OT1.8.1	scene	Equipment provision, factors in…	Complexity of community rehab	Social services involved and client means tested
OT1.8.3	E & I	Equipment provision, factors in…	Perception of expensiveness	£3000-4000+ considered especially expensive
OT1.9.1	E & I	Equipment provision, factors in…	Bureaucracy, problems of…	Items costing more than £1k cause bureaucratic complexity
OT1.9.1	E & I	Equipment provision, factors in…	Variation of workplace cultures	In some workplaces, items costing £20 need authorization
OT1.9.2	E & I	Equipment provision, factors in…	Bureaucracy, problems of…	Equipment can cause duplication of work as social services are involved
OT1.9.3	work	Client engagement	Changing attitudes to clients, long term	NHS staff often uncomfortable with client involvement
OT1.9.3	scene	Client engagement	Changing attitudes to clients	Service is intended to be transparent
OT1.9.3	scene	Client engagement	Changing attitudes to clients	There is friction between pressure groups and therapy staff in this issue
OT1.9.3	work	Client engagement	Client choice, limits of	Conflict of perspectives between social and care services
OT1.9.3	E & I	Equipment provision, factors in…	Bureaucracy, problems of…	Conflict of perspectives between social and care services regarding client choice
OT1.9.5	ICT	Provider use of ICT	Level of use	Regular use of ICT
OT1.9.6	ICT	Provider use of ICT	Range of use	Admin, correspondence, sourcing information, knowledge of clients, client management
OT1.9.6	ICT	Provider use of ICT	Range of use	Internet used for info about services, clinical issues
OT1.10.2	ICT	Provider use of ICT	Level of use	ICT as a substitute for traditional data searching and storing methods
OT1.10.2	ICT	Provider use of ICT	Level of use	ICT provided more efficient data search and store
OT1.10.2	ICT	Provider use of ICT	Range of use	Internet provides info of variable quality
OT1.10.3	ICT	Provider use of ICT	Level of use	Therapist has access to closed, specialised db's
OT1.10.4	ICT	Client use of ICT	Range of use	Client encourage to source info from charity sites
OT1.10.4	ICT	Provider use of ICT	Level of use	Charity sites provide rich, reliable information
OT1.10.7	E & I	ICT in care provision	General overview	Electronic notes available to all authorized staff in the borough
OT1.10.7	ICT	ICT in care provision	General overview	Electronic notes available to all authorized staff in the borough
OT1.10.7	scene	ICT in care provision	General overview	Strong trend toward using ICT in last five years
OT1.10.8	ICT	ICT in care provision	Range of use	Daily Events (?) is a log of client progress available to therapists only
OT1.11.2	ICT	ICT in care provision	ICT for management	Email is main means of communication between providers
OT1.11.2	ICT	ICT in care provision	ICT for management	Email is means for information dissemination
OT1.11.3	ICT	ICT in care provision	ICT for management	Email is not always a good means of communication
OT1.11.3	ICT	ICT in care provision	ICT for management	Rise is email use results from ubiquity of PC use
OT1.11.4	ICT	Client use of ICT	Client knowledge is variable	Client only occasionally sources info independently
OT1.11.5	work	Client engagement	Client sources information	Client responds to print media sensationalising of some medical treatments
OT1.11.5	scene	Client engagement, problems of	Client sources information	Print media can have a persuasive influence on client
OT1.12.1	scene	Client engagement	Client sources information	Client use of internet might affect care provision in unforeseen ways
OT1.12.2	work	Client use of ICT	Range of use	Clients unlikely to use PCs
OT1.12.3	work	Client use of ICT	Range of use	Younger clients might use PC for hobbies
OT1.12.4	work	Client use of ICT	Range of use	It is unknown for clients to have sourced info about their condition using the internet
OT1.12.4	work	Client use of ICT	Range of use	PC use for hobbies can be meaningful activity
OT1.12.6	work	Client use of ICT	Level of use	Access to information is important for client
OT1.12.6	work	Client use of ICT	Level of use	Importance of access to information is not always recognised
OT1.13.2	work	Client engagement	Care process is transitional	Client needs to make transition from medical to rehab model
OT1.13.2	scene	Client engagement	Rehabilitation and medicine	Client needs to make transition from medical to rehab model
OT1.13.2	work	Client focus	Environment, client's...	Client and therapist assess client's environment
OT1.13.2	work	Client focus	Intervening in client problems	Client needs to be won over to the 'rehab way of thinking'
OT1.13.2	work	Rehab at home	Intervening in client problems	Client often has poor ability to perform ADLs
OT1.13.2	work	Rehab at home	Intervening in client problems	Client often has poor understanding his/her own problems
OT1.13.2	work	Rehab at home	Intervening in client problems	Client often has poor understanding of care process
OT1.13.3	work	Client engagement	Client use of equipment	Client is engaged in equipment choice
OT1.13.3	work	Client engagement	Intervening in client problems	Client and therapist assess client's functional problems
OT1.13.3	work	Client engagement	Transition towards independence	Client encouraged to continue activities between therapist visits
OT1.13.3	E & I	Equipment provision, factors in…	Client use of equipment	Client is engaged in equipment choice
OT1.14.2	work	Client focus	Transition towards independence	Dependence is avoided
OT1.14.4	scene	Client engagement, problems of	Care process is transitional	Rehab way of thinking' not easy to achieve
OT1.14.5	scene	Client engagement, problems of	Care process is transitional	Clients can be resistant to rehab care
OT1.14.6	scene	Client engagement, problems of	Communication with client, problems of	Resistance to rehab might extend cognitive problems
OT1.14.6	scene	Client engagement, problems of	Communication with client, problems of	Resistance to rehab might extend from poor communication with the client

Para.Ref	Area	Major themes	Emergent themes	Specific point
OT1.14.7	work	Client focus	Care process is transitional	Client's confidence is won over through several home visits
OT1.15.1	work	Client focus	Care process is transitional	Client is encouraged to reflect on their needs
OT1.15.2	scene	Client engagement, problems of	Role has limited scope	OT cannot overturn client's resistance to rehab
OT1.15.3	scene	Client engagement, problems of	Role has limited scope	OT avoids risk of injury to self or client
OT1.15.5	E & I	Equipment provision, factors in…	Client use of equipment	Complex equipment leads to delay in break-off point for rehab
OT1.16.1	work	Equipment provision, factors in…	Client use of equipment	Rehab break-off point is dependent on client's own goals
OT2.1.2	scene	Definition of therapy	Difference between acute and chronic	Acute is an unstable stage, chronic as therapy-led
OT2.1.5	scene	Definition of therapy	Normal movement	CNS operates patterns of movements
OT2.1.6	scene	Client engagement	Therapy as a dynamic process	Affected limbs are used for weight-bearing
OT2.1.6	scene	Definition of therapy	Rehab as a 'hands-on' process	Client's limbs directly manipulated
OT2.1.6	scene	Goal-setting	Normal movement	Normal movement as a therapeutic goal
OT2.1.6	scene	Goal-setting	Normal movement	Analysis of muscles leads to goal-setting
OT2.1.6	scene	Goal-setting	Therapy embedded in ADLs	Functional task as a goal
OT2.1.6	scene	Knowledge of client	General knowledge of condition leads to forward planning	Therapy scheme based on client record
OT2.1.6	scene	Limitations of resources	Limitations of staffing resources	Full therapy not possible due to staff shortage
OT2.1.6	scene	Task performance	Normal movement	Complex movements embedded in the CNS
OT2.1.6	scene	Task performance	Therapy embedded in ADLs	Functional task as a goal
OT2.3.1	scene	Client focus	Body parts reflect different task requirements	OTs focus on upper limb as means of performing meaningful tasks
OT2.3.1	work	Task performance	Goal-orientated behaviour	Goals need not be meaningful
OT2.3.1	work	Task performance	Meaningful behaviour	Meaningful behaviour need not have a goal
OT2.3.1	work	Task performance	Optimal therapeutic intervention	Intervention must be both goal-directed and meaningful to the patient
OT2.3.2	work	Client engagement	Goal-orientated behaviour	Goals lead to fuller engagement at the cortical level
OT2.3.3	work	Client engagement, problems of…	Client continues therapeutic activities	Limited number of clients do this
OT2.3.3	work	Client focus	Complexity of movement	Therapy embedded in ADLs
OT2.3.3	E & I	Client focus	Equipment reflects clients needs and abilities	Tubiso allows therapist to create bespoke adaptations
OT2.3.3	work	Initiation, problems of…	Client continues therapeutic activities	Limitation of contact with client leads to tasks not being continued
OT2.3.3	work	Initiation, problems of…	Client continues therapeutic activities	Problems resulting from stroke lead to poor initiation of tasks
OT2.3.3	work	Limitations of time	Client continues therapeutic activities	Limitation of contact with client leads to tasks not being continued
OT2.4.1	E & I	Limitations of resources	Cutlery adaptations considered expensive	Tubiso cheap and appropriate means of adapting cutlery
OT2.4.2	work	Client engagement	Client continues therapeutic activities	Client-led organisation of activities as therapeutic process
OT2.4.2	work	Client engagement	Client continues therapeutic activities	Clients organisation of activities leads to maximised outcomes
OT2.4.2	scene	Clinical outcomes, factors in…	Social disparity	Education leads to goal-orientated behaviour
OT2.4.3	work	Client engagement, problems of…	Client continues therapeutic activities	Density of stroke affects client's engagement
OT2.5.2	work	Client focus	Goals reflect client's abilities and needs	Therapist gauges client's goals; here ADLs
OT2.5.2	work	Client focus	Goals reflect client's abilities and needs	Therapist gauges client's goals; here dignity independence self-regard
OT2.5.2	scene	Limitations of time	Clients don't receive adequate intervention	Goal-planning limited by therapy time
OT2.5.3	scene	Caseload management	Limitations of staffing resources	Backlogs lead to limited time for clients
OT2.5.3	scene	Clinical outcomes, problems of…	Value of early intervention	Prolonged intervention leads to poorer recovery
OT2.5.3	scene	Contact with clients	Clients don't receive adequate intervention	OT only sees patients for half the necessary time
OT2.5.3	work	Goal-setting	Therapy as a dynamic process	Goals are adjusted as client recovers
OT2.5.3	scene	Limitations of resources	Limitations of staffing resources	Limited staffing leads to poor clinical outcome
OT2.5.3	work	Service integration, problems of…	Client is fragmented by therapeutic perspectives	OTs and physios have very different ways of working
OT2.5.3	work	Service integration, problems of…	Client is fragmented by therapeutic perspectives	Physios have narrow clinical focus
OT2.5.3	work	Task performance	Value of repetition	Evidence from neuropsychology points to value of repetition to outcomes
OT2.5.8	scene	Clinical outcomes, problems of…	Environment, optimal therapeutic...	Rehab environment should be homely
OT2.6.2	work	Client engagement, problems of…	Environment, inappropriate…	Medical environment promotes passivity to care process
OT2.6.2	work	Client engagement, problems of…	Environment, inappropriate…	Medical environment does not promote positive feeling in client
OT2.6.2	scene	Clinical outcomes, problems of…	Environment, inappropriate…	Medical environment promotes feeling of illness
OT2.6.3	scene	Clinical outcomes, problems of…	Environment, optimal therapeutic...	Rehab environment should be away from medical area
OT2.6.4	E & I	Sufficiency of resources	Resources are sufficient	Therapist requires only basic equipment
OT2.6.7	E & I	Equipment provision, factors in…	Wealth disparity	Wealthier areas have better equipment provision
OT2.6.8	scene	Limitations of resources	Environment, inappropriate…	Rehab wing was sold, rehab now carried out it old medical ward
OT2.7.4	E & I	Knowledge of VR	Mixed response to VR	Engineers do not always identify the clinically important results of their work

Para.Ref	Area	Major themes	Emergent themes	Specific point
OT2.8.1	work	Goal-setting	Environment, optimal therapeutic...	Environments affect goal-orientated behaviour
OT2.8.1	work	Motivation, means of…	Environment, optimal therapeutic...	Environments affect motivation
OT2.8.2	work	Goal-setting	Goals reflect client's abilities and needs	Goal-setting is a discrete, refinable skill
OT2.8.3	work	Goal-setting	Care process is transitional	Functional goals become more refines as client recovers
OT2.8.3	work	Goal-setting	Therapy as a dynamic process	Need for reassessment as the client recovers
OT2.8.4	work	Clinical outcomes, factors in…	Client must be challenged by rehab	Client must get out of 'comfort zone'
OT2.8.4	work	Service integration, problems of…	Meaningful behaviour	Some OTs do copy physio methods and disregard 'meaningful' activity
OT2.8.4	ICT	Service integration, problems of…	Rehab as a 'hands-on' process	Distinction between therapy perspectives
OT2.8.4	scene	Weekly routine	Therapy as a dynamic process	Treatment plans reviewed weekly
OT2.9.1	scene	Engaging the client	Problems can be compounded	Attention, memory and disexecutive function lead to problems in therapeutic activities
OT2.9.1	scene	Level of expertise	Knowledge of client	Treatment brings knowledge dynamically to the fore
OT2.9.1	scene	Level of expertise	Optimal therapeutic intervention	OT requires knowledge of muscles and brain
OT2.9.1	scene	Level of expertise	Optimal therapeutic intervention	OT should study continually
OT2.9.2	work	Client engagement, problems of…	Therapy as a dynamic process	Client's behaviour can be very unpredictable
OT2.9.2	scene	Level of expertise	Rehab as a 'hands-on' process	Textbooks do not reflect reality of clinical work
OT3.1.1	scene	Level of expertise	Broad range of experience	Clinical specialist and assessing cleint pathways; experience in TBI, cog. and behav.
OT3.1.2	scene	Level of expertise	Unusual type of work	OT for working memory, cognitive function in ADLs
OT3.1.3	scene	Nature of duties	Rehab in community	Exposes clients to workplaces, libraries home, etc
OT3.1.4	work	Client engagement	Environments, public...	Therapist takes client to community settings, eg library
OT3.1.4	E & I	ICT as a meaningful activity	Environments, public...	PCs in library offer meaning full activity
OT3.1.4	ICT	ICT as a meaningful activity	Technology reflects clients' needs	Outlook diary provided to and developed by client
OT3.1.4	ICT	ICT as a therapeutic tool	Technology reflects clients' needs	Outlook diary provided to and developed by client
OT3.1.4	work	Task performance	Environments, public...	Therapist takes client to community settings, eg library
OT3.2.1	ICT	Goal-setting	Technology reflects clients' needs	Outlook helps working memory recovery
OT3.2.1	work	Goal-setting	Technology reflects clients' needs	Outlook helps working memory recovery
OT3.2.1	E & I	Goal-setting	Technology reflects clients' needs	PC use help in return to work
OT3.2.3	scene	Impact of injury	Client leads goal-setting	Client must reassess lifestyle and come to terms with condition
OT3.2.4	scene	Impact of injury	Care process is transitional	Client frustrated by slow progress
OT3.2.5	scene	Impact of injury	Care process is transitional	Client must acknowledge limitations
OT3.2.5	scene	Impact of injury	Client knowledge of condition	Client often don't recognise their own problems
OT3.2.6	scene	Client group	Age range	Mid-twenties TBI
OT3.2.7	scene	Client group	Causes of injury	Road accidents, assault, drugs, sports
OT3.3.1	scene	Client group	Gender differences	Mostly males
OT3.3.2	work	Client group	Gender differences	Men face major, single, career problems
OT3.3.2	work	Client group	Gender differences	Men find taking simpler job a problem
OT3.3.2	work	Client group	Gender differences	Women more used to juggling roles
OT3.3.3	work	Client group	Gender differences	Men's' greater wish return to normal sex life
OT3.3.3	work	Client group	Gender differences	Men's' greater wish return to normal work life
OT3.3.4	work	Goal-setting	Rehab in community	Gym, library and shops used for rehab setting
OT3.3.4	work	Goal-setting	Way-finding	Routes to community settings relearned
OT3.3.6	work	Goal-setting	Client leads goal-setting	Client selects goals as motivating activity
OT3.3.6	work	Goal-setting	Client leads goal-setting	Way-finding as a client-led activity
OT3.3.6	work	Goal-setting	Environment, client's…	Way-finding as a client-led activity
OT3.3.6	work	Goal-setting	Problems of goal-setting	Way-finding requires monitoring
OT3.3.6	work	Impact of injury	Initiation, problems of…	Frontal lobe damage causes problems with initiation
OT3.3.6	work	Impact of injury	Motivation, problems of…	Frontal lobe damage causes problems with motivation
OT3.4.1	scene	Client group	Client's support network	Clients often have no daytime support
OT3.4.1	work	Goal-setting	Client's support network	Friends and family are used in way-finding where possible
OT3.4.3	scene	Client group	Environment, client's...	Clients are usually out and about
OT3.4.4	work	Goal-setting, problems of…	Care process is transitional	Client must acknowledge limitations
OT3.4.4	work	Goal-setting, problems of…	Client's fear of failure	Problems with way-finding and stamina lead to loss of confidence in driving
OT3.4.6	scene	Client group	Client group is disparate	High wealth disparity
OT3.4.6	scene	Client group	Environment, client's...	Poorer clients often have transient lifestyle

Para.Ref	Area	Major themes	Emergent themes	Specific point
OT3.4.6	scene	Client group	Environment, client's...	Poorer clients often in infested accommodation
OT3.4.6	work	Client group	Wealth disparity	Poorer clients often have transient lifestyle
OT3.4.6	work	Client group	Wealth disparity	Poorer clients often in infested accommodation
OT3.4.6	work	Clinical outcomes, factors in…	Wealth disparity	Wealth affects abilities, expectations and goals
OT3.5.1	work	Clinical outcomes, factors in…	Pre-morbidity factors	Education and intellect impacts on client's goals
OT3.5.1	work	Goal-setting, problems of…	Client leads goal-setting	Cognitive impairment leads to risky goals
OT3.5.1	work	Goal-setting, problems of…	Client leads goal-setting	Highly risky goals for wheelchair navigation
OT3.5.1	work	Goal-setting, problems of…	Pre-morbidity factors	Client's character prior to injury affects behaviour
OT3.5.2	work	Impact of injury	Pre-morbidity factors	Inner self is intact but injury leads affects performance/presentation
OT3.5.3	work	Goal-setting	Pre-morbidity factors	Career-minded people respond better to rehab
OT3.5.3	work	Goal-setting	Pre-morbidity factors	Goal-driven clients respond better to rehab
OT3.5.3	work	Goal-setting	Wealth disparity	Affluent background leads to goal orientated behaviour
OT3.6.1	work	Client group	Age differences	Younger clients stronger to use equipment
OT3.6.1	E & I	Equipment provision, factors in…	Differing requirements of cognitive and physical therapy	Small kitchen equipment sometimes used
OT3.6.1	E & I	Equipment provision, factors in…	Differing requirements of cognitive and physical therapy	TBI clients usually require cog treatment, opposed to physical
OT3.6.1	E & I	Equipment provision, factors in…	Technology reflects clients' needs	Client must retrain in diary use
OT3.6.1	E & I	Equipment provision, factors in…	Technology reflects clients' needs	Filofaxes, etc, used for working memory
OT3.6.1	E & I	Equipment provision, factors in…	Technology reflects clients' needs	Talking watch used for visual impairment
OT3.6.3	ICT	Task performance	Remote monitoring	NeuroPage prompts client to perform tasks
OT3.6.4	E & I	Task performance	Remote monitoring	Simple medicine boxes offer remote monitoring
OT3.6.5	E & I	Equipment provision, factors in…	Funding	Remote monitoring service funded from variety of sources
OT3.6.6	E & I	Equipment provision, factors in…	Funding	Provider must make a case for specialised equipment/service
OT3.6.7	E & I	Equipment provision, factors in…	Funding	Equipment can alleviate costs for extra care, etc
OT3.6.7	E & I	Equipment provision, problems in…	Funding	Social services can be cost-conscious in the extreme
OT3.7.2	scene	Complexity of service	Bureaucracy, problems of…	Poor communication between therapists and social services
OT3.7.2	scene	Service integration, problems of…	Client is fragmented by services	Need for social-health integration
OT3.7.2	scene	Service integration, problems of…	Client is fragmented by services	Social services and therapists only regard area of patient of interest to them
OT3.7.3	scene	Service integration	Desire for integration	Social workers sometimes funded for client discharge, leads to efficient transfer
OT3.7.3	scene	Service integration	Networks for organisation, informal	Social-health integrated through informal networks
OT3.7.3	scene	Service integration	Staff turnover affects integration	Longevity leads to better social-health integration through informal networks
OT3.8.1	scene	Service integration	National Service Framework	Problem of creating standards
OT3.8.2	scene	Service integration	National Service Framework	Creating single assessment
OT3.8.4	scene	Problems of diagnosis	Support network's knowledge of condition	Client's prevalent behaviour disguises clinical problems
OT3.9.1	scene	Service integration	Environment, client's...	Overcome problems of integration, duplication and timing for sudden and progressive conditions, in spite of change to environment through the care journey
OT3.9.1	scene	Service integration	National Service Framework	Overcome problems of integration, duplication and timing for sudden and progressive conditions, in spite of change to environment through the care journey
OT3.9.2	work	Contact with clients	Positive response to VR	VR appropriate as a means of remote observation
OT3.9.2	E & I	Knowledge of VR	Positive response to VR	VR appropriate as a means of remote observation
OT3.9.3	ICT	Contact with clients	Remote monitoring	ICT technology maximises contact time
OT3.9.3	work	Contact with clients	Remote monitoring	Technology maximises contact time
OT3.9.3	work	ICT as a therapeutic tool	Client preferences are considered	PDA diary used for working memory rehab
OT3.9.3	ICT	ICT as a therapeutic tool	Interface, appropriate to	PDA diary used for working memory rehab
OT3.10.2	E & I	Knowledge of VR	Environment, virtual models of...	Example of Easy Street
OT3.10.5	E & I	Knowledge of VR	Positive response to VR	VR for modelling street environments particularly useful
OT3.10.6	E & I	Knowledge of VR	Positive response to VR	VR environmental variability very useful
OT3.10.7	E & I	Knowledge of innovation	Ideas for innovations	Remote monitoring delivered through mobile phones
OT3.11.5	scene	Level of expertise	Comparative experience	Reliance on car in USA creates access problems
OT3.11.6	scene	Level of expertise	Comparative experience	Private insurance leads to more specialised medic-phsyio intervention in USA
OT3.11.7	scene	Level of expertise	Comparative experience	Private insurance leads to less rehab-phsyio intervention in USA, very few home visits
OT3.12.1	scene	Level of expertise	Comparative experience	USA has more medicalised model of health provision
OT3.12.2	ICT	Problems of diagnosis	Remote monitoring	NHS Direct misdiagnosed symptoms
OT3.12.3	ICT	ICT in care provision	Inappropriate use of technology	NHS Direct misdiagnosed symptoms
OT3.13.2	E & I	ICT in care provision	Ideas for innovations	Technology could replace dogs as alerts to seizures
OT3.13.4	scene	Caseload	National Service Framework for Long-Term Care	Government seeking to keep clients in the community

Para.Ref	Area	Major themes	Emergent themes	Specific point
OT3.13.4	E & I	Contact with client	National Service Framework for Long-Term Care	Technology can help elderly maintain contact
OT3.13.4	ICT	ICT in care provision	National Service Framework for Long-Term Care	Technology can help elderly maintain contact
OT3.13.4	work	Service integration	National Service Framework for Long-Term Care	Technology can help elderly maintain contact
OT3.13.5	work	Client engagement	Client preferences are considered	Outlook used to coordinate visits with client
OT3.13.5	ICT	ICT as a therapeutic tool	Client preferences are considered	Outlook for organisation and memory training
OT3.13.5	ICT	ICT as a therapeutic tool	Client preferences are considered	PC used for return to work training
OT3.13.5	ICT	ICT in care provision	ICT for management	Outlook used to coordinate visits with client
OT3.14.1	ICT	ICT in care provision	ICT for management	Patient database used
OT3.14.2	scene	Level of expertise	Comparative experience	USA: money management training and monitoring systems used
OT3.14.3	E & I	Equipment provision, problems in…	Inappropriate use of equipment	Client using equipment does not equate with successful use
OT3.14.3	E & I	Equipment provision, problems in…	Inappropriate use of equipment	Inappropriate use might lead to error learning; common problem
OT3.14.3	ICT	ICT as a therapeutic tool	Therapy as a dynamic process	System is adjusted as time and performance is improved
OT3.15.1	E & I	Equipment provision, factors in…	Errorless learning	Equipment use must avoid learning errors
OT3.15.1	ICT	ICT as a therapeutic tool	Ideas for innovations	PCs used for errorless way-finding training
OT3.15.1	ICT	ICT as a therapeutic tool	Remote monitoring	PCs could promote errorless training
OT3.15.2	E & I	Knowledge of VR	Mixed response to VR	VR as an adjunct to real street training
OT3.15.2	E & I	Knowledge of VR	Mixed response to VR	Full and spontaneous environmental conditions of street would be needed
OT3.15.3	E & I	Knowledge of VR	Interface, problems of	HMD could cause claustrophobia
OT3.16.1	E & I	Knowledge of VR	Mixed response to VR	
OT3.16.2	E & I	Assessment of equipment	Mixed response to VR	Wish to test equipment before using with client
OT3.16.2	E & I	Knowledge of VR	Interface, problems of	Dataglove not appropriate where brain injury has impaired perception
OT3.16.2	E & I	Knowledge of VR	Interface, problems of	Dataglove not appropriate where brain injury has impaired sensation
PT1.1.3	E & I	Evaluation of VR	Negative responses to VR	Rutgers Ankle does not provide a functional task
PT1.1.3	E & I	Knowledge of VR	Interface, problems of…	Rutgers Ankle not an appropriate interface for task performance
PT1.1.3	E & I	Knowledge of VR	Mixed response to VR	Simulation of client's home might have value
PT1.1.3	E & I	Knowledge of VR	Mixed response to VR	VR providing mental imagery might have value
PT1.1.3	E & I	Knowledge of VR	Mixed response to VR	Rutgers Ankle provides functional goal
PT1.1.3	E & I	Knowledge of VR	Negative reposes to VR	Not relevant to area of work, after seeing Rutgers Ankle
PT1.1.4	scene	Daily routine	Routine reflects rhythm of rehab	Handover in the morning, clinical work rest of day
PT1.1.4	scene	Routine	Rehab in ward	Early-stage stroke rehab conducted at bedside
PT1.1.4	scene	Service integration	Role has limited scope	Physio works with OT for ADL rehab
PT1.1.4	scene	Weekly routine	Routine reflects rhythm of rehab	Some days ward-based, some days gym
PT1.2.1	work	Assessment of client	Pre-morbidity factors	Client's pre-morbid condition acknowledged
PT1.2.1	work	Client group	Age differences	Broad range of ages (30-85 years old)
PT1.2.1	work	Therapeutic perspective	Physio has analytical attitude to motor function	Strength, balance, coord, sensation, fibular work, arm, leg, trunk
PT1.2.2	work	Client engagement	Goals reflect client's abilities and needs	Meaningful goals promotes engagement and recovery
PT1.2.2	work	Client focus	Client leads goal-setting	Physio rehabilitates motor function as OT retrains ADLs
PT1.3.1	work	Service integration	Multi-disciplinary teams	Rarity of this; treatment centre integrated to a high degree
PT1.3.2	work	Client focus	Changing attitudes to clients	Traditionally the client had been passive to treatment
PT1.3.2	work	Service integration	Multi-disciplinary teams	Nurses observe therapist in washing to promote client participation
PT1.3.3	work	Client focus	Range of client activities	Examples of all activities provides
PT1.3.4	work	Client focus	Environment, limitations of hospital...	Hospital environment is very difficult to return home training
PT1.4.1	E & I	Knowledge of VR	Mixed response to VR	VR provides return home training, but sensory feedback is limited
PT1.4.1	work	Problem of transfer	Environment, client's...	OT provides overview of client's home prior to return
PT1.4.1	work	Problem of transfer	Environment, limitations of hospital...	Layout of hospital is not like client's home
PT1.4.1	work	Problem of transfer	Imagery and rehearsal	VR might provide means client's to imagine being at home; value of imagery
PT1.4.3	work	Client engagement	Imagery and rehearsal	Actively imagining movement might promote recovery
PT1.4.3	work	Client engagement	Imagery and rehearsal	Actively imagining movement might promote ADL performance
PT1.4.4	E & I	Evaluation of VR	Mixed response to VR	VR useful if client has sufficient physical ability
PT1.4.4	E & I	Evaluation of VR	Positive response to VR	VR valuable as a movement rehearsal tool
PT1.5.1	work	Client focus	Return to normality	Therapy as means to restore functions to normal life
PT1.5.1	E & I	Evaluation of VR	Negative reposes to VR	Lack of appropriate sensory feedback leads to undynamic retraining
PT1.5.1	E & I	Evaluation of VR	Negative reposes to VR	VR lack of sensory feedback especially unsuited to neuro conditions

Para.Ref	Area	Major themes	Emergent themes	Specific point
PT1.5.1	E & I	Evaluation of VR	Positive response to VR	Physio foot exercises with purposeful goal of steering plane
PT1.5.1	E & I	Knowledge of VR	Negative reposes to VR	Rutgers Ankle can't provide a means to achieve functional integration
PT1.5.1	E & I	Knowledge of VR	Positive response to VR	Rutgers Ankle provides a way of training space perception
PT1.5.1	E & I	Knowledge of VR	Positive response to VR	VR provides a way of abstracting functional abilities for training
PT1.5.1	E & I	Knowledge of VR	Positive response to VR	VR as adjunct to exercise
PT1.6.1	work	Contact with client	Rehab as a 'hands-on' process	Physical contact with client important in early stages for assessment
PT1.6.1	E & I	Evaluation of VR	Negative reposes to VR	VR does not allow physical contact assessment
PT1.6.1	E & I	Knowledge of VR	Mixed response to VR	VR regarded as a hands-off intervention
PT1.6.1	work	Therapeutic perspective	Rehab as a 'hands-on' process	Physio hands-on, VR as hands-off process
PT1.6.2	E & I	Evaluation of VR	Negative reposes to VR	VR can never replace therapist
PT1.6.3	E & I	Evaluation of VR	Negative reposes to VR	Abstraction in VR tasks is not helpful
PT1.6.3	E & I	Evaluation of VR	Positive response to VR	VR provides means to perform purposeful tasks
PT1.6.3	E & I	Knowledge of VR	Mixed response to VR	VR might have value in restoring motor function 10-15 years after stroke
PT1.6.3	work	Knowledge of VR	Normal movement	VR might help restore normal movement 10-15 years after stroke
PT1.6.3	work	Knowledge of VR	Rehab as a 'hands-on' process	VR as a hands-off tool for restoration of normal movement 10-15 years after stroke
PT1.7.4	scene	Routine	Care process is transitional	Patients soon move to other centre or home
PT1.7.5	scene	Client group	Age difference	Younger patients less co-morbidity
PT1.7.5	scene	Client group	Recovery, factors in…	Density of stroke affects time for recovery
PT1.8.1	scene	Client group	Age difference	Access to work more a concern among younger clients
PT1.8.1	scene	Client group	Age difference	Family provision a concern among younger clients
PT1.8.2	work	Client focus	Range of client activities	Examples of all activities provides
PT1.8.2	E & I	Client use of equipment	Interface, appropriate to	Clients sometimes use exercise bikes
PT1.8.3	ICT	ICT as a meaningful activity	Interface, appropriate to	PC used by patient normally
PT1.8.3	ICT	ICT as a therapeutic tool	Interface, appropriate to	PC mouse provides means of therapy
PT1.9.1	E & I	Client use of equipment	Interface, appropriate to	PC mouse as a motor therapy; PC exercise as a goal
PT1.9.1	work	Goal-setting	Physio has analytical attitude to motor function	Physio acknowledges the limitations of this and need for targets/goals in achieving normal movement
PT1.9.1	E & I	Knowledge of VR	Mixed response to VR	Home simulation might provide meaningful activities
PT1.9.2	E & I	Client use of equipment	Interface, appropriate to	Sensory feedback as audio signal assists appropriate muscle contraction
PT1.9.2	E & I	Client use of equipment	Interface, appropriate to	Sensory feedback as visual signal assists appropriate muscle contraction
PT1.10.3	ICT	Client use of equipment	Interface, inappropriate to	Abstract models do not allow prior knowledge of object; can cause damage
PT1.10.3	ICT	ICT as a therapeutic tool	Interface, appropriate to	Myometry equipment: handle connected to PC for feedback
PT1.10.4	E & I	Evaluation of VR	Interface, inappropriate to	General concern about engineers understanding patient limitations
PT1.10.4	E & I	Evaluation of VR	Positive response to VR	VR can provide a tool for independence training
PT1.10.4	E & I	Evaluation of VR	Positive response to VR	VR as a training tool for better task performance
PT1.10.4	E & I	Evaluation of VR	Positive response to VR	VR as an adjunct to strength training
PT1.10.4	E & I	Evaluation of VR	Positive response to VR	VR as a an aid to navigation around home
PT1.11.1	work	Assessment of client	Environments, public...	Public environments reveal unseen problems
PT1.11.1	work	Clients and carers	Environments, public...	Carers made aware of risks in public environments
PT1.11.1	work	Environment, difficulties of...	Environment, limitations of hospital...	Hospital environment is confined
PT1.11.1	work	Environment, difficulties of...	Environments, public...	Taking clients to the street can be risky
PT1.11.1	work	Problem of transfer	Care process is transitional	Function within the hospital does not necessarily translated to outside
PT1.11.1	work	Problem of transfer	Environments, public...	Public environments are sensorally complex
PT1.11.2	work	Assessment of client	Environments, public...	Client taken to range of public environments, streets, café, shops, lifts, escalators and public transport
PT1.11.2	work	Assessment of client	Environments, public...	Public environment as the setting for normal life
PT1.11.2	work	Assessment of client	Environments, public...	Kerbs and uneven pavements assessed
PT1.11.2	work	Assessment of client	Environments, public...	Assessment of balance, avoidance of collision
PT1.11.2	work	Assessment of client	Environments, public...	Wheelchair access in shops, etc
PT1.12.1	work	Assessment of client	Environment, limitations of hospital...	Client's ability to traverse hospital not necessarily translate to normal settings
PT1.12.1	work	Client focus	Client's preferences	Client often expresses wish to be out and about
PT1.12.1	work	Clients and carers	Environments, public...	Family usually wants client off the ward and back into normal settings
PT1.12.2	work	Assessment of client	Environment, limitations of hospital...	Clients often functions better at home than in hospital
PT1.12.2	work	Pre-morbidity factors in care provision	Environments, public...	Training environments usually selected as familiar to the client; importance of this, especially where memory problems
PT1.13.1	work	Pre-morbidity factors in care provision	Environments, public...	Level of environmental complexity to which the client is exposed reflects pre-morbid normal life

Para.Ref	Area	Major themes	Emergent themes	Specific point
PT1.13.2	E & I	Evaluation of VR	Mixed response to VR	VR might offer safe way of exploring an environment, assessing processing skills; but this is not a physio concern
PT1.13.3	E & I	Attendance	Positive response to VR	VR provides means of promoting attendance to limb function
PT1.13.3	E & I	Knowledge of VR	Mixed response to VR	VR does not assist in strengthening limbs
PT1.13.3	E & I	Knowledge of VR	Positive response to VR	VR provides means of mentally rehearsing movement
PT1.14.1	work	Attendance	Client must be challenged by rehab	Rehab prompts client to overcome limb disuse
PT1.14.1	E & I	Attendance	Positive response to VR	VR offers way of prompting client to avoid limb disuse
PT1.14.2	ICT	ICT as a therapeutic tool	PCs used as part of rehabilitation	Client with vestibular dysfunction scrolls through complex material on screen
PT1.14.2	E & I	Knowledge of VR	Ideas for innovations	VR can be used to overcome vestibular dysfunction in busy environments
PT1.15.1	work	Therapeutic perspective	Client must be challenged by rehab	Visual system is challenged in vestibular rehab to avoid sensory compensation
PT1.15.5	work	Therapeutic perspective	Client must be challenged by rehab	Client must be challenged physically and mentally for incremental recovery
PT1.16.3	E & I	Knowledge of innovation	Active seeking of innovations	CSP website has tick-box newsletter options
PT1.16.3	E & I	Knowledge of innovation	Networks for information, formal	CSP website offers info about new developments
PT1.16.3	E & I	Level of expertise	Networks for information, formal	Staff encouraged to read journals
PT1.16.3	scene	Level of expertise	Sufficiency of resources	High level of expertise and research
PT1.16.3	E & I	Prior knowledge of VR	Multi-disciplinary teams	Interviewee had been to VR conference as part of staff development
PT1.16.4	E & I	Evaluation of VR	Mixed response to VR	Perception that VR is expensive and takes up space
PT1.16.4	E & I	Evaluation of VR	Mixed response to VR	Perception that VR needs a PC
PT1.16.4	ICT	Limitations of resources	Funding	Perception than NHS lacks money for innovations
PT1.16.4	ICT	Limitations of resources	Funding	Perception than NHS lacks money for PCs
PT1.17.1	E & I	Assessment of equipment	Equipment borrowed for trials	Chairs and some electronic equipment trialled for two months
PT1.17.2	E & I	Use of innovative equipment	Developing equipment takes time	Little time to fully develop equipment in acute
PT1.17.2	E & I	Use of innovative equipment	Interface, problems of	Poor understanding of equipment leads to limited clinical impact and eventual abandonment
PT1.17.3	E & I	Assessment of equipment	Considerations for innovation	Innovations must be clinically relevant
PT1.17.3	E & I	Equipment provision, factors in…	Considerations for innovation	Time and cost must be concerns of innovator
PT1.17.4	E & I	Equipment provision, factors in…	Considerations for innovation	Cognitive ability affects use of equipment
PT1.17.4	E & I	Equipment provision, factors in…	Considerations for innovation	Therapist plays active role in helping client adjust to new equipment
PT2.2.1	E & I	Knowledge of VR	Positive response to VR	Mixed reality has been used as visual cue for Parkinson
PT2.2.2	scene	Daily routine	Routine reflects rhythm of rehab	Unusually high level of organisation and integration
PT2.2.2	scene	Goal-setting	Team integration	Goal-setting used as a general management approach
PT2.2.2	scene	Service integration	Multi-disciplinary teams	Unusually high level of organisation and integration
PT2.2.3	scene	Goal-setting	Care process is transitional	Transition between acute, rehab and home requires dynamic goal-setting
PT2.2.3	scene	Goal-setting	Goal-setting environments	Acute, rehab and home provide three different goal environments
PT2.2.4	work	Client's relative abilities	Client's sometimes fatigued easily	This is not always anticipated
PT2.2.4	work	Client's relative abilities	Goals reflect client's abilities and needs	Client's sometimes fatigued easily
PT2.2.4	work	Client's relative abilities	Goals reflect client's abilities and needs	Many clients have limited ability
PT2.2.4	work	Goal-setting	Client leads goal-setting	Street navigation as a client's choice of goal
PT2.2.4	work	Goal-setting	Goals are encapsulated in activities	Sitting up for visitors can be a goal
PT2.2.4	work	Task performance	Environment, limitations of hospital...	Clients can only see other patients
PT2.2.4	work	Task performance	Sensitivity to task context	Sitting up' performed at visitors' time
PT2.2.4	work	Task performance	Tasks as meaningful activities	Sitting up' performed at visitors' and meal time
PT2.3.1	scene	Service integration	Integration benefits care provision	Team integration creates efficient care provision
PT2.3.1	scene	Service integration	Integration benefits client	Team integration forms holistic approach to client
PT2.3.1	scene	Service integration	Team integration	Unusually high level of organisation and integration
PT2.3.3	scene	Service integration	Variation of workplace cultures	Workplace culture results from management actions
PT2.3.4	scene	Service integration	Care process is transitional	Client is supported in handover from acute to rehab
PT2.3.4	scene	Service integration	Multi-disciplinary teams	Information is passed through semi-formal networking events
PT2.3.4	scene	Service integration	Problems of handover	Acute-rehab handover done verbally through semi-formal networks
PT2.3.4	scene	Service integration	Problems of handover	Physical distance of treatment centres creates handover problems
PT2.3.4	scene	Service integration	Staff turnover	Staff leaving affects the efficiency of handover
PT2.4.1	scene	Service integration	Multi-disciplinary teams	Networking provides valuable information
PT2.4.1	scene	Service integration	Multi-disciplinary teams	Networking provides insight into client's journey
PT2.4.1	scene	Service integration	Multi-disciplinary teams	Networking provides information useful for career progression
PT2.4.2	work	Client group	Age differences	Clients often young head-injury patients

Para.Ref	Area	Major themes	Emergent themes	Specific point
PT2.4.2	work	Client group	Age differences	Older patients often have co-morbidity
PT2.4.2	work	Client group	Age differences	Young head-injuries often with social probs such as drug abuse, homelessness, prone to assault
PT2.4.2	work	Client group	Age differences	Younger patients can experience greater anxiety about their condition
PT2.4.2	work	Client group	Age differences	Younger patients have family and work goals
PT2.4.2	scene	Client group	Age range	Older patients can require longer care than younger
PT2.4.2	scene	Limitations of time	Limitations of hospital environment	Acute unit is fast-paced
PT2.5.1	work	Client group	Age differences	Younger patients can experience greater anxiety about their condition
PT2.5.2	work	Service integration	Assessment of service	Centre assessed pathways, ADLs, service over-loading, waiting times, flexibility, throughput, perceived limitations of resources, management of resources
PT2.5.3	work	Service integration	Complexity of service	Multi-tasking is part of dynamic service provision
PT2.5.4	work	Contact with client	Goals reflect client's abilities and needs	Home visits are vital when clients return home
PT2.6.1	scene	Clients and carers	Client's support network, problems…	Family can resist client receiving in-patient care
PT2.6.1	scene	Contact with clients	Client's environment	Home visits done jointly to assess client environment and disability
PT2.6.1	scene	Service integration	Poor integration leads to client vulnerability	Poor connections with social services
PT2.6.2	scene	Service integration	Multi-disciplinary teams	Therapists work as dynamic whole
PT2.6.3	scene	Definition of therapy	Multi-disciplinary teams	Limits of role outlined, pithy definition, but not universally accepted
PT2.7.1	work	Task performance	Environments, public...	All therapists observe client in street situations
PT2.7.1	work	Task performance	Environments, public...	Training for normal means of street navigation, pedestrian crossing controls, etc
PT2.7.1	work	Task performance	Environments, public...	Various levels of environmental complexity sourced
PT2.7.3	work	Task performance	Environments, public...	Normal means of navigations assessed as a standard sequence
PT2.7.4	work	Client engagement	Avoiding client withdrawal	Public environments used to build client communication
PT2.7.4	work	Client engagement	Language and emotional well-being	Public environments used to build client communication
PT2.7.4	work	Task performance	Environments, public...	Public environments used to build client confidence
PT2.7.4	work	Task performance	Environments, public...	Shops used for training environment
PT2.7.5	work	Environment, difficulties of...	Environments, public...	Gym environment alien to many older clients
PT2.7.6	work	Client engagement	Environments, public...	Induction to gym as an engaging process
PT2.7.6	work	Goal-setting	Environments, public...	Gym instructor aids long-term goal setting
PT2.8.1	E & I	Assessment of equipment	Environments, public...	Gyms provide useful test-bed for innovation
PT2.8.1	E & I	Difficulties of environment	Environments, public...	Gym equipment too technical for older clients
PT2.8.1	work	Environment, difficulties of...	Environments, public...	Gym equipment too technical for older clients
PT2.8.2	E & I	Assessment of equipment	Environments, public...	Gym induction necessary
PT2.8.2	E & I	Difficulties of environment	Environments, public...	Gym induction avoids fear of failure
PT2.8.2	work	Environment, difficulties of...	Environments, public...	Gym environment uncomfortably noisy
PT2.8.2	work	Environment, difficulties of...	Environments, public...	Gym induction avoids fear of failure
PT2.8.2	work	Environment, difficulties of...	Environments, public...	Gym induction necessary
PT2.8.3	work	Client engagement	Environment, therapeutic…	Client must enjoy the experience in order to engage
PT2.8.3	work	Client engagement	Environment, therapeutic…	Client must feel relaxed in order to engage
PT2.8.3	work	Client engagement	Environment, therapeutic…	Fear of failure must be avoided
PT2.8.4	E & I	Knowledge of VR	Positive response to VR	VR as physio adjunct for Parkinson's and optical flow in treadmill use
PT2.8.4	E & I	Use of innovative equipment	Technical advice	Innovative equipment requires specialist technical advice
PT2.8.4	E & I	Use of innovative equipment	Willingness to use innovative equipment	Client expresses wish to use innovative equipment
PT2.9.1	E & I	Funding for innovation	Funding	Treatment centre has received charitable funding to buy equipment
PT2.9.1	E & I	Use of innovative equipment	Willingness to use innovative equipment	Enthusiasm wanes after a few months
PT2.9.1	E & I	Use of innovative equipment	Willingness to use innovative equipment	Thorough introduction to equipment may lead to its uptake
PT2.9.2	E & I	Limitations of resources	Willingness to use innovative equipment	Equipment can lead to decrease in staffing demands
PT2.9.2	work	Task performance	Complexity of movement	Example given of complexity in walking
PT2.9.2	E & I	Task performance	Technology reflects clients' needs	Innovation may help client perform tasks
PT2.9.2	E & I	Task performance	Technology reflects clients' needs	Innovation may help client train in tasks
PT2.9.2	E & I	Use of innovative equipment	Limitations of staffing resources	Innovation may help overcome staff limitations
PT2.9.2	E & I	Use of innovative equipment	Technology reflects clients' needs	Innovation may help client avoid risk
PT2.10.1	E & I	Limitations of time	Willingness to use innovative equipment	Equipment can lead to decrease in staffing demands
PT2.10.1	work	Task performance	Complexity of movement	Improvement in motor function doesn't equate to task performance
PT2.10.2	work	Equipment provision, factors in…	Need for supervision	Client independence in equipment use related to level of disability
PT2.10.2	work	Equipment provision, factors in…	Need for supervision	Two staff needed to avoid fall, entanglement, etc

Para.Ref	Area	Major themes	Emergent themes	Specific point
PT2.10.2	E & I	Use of innovative equipment	Need for supervision	Client independence in equipment use related to level of disability
PT2.10.3	E & I	Equipment provision, factors in…	Client use of equipment	Clients can tire easily
PT2.10.3	E & I	Equipment provision, range of…	Tabletop equipment	Tabletop equipment is qualitatively different
PT2.10.3	E & I	Limitations of resources	Tabletop equipment	Tabletop equipment is less space demanding
PT2.10.3	work	Use of innovative equipment	Need for supervision	Tabletop equipment generally requires less supervision
PT2.11.1	E & I	Knowledge of innovation	Networks for information, informal	New equipment sourced through word of mouth
PT2.11.1	E & I	Knowledge of innovation	Networks for information, informal	Client supplies information about innovations
PT2.11.2	E & I	Knowledge of innovation	Networks for information, formal	Salesmen not usually welcome
PT2.11.2	E & I	Knowledge of innovation	Networks for information, formal	Professional bodies supply reliable information
PT2.11.3	E & I	Assessment of equipment	Considerations for innovation	Equipment measured against impact on clinical outcomes
PT2.11.3	E & I	Knowledge of innovation	Networks for information, formal	Targeting specific problems leads to willing audience for sales pitch
PT2.11.4	ICT	Provider use of ICT	Level of use	Used a lot
PT2.11.4	ICT	Provider use of ICT	Range of use	Admin, stats, info, presentation
PT2.12.1	ICT	Provider use of ICT	Range of use	Gait analysis a specialism, 'expensive and rare'
PT2.12.4	ICT	Client use of ICT	Interface, appropriate to	Better to interface with a familiar object
PT2.13.1	E & I	Knowledge of VR	Interface, appropriate to	HMD and dataglove lead to natural movement
PT2.13.2	E & I	Knowledge of VR	Interface, appropriate to	VR interface can be intuitive
PT2.13.2	E & I	Knowledge of VR	Interface, appropriate to	Training required, but still usable
PT2.13.3	E & I	Knowledge of VR	Willingness to use innovative equipment	Therapists in neuro rehab particularly keen to try new equipment
PT2.13.4	E & I	Assessment of equipment	Pilot demonstrations	Pilots of crucial to winning confidence
PT2.13.4	ICT	Provider use of ICT	Interface, problems of	Complicated software leads to equipment being abandoned
PT2.14.1	scene	limitations of resources	Increasing pressure on resources	Departments are getting busier, resources squeezed
PT2.14.1	ICT	limitations of resources	Interface, problems of	Increased pressure requires simpler interfaces
PT2.14.1	ICT	limitations of resources	Interface, problems of	Simple interface requires technical support
PT2.14.3	ICT	Provider use of ICT	Therapy as a dynamic process	System changes made dynamically within treatment session
PT2.14.4	E & I	Assessment of equipment	Pilot demonstrations	Range of grips would be of interest to OTs and physios
PT2.14.5	work	Goal-setting	Problems of goal-setting	Gap between patient goals and therapist goals
PT2.14.5	E & I	Goal-setting	Tabletop equipment	Table-based activity satisfy patient and therapist goals
PT2.15.1	E & I	Assessment of equipment	Pilot demonstrations	Demonstration of motivating system would be of interest
PT2.15.1	work	Goal-setting	Motivation, means of…	Games might require therapeutic hand and arm movements
PT2.15.1	work	Use of innovative equipment	Motivation, means of…	Games might provide motivation
Tech1.1.3	scene	Knowledge of VR	Prior experience of VR	Details of VR project given
Tech1.1.4	scene	Limitations of time	Limitations of time for research	Software difficult to use
Tech1.1.4	scene	Limitations of time	Limitations of time for research	Technical skills not available
Tech1.1.5	scene	Knowledge of VR	Positive response to VR	Further research required
Tech1.1.6	scene	Knowledge of VR	Problems of collaboration	Enlisting outside technical support
Tech1.1.6	scene	Limitations of resources	Limitations of staffing resources	Smaller projects more manageable
Tech1.1.6	scene	Limitations of time	Limitations of time for research	Technical demands lead to project abandoned
Tech1.2.1	scene	Knowledge of VR	Positive response to VR	Qualified in 3D graphics and also OT
Tech1.2.2	scene	Service integration	Role has limited scope	Tech1 manages assistive technology team
Tech1.2.3	scene	Service integration	Service not wholly integrated	Tech1 no longer working in OT department
Tech1.3.1	work	Client focus	Client preferences are considered	Technology reflects clients' needs
Tech1.3.2	E & I	Client focus	Technology reflects clients' needs	PCs are adapted to clients' need
Tech1.3.3	E & I	Assessment of equipment	PCs provide manageable interface	Joystick training
Tech1.3.3	E & I	Client focus	PCs used as part of rehabilitation	PCs are used for cognitive and motor therapy
Tech1.3.3	E & I	Client focus	PCs used as part of rehabilitation	PCs used for communication and entertainment
Tech1.3.3	E & I	Limitations of resources	PCs provide cost saving	PCs used to assess expensive comms equipment
Tech1.4.1	work	Goal-setting	Multidisciplinary concerns embedded in wheelchair training	Therapy is embedded in tasks
Tech1.4.1	E & I	Sufficiency of resources	Benefits of available space	Greater available space allows innovative equipment use
Tech1.4.2	E & I	Limitations of resources	Cost of VR equipment	HMDs not considered due to cost
Tech1.4.2	E & I	Prior knowledge of VR	Assessment of equipment	Datagloves disallowed due to disability
Tech1.4.2	E & I	Prior knowledge of VR	Assessment of equipment	Joystick suitable interface due to similarity to wheelchair control
Tech1.4.2	E & I	Prior knowledge of VR	Development of equipment over time	Experiments undertaken as appropriate joysticks emerge

Para.Ref	Area	Major themes	Emergent themes	Specific point
Tech1.4.2	E & I	Prior knowledge of VR	Development of equipment over time	HMDs not used due to cost and possible sickness
Tech1.4.2	E & I	Prior knowledge of VR	Task performance tests	Experiments compares wheelchair navigation task VR and real world
Tech1.4.2	E & I	Prior knowledge of VR	Task performance tests	Experiments measures time to complete wheelchair route finding task
Tech1.4.2	E & I	Prior knowledge of VR	Task performance tests	Transfer of training not measured due to poor performance
Tech1.5.1	E & I	Assessment of equipment	Interface, problems of	Laptops deemed inappropriate due to limited visual field
Tech1.5.1	E & I	Assessment of equipment	Interface, problems of	Projection deemed inappropriate due to limited visual field
Tech1.5.2	E & I	Assessment of equipment	Interface, appropriate to	HMDs appropriate to mid-level spine injury due to greater head control
Tech1.5.2	E & I	Assessment of equipment	Interface, problems of	HMDs inappropriate due to limited head control
Tech1.5.2	E & I	Assessment of equipment	Interface, problems of	HMDs inappropriate due to visual disturbance
Tech1.6.1	scene	Catchment	Level of expertise	National and international catchment
Tech1.6.2	ICT	Client focus	Client use of technology	Regular and sometimes independent use of technology among clients
Tech1.6.2	scene	Client group	Specific clients	Long-term care, severe disability
Tech1.6.3	work	Client focus	Client preferences are considered	TV channel changing an ADL
Tech1.6.3	work	Client focus	Client preferences are considered	TV remote as an environmental control
Tech1.6.3	work	Client focus	Environment, client's...	TV forms clients' environment
Tech1.6.3	E & I	Client use of equipment	Client level of client technology use	Less able clients require greater use of technology
Tech1.6.3	E & I	Client use of equipment	Interface, appropriate to	TV remote provides an appropriate interface
Tech1.7.1	ICT	Client use of ICT	Interface, problems of…	Goal-setting with ICT must be sensitive to client's IT literacy
Tech1.7.1	ICT	Client use of ICT	Interface, problems of…	Many older patients are not familiar with IT interfaces
Tech1.7.1	ICT	Client use of ICT	Interface, problems of…	Pre-morbid attitude to ICT should be considered
Tech1.7.1	ICT	Client use of ICT	Motivation, means of…	IT used to successfully perform ADLs
Tech1.7.2	work	Client focus	Interface, appropriate to…	Available motor function is used, however limited
Tech1.7.2	work	Client focus	Interface, appropriate to…	Interface can be changed as motor function recovers
Tech1.7.3	work	Goal-setting	Motivation, means of…	Achievable goals lead to sense of success
Tech1.7.3	work	Goal-setting	Motivation, problems of…	Goals might reveal client's limitations
Tech1.7.3	work	Goal-setting	Motivation, problems of…	Motivation is subjective
Tech1.8.1	work	Client focus	Environment, client's...	Bed can be a limiting environment
Tech1.8.1	work	Client focus	Interface, appropriate to…	Available motor function is used, however limited
Tech1.8.1	E & I	Client focus	Interface, problems of	Equipment may injure unattended client
Tech1.8.1	E & I	Client focus	Interface, range of…	Equipment is bespoke
Tech1.8.2	scene	Service integration	Experience is recalled	Technology expertise develops over time
Tech1.8.3	scene	Level of expertise	Treatment centre is not representative	Rehabilitation engineers develop chips
Tech1.9.1	scene	Limitations of time	Developing equipment takes time	New equipment is developed only when necessary
Tech1.9.2	E & I	Knowledge of innovation	Networks for information, informal	Small innovation community leads to stronger knowledge of innovations
Tech1.9.3	E & I	Knowledge of innovation	Innovation, formal development…	Innovation process can be bureaucratic
Tech1.9.3	E & I	Knowledge of innovation	Innovation, informal development…	Innovation can be regarded as a by-product of the care process
Tech1.9.3	E & I	Knowledge of innovation	Networks for information, informal	Solutions are developed ad hoc and informally
Tech1.9.3	E & I	Limitations of resources	Innovation, formal development…	Specialised body is required for innovation development
Tech1.9.3	E & I	Limitations of time	Innovation, formal development…	Bureaucracy can be an obstacle to innovation
Tech1.9.3	E & I	Limitations of time	Innovation, formal development…	Innovation bureaucracy can be time-consuming
Tech1.9.3	E & I	Limitations of time	Innovation, formal development…	Private companies have greater resources for developing innovation
Tech1.10.1	E & I	Knowledge of innovation	Innovation, formal development…	Existing innovation companies lack specialist capability
Tech1.10.1	E & I	Knowledge of innovation	Innovation, formal development…	Market is niche, for severely disables clients
Tech1.10.1	E & I	Knowledge of innovation	Innovation, formal development…	Perceived difference between 'small' and 'big' companies and innovation capability
Tech1.10.1	E & I	Knowledge of innovation	Innovation, formal development…	Perceived lack of market for equipment
Tech1.10.1	E & I	Knowledge of innovation	Innovation, informal development…	Innovation can be regarded as a by-product of the care process
Tech1.10.1	E & I	Knowledge of innovation	Networks for information, informal	Links with innovation companies have some benefit to technology development
Tech1.10.2	E & I	Client focus	Innovation, formal development…	Conflict of generic over specific innovation
Tech1.10.2	E & I	Knowledge of innovation	Innovation, formal development…	Conflict of generic over specific innovation
Tech1.10.2	E & I	Knowledge of innovation	Innovation, formal development…	Qualitative shift between test and delivery of technology
Tech1.11.1	E & I	Knowledge of innovation	Networks for information, formal	Attractiveness of technology innovation in healthcare
Tech1.11.1	E & I	Problems of design	Innovation, formal development…	Conflict of interests between engineers and care providers
Tech1.11.1	E & I	Problems of design	Innovation, formal development…	Technology is difficult to implements in clinical setting

Para.Ref	Area	Major themes	Emergent themes	Specific point
Tech1.11.2	scene	Level of expertise	Multi-disciplinary background	Trained in 3D modelling for rehab, then OT
Tech1.11.3	work	Contact with client	Rehab as a 'hands-on' process	Interviewee chose to do 'hands-on' work over technical work
Tech1.11.3	scene	Motivation, providers…	Multi-disciplinary background	Choice to do 'hands-on' work
Tech1.11.3	scene	Motivation, providers…	Multi-disciplinary background	Wish to work with technology in a rehab setting
Tech1.12.1	ICT	Provider use of ICT	Level of use	Constant use of ICT
Tech1.12.1	ICT	Provider use of ICT	Range of use	Reports, Multi-tasking, goal-setting as a manager, sourcing information, product info, pricing, equipment applications, software development, organisation.
Tech1.12.3	scene	Service integration	Team integration	Small assistive technology team
Tech1.12.4	scene	Knowledge of technology	Innovation, formal development	Staff have low knowledge of technology
Tech1.12.4	scene	Limitations of resources	Innovation, formal development	Poor organisation within the treatment centre leads to low technology uptake
Tech1.12.4	scene	Limitations of time	Innovation, formal development	Limitations of staff time lead to low technology uptake
Tech1.12.4	scene	Limitations of time	Treatment centre integration	Ward therapists not always able to work with technology staff
Tech1.12.4	ICT	Provider use of ICT	ICT for management	Databases manage workload
Tech1.12.4	scene	Service integration	Treatment centre integration	Poor organisation within the treatment centre
Tech1.12.4	scene	Service integration	Treatment centre integration	Technology staff provide support and advice to therapists
Tech1.12.4	scene	Service integration	Treatment centre integration	Ward therapists often have conflicting priorities
Tech1.12.4	scene	Service integration	Treatment centre integration	Weak links between technology staff and therapists
Tech1.13.1	ICT	Knowledge of innovation	ICT for management	Interviewee tracks developments in ICT
Tech1.13.1	ICT	Provider use of ICT	ICT for management	Data sharing, security networks. Not for patient records
Tech1.13.2	ICT	Knowledge of innovation	Innovation, formal development…	Expert knowledge does not lead to technology uptake among staff
Tech1.13.2	ICT	Provider use of ICT	ICT for management	Workload management
Tech1.13.3	ICT	Knowledge of innovation	Innovation, formal development…	Developing an automated learning system to support dynamic goal-setting
Tech1.13.3	E & I	Knowledge of innovation	Networks for information, informal	Evidence for research collected through travel
Tech1.13.3	scene	Knowledge of technology	Level of expertise	Interviewee undertaking PhD in technology for goal-setting
Tech1.13.3	ICT	Service integration	Innovation, formal development…	ICT as a means to integrate service provision
Tech1.13.3	scene	Service integration	Rehabilitation and medicine	Resources seem to be geared towards doctors
Tech1.14.1	work	Client engagement	Motivation, problems of…	Cognitive disability leads to poorer information gathering
Tech1.14.1	work	Client knowledge of service	Client knowledge is variable	Knowledge leads to greater access to services
Tech1.14.1	work	Client knowledge of service	Client knowledge is variable	Unusually informed clients and carers
Tech1.14.1	work	Clients and carers	Carer engagement	Carer engagement leads to better care provision
Tech1.14.2	E & I	Knowledge of innovation	Carer engagement	Carers learn of innovation and ask care provider
Tech1.14.3	E & I	Knowledge of innovation	Networks for information, informal	Knowledge of prior problems elsewhere leads to solutions sought
Tech1.14.3	E & I	Knowledge of innovation	Networks for information, informal	Population density leads to greater information sharing
Tech1.14.3	E & I	Knowledge of innovation	Networks for information, informal	Treatment centres share information through web-based resources
Tech1.14.3	E & I	Knowledge of innovation	Networks for information, informal	Word-of-mouth among carers and providers
Tech1.15.1	scene	Knowledge of technology	Staff training	Poor integration between techs and therapists leads to poor technical training
Tech1.15.1	E & I	Service integration	Networks for information, informal	Longevity of staff leads to better information sharing
Tech1.15.1	scene	Service integration	Staff training	Poor integration between techs and therapists leads to poor technical training
Tech1.15.1	scene	Service integration	Staff turnover	Longevity of staff leads to better information sharing
Tech1.15.2	scene	Service integration	Funding	Poor integration leads to duplicated funding applications
Tech1.15.2	ICT	Service integration	ICT for management	Multi-tasking in IT could lead to better service integration; need for development of this

Appendix 6 – Clinical Observations

The washing and dressing assessments were of two male stroke patients. The first (*Patient A*) a 75 year-old and the second (*Patient B*) an 80 year-old, who each suffered sensory-motor impairment to their left side. Prior to the assessment taking place, *Patient A* was lying in bed and seemed somewhat anxious about the process. As the usual, experienced OT Assistant was not present that morning, the therapist was being assisted by a student nurse (an affable young woman with a manner common to the local area who seemed to have a familiar yet professional rapport with the patients). This unusual set-up and my presence may have induced an air of uncertainty in approaching the assessment, perhaps increasing the anxiety which seemed to continue well into the treatment session. Yet at a certain point, perhaps when the session was shown to be going well, everyone present relaxed and *Patient A* became more chatty, not least as the assessment neared completion. Interestingly, coupled with his acquiescence to the process, *Patient A* had particular intentions as to the clothes he wished to wear and also the towel he wanted to use, remarking that one was too rough, and the student nurse was keen to work with him to ensure he had everything he required.

Patient A required considerable assistance moving from his bed to the assessment area. In moving *Patient A* from bed to wheelchair and then to assessment area I noticed how the load of a sensory-motor impaired human body must be manoeuvred serially, interactively, and intricately with knowledge of weight-shifting brought to play. Moving the patient this involved 'ready-steady-go' instructions; the patient holding on to the OT while the OT supported the buttock of his affected side; a 'nose before toes' instruction for standing up; ensuring movements were smooth and not too rapid, and so on. In spite of the considerable difficulties, confidence was also brought to bear in the patient in order to overcome the serious impairments to once intuitive body functions.

Patient B, who had also contracted MRSA, was confined to an isolated and cramped room which he traversed by using his feet to push his chair around. *Patient B* appeared less than happy and seemed annoyed that the assessment had been delayed by two hours. An apparently successful businessman (and, I would guess by his manner and accent, 'self-made') he also complained of getting the "moody blues" while sitting alone in hospital. *Patient B* seemed to enjoy the chance to become active and joked, perhaps condescendingly, with the student nurse present ("Don't just stand there, I'm paying your wages"). *Patient B* also mentioned specific motivators for leaving hospital: to attend his mother's 100th birthday party without the use of a wheelchair and for his sexual function to return as he, to paraphrase, 'sees a couple of girls'.

Patient B thus evinced a matter-of-fact willingness to succeed by gradual means as well as pride in the progress made thus far.

Regarding both patients I was struck by how much contingent communication was employed by the OT as he responded to chance information provided by the patient as the assessment ensued as a dynamic process. This also actively involved the patients in their own treatment. For example, *Patient A* suddenly mentioned that he could now grasp an object, and the OT responded by focussing on detailed finger function. Movements that were painful to *Patient B* were assessed and considered throughout the treatment session (in this case, fairly typical shoulder pain).

Although encouraging in manner, the OT sometimes provided realistic performance feedback to the patients, pointing out to a proud *Patient B* that he was in fact assisting in that particular movement. The OT also provided direct guiding movements, such as enclosing *Patient A*'s hand in his to lead the movements for hair combing to give the hand a 'sense' of normal movements prior to the task being performed. The OT also posed some challenges to *Patient A,* such as asking his him to wash his own back, while using a full-length mirror to lead certain movements. This request provoked anxiety, slight protest and some difficulty in performance but led to a previously problematic task being completed. In washing the genitals of each patient the OT was keen to be as circumspect as possible while the assistant helped in using a towel to preserve the patients' modesty.

After tasks were performed the OT carefully led the affected limbs to an aligned position, with *Patient A*'s affected hand resting on his knee and *Patient B*'s resting on the sink with the thumb, which is prone to abnormal flexion due to impaired muscle tone, positioned with particular attention. In this case the curve of the sink itself was used as a convenient and appropriate guide to correct hand posture.

The OT expressed some frustration that time with the patients had been limited, not least with *Patient B* who seemed not to fully understand instructions for further hand exercises to be undertaken after the treatment session. The space available was also a problem for *Patient B* as his isolated room was very small indeed and allowed little room for a fuller treatment.

In conclusion to these observations, the key notes to regard might be such:

- the treatment is embedded in an ADL through several dimensions, including use of domestic equipment (the sink for thumb alignment)
- the treatment process is both contingent and dynamic

- manoeuvring the patient is serial and highly interactive
- the patient’s preferences are acknowledged throughout
- the therapist interacts intimately with the patient’s movements, considering also problems with pain and lack of sensory feedback
- a patient’s body must be correctly aligned, including at rest
- a patient must be filled with confidence, even when challenged
- patients respond differently to the treatment and have very subjective motivations
- a patient’s condition and environment might effect their mood and motivation
- patient’s do not always understand instructions for further exercises
- the treatment is sometimes limited in time and space

We might note therefore that introducing an innovative system or piece of equipment to the chronic therapeutic process would involve interfacing with these factors. Given the contingent and dynamic communication; the highly physical and interactive nature of the treatment; the anxiety often engendered by the treatment and the need for meeting the patient’s preferences; the requirement to introduce appropriate challenges and the limitations of time, space and the patients’ various cognitive abilities, we might say that in many such circumstances a system might only be administered with a human therapist present.

Appendix 7 – Task Specific Feedback Questionnaire (adapted)

Task Specific Feedback Questionnaire **Date:**
Adapted from Kizony et al, 2003. Adapted from Witmer and Singer (1998) **Participant:**
Assessor:

Score your answers to the following questions:

1 = strongly disagree, 2 = disagree, 3 = unsure, 4 = agree and 5 = strongly agree

1. **I experienced a feeling of enjoyment / interest?**

1 2 3 4 5

2. **I had a sense of being in the environment?**

1 2 3 4 5

3. **I was successful at doing the task?**

1 2 3 4 5

4. **I felt as though I was control in the environment?**

1 2 3 4 5

5. **Some parts of the environment felt like my own home.**

1 2 3 4 5

6. **There were some things in the environment that did *not* feet like my own home.**

1 2 3 4 5

7. **The feedback from the computer understandable.**

1 2 3 4 5

8. **I felt discomfort during the session.**

Yes / No