ELEMENTS:
The Design of an Interactive Virtual Environment for Movement Rehabilitation of Traumatic Brain Injury Patients

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy from the Royal Melbourne Institute of Technology

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DECLARATION

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; and the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

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ABSTRACT

This exegesis details the development of an interactive art work titled *Elements* designed to assist upper limb movement rehabilitation for patients recovering from traumatic brain injury. Enhancing physical rehabilitative processes in the early stages following a brain injury is one of the great challenges facing therapists. *Elements* enables physical user interaction that may present new opportunities for treatment.

One of the key problems identified in the neuro-scientific field is that developers of interactive computer systems for movement rehabilitation are often constrained to the use of conventional desktop interfaces. These interfaces often fall short of fostering natural user interaction that translates into the relearning of body movement for patients, particularly in ways that reinforce the embodied relationship between the sensory world of the human body and the predictable effects of bodily movement in relation to the surrounding environment. Interactive multimedia environments that can correlate a patient's sense of embodiment may assist in the acquisition of movement skills that transfer to the real world. The central theme of my exegesis will address these concerns by analysing contemporary theories of embodied interaction as a foundation to design *Elements*.

Designing interactive computer environments for traumatic brain injured patients is, however, a challenging issue. Patients frequently exhibit impaired upper limb function which severely affects activities for daily living and self-care. *Elements* responds to this level of disability by providing the patient with an intuitive tabletop computer environment that affords basic gestural control.

As part of a multidisciplinary project team, I designed the user interfaces, interactive multimedia environments, and audiovisual feedback (visual, haptic and auditory) used to help the patients relearn movement skills.

The physical design of the *Elements* environment consists of a horizontal tabletop graphics display, a stereoscopic computer video tracking system, tangible user interfaces, and a suite of seven interactive software applications. Each application provides the patients with a task geared toward the patient reaching, grasping, lifting, moving, and placing the tangible user interfaces on the display. Audiovisual computer feedback is used by patients to refine their movements online and over time. Patients can manipulate the feedback to create unique aesthetic outcomes in real time. The system design provides tactility, texture, and audiovisual feedback to entice patients to explore their own movement capabilities in externally directed and self-directed ways.

This exegesis contributes to the larger research agenda of embodied interaction. My original contribution to knowledge is *Elements*, an interactive artwork that may enable patients to relearn movement skills, raise their level of self-esteem, sense of achievement, and behavioural skills.

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Chapter 1: Introduction

1.1 Description of project

My project, *Elements*, is an interactive multimedia artwork that aims to support movement assessment and rehabilitation for patients recovering from traumatic brain injury (TBI). It is intended for TBI adults with moderate or severe upper limb movement disabilities.

As shown in Figure 1, *Elements* comprises a horizontally mounted table top LCD screen that displays the interactive environments to the patient. The patient interacts with the environment via four tangible user interfaces (TUIs). The TUIs are soft graspable interfaces that mediate the form of interaction between patient and the environment. A computer camera mounted above the main display identifies the TUI and tracks its position and orientation relative to the computer display. Essentially, the camera tracks the endpoint motion of the patient's arm while performing an activity holding the TUI. Real-time audiovisual feedback can be used by patients to refine their movements over time. Patients can also manipulate the computer generated feedback to create unique audiovisual outcomes. The overall system design provides tactility, texture, and audiovisual feedback to entice patients to explore their own movement capabilities in externally directed and self-directed ways.

Figure 1: Illustration of *Elements* prototype. Image key - 1) Patient; 2) Computer camera and mount; 3) Patient display; 4) TUIs; 5) Therapist display; 6) Therapist administrator

Specific to my project, I designed the tangible user interfaces, the interactive multimedia environments, and the audiovisual feedback (visual, haptic and auditory) to engage and motivate the recovering patient. The multimedia environments provide patients with the ability to predict and control their actions flexibly, and to provide new possibilities to relearn upper limb movement skills. My design may enable therapists to reintegrate a patient's sense of space and of their body through physical user interaction with computer environments. To achieve my aim I will investigate theories and methods related to the design of user interfaces that promote the augmentation of human movement.

1.2 Background to research

An important subject of interest for new media art and communication study is the design of physical interfaces with which people interact with media. Interaction designers and new media artists are exploring how to design computer interfaces that enhance physical user interaction and experience. For example, the advances and availability of computer sensing technologies such as the Nintendo Wii Remote controller enables the human body to interact in more natural and expressive ways with computer technology.[1] The designers of such interfaces are striving to link the user's physical environment and the human body with computer environments through the user interface.

Understanding how users interact with computers and new technology is representative of a larger general problem in human computer interaction (HCI). HCI provides theories in terms designing user interfaces for interactive media applications. According to HCI designer Paul Dourish, the rise in the development of mobile and tangible electronic products has led user interaction away from the computer display screen and into the physical space of the user (Dourish 2001). Dourish suggests this represents a change in culture for HCI as designers shift their focus from the functional usability of interfaces to the experience of user interaction.

Dourish suggests that research in HCI should further explore how users experience their interaction with technology as a way to understand the opportunities emerging from new forms of technological practice. He argues for an 'embodied' approach to interaction design that factors in the relationship between the user's body

[1] http://www.nintendo.com/wii/what/controllers

and the user's environment with computer systems. The embodied approach to interaction design capitalises on our physical skills and our familiarity with real-world objects. In short, Dourish argues that the basis for user interaction should focus on first-person, lived, human body experience and its relation to the environment.

Dourish's embodied perspective of human interaction with computer technology is consistent with *ecological* approaches to movement rehabilitation. An ecological approach refers to the degree of relevance or similarity that a rehabilitation activity has relative to the 'real' world, and in its value for improving a patients everyday functioning (Rizzo 2005). According to key theorists in motor rehabilitation, including Maureen K. Holden and Heidi Sveistrup, interactive multimedia environments hold great potential to augment physical awareness and recovery for patients with traumatic brain injury (Holden 2005), (Sveistrup 2004). They suggest that a broad range of interactive technologies may enable therapists to reintegrate a patient's sense of space and of their body in ecologically valid ways.

Designing user interfaces for traumatic brain injured patients is however a challenging issue. In TBI, the main streams of sensory information that contribute to a patient's sense of embodiment (visual, auditory, tactile, and somatic) are fragmented as a result of their injury. More holistically, the patient's sense of position in space – their sense of embodiment – is severely compromised. According to Holden, in order to rebuild body sense and the ability to effect action, the damaged motor system must receive varied but correlated forms of sensory input during the early phase of recovery; this is seen to maximise the opportunity for recovery (Holden 2005). This raises the issue of how one might design multimedia environments for rehabilitation that can correlate a patient's sense of embodiment.

According to Maria Shulthies and Albert Rizzo, traditional therapies for TBI patients employ interventions that tend to be tedious, monotonous and provide little opportunity for grading the level of difficulty (Schultheis and Rizzo 2001). They discuss how these approaches are often labour and cost-intensive; they require one-to-one physical and occupational therapy over an extended period using a variety of props, in relatively large workspaces. My project is a direct response for the need to design interactive environments that will engage, motivate, and correlate a patient's sense of embodiment in ways conducive to relearning motor skills.

1.3 Rationale

According to several researchers in motor rehabilitation, interactive technologies may assist health providers to accelerate the recovery process, and show great potential in advancing rehab practices (Holden 2005), (Rose, Brooks et al. 2005), (Schultheis and Rizzo 2001). Traumatic brain injury refers to a cerebral injury caused by a sudden external physical force. Such physical trauma can lead to a variety of physical, cognitive, emotional and behavioural deficits that may have long-lasting and devastating consequences for the victims and their families. TBI represents a significant health issue for Australians with approximately 2% of the population living with disabilities stemming from cerebral injury (Fortune and Wen 1999). The cost of disability is estimated to exceed $3 billion per year in Australia. The ability to enhance rehabilitative processes in the early stages following TBI is one of the great challenges for therapists. Consequently, movement rehabilitation specialists, families, and helpers are continually looking for novel approaches that will assist TBI patients relearn basic mobility skills and improve quality of life. Developing new therapeutic treatments using interactive computer technology may improve the rate of recovery, increase the quality of life for patients, and reduce the cost to society.

Traumatic brain injured patients frequently exhibit impaired upper limb function, including reduced range of motion, accuracy of reaching, inability to grasp and lift objects, or perform fine motor movements (McCrea, Eng et al. 2002). These symptoms, among many others, often lead to a significant incidence of depression among people with physical and intellectual disabilities, which presents a psychological barrier to engaging in rehabilitation and daily living (Esbensen, Rojahn et al. 2003) (Shum, Valentine et al. 1999). According to psychologist David Shum, TBI patient engagement is one of the key elements to maintaining motivation in rehabilitation therapy. The issue of maintaining patient engagement underlines the importance of designing therapeutic tasks and environments that can be presented in a meaningful and stimulating way. My research aim is to design an interface that can maximise a TBI patient’s engagement in relevant and pleasurable activities that may complement existing, often tedious, approaches to rehabilitation.

My project is important because there is a need to explore approaches and methodologies to design user interfaces for rehab applications. In an analysis of virtual reality technology for rehabilitation, Albert Rizzo identifies the design of user interfaces as the area that requires most attention in research (Rizzo 2005). He suggests the development of naturalistic interfaces for user interaction is of vital importance in optimising performance and improving access for patients with cognitive and motor impairments. Rizzo notes that developers of rehabilitation systems are often constrained to using conventional computer hardware such as joysticks, mice, and keyboards. These user interfaces often fall short of fostering natural interaction, as they do not reflect how we interact with our environment and manipulate objects in the real world, particularly in ways that reinforce the embodied relationship between the sensory world of the human body, and the predictable effects of movement of one's body in relation to one's surrounding environment. For this reason, I will define and clarify what embodiment is, and why and how it is being applied to the field of HCI design, and new media art. The central theme of my exegesis will address these concerns by analysing the role of embodiment as an approach to design my project.

1.4 Methodology

I will begin in Chapter 2 by reviewing a broad range of literature related to an embodied view of interaction design and physical user interaction with computer environments. I will draw on a multiplicity of dialogues, methods, contexts and practices from a variety of disciplines. I will examine the theories of HCI design (Dourish 2001), (Ishii and Ullmer 1997), (Norman 2002), interactive art (Krueger 1991), and provide examples of interactive artistic applications developed for rehabilitation (Brooks, Camurri et al. 2002) (Hasselblad, Petersson et al. 2007). The theories, approaches, and techniques identified may provide me with a conceptual foundation for the development of my project. By understanding the approaches of HCI designers, new media artists, and scientists, I will in later stages develop new design strategies for therapy delivery.

Questions for my research revolve around the embodied nature of the human body interacting with a computer simulated environment. As a direct response to the needs of therapists and patients, I will explore the nature of embodied interaction as a design approach for my project. I will discuss my approach through three research questions:

Research Question 1: According to HCI designer Paul Dourish, how may we define the embodied nature of user experience with interactive media?

In Chapter 3, I will examine Research Question 1. I will expand in more detail the theories of embodied interaction according to HCI designer Paul Dourish. Dourish provides five foundational theories (ontology, intersubjectivity, intentionality, coupling, and metaphor) as an approach to understand the experience of user interaction with computers. Through these interrelated theories I will explore the nature of embodiment, user experience, and computer response as a design approach to movement rehabilitation.

Research Question 2: How may we observe Dourish's theory for embodied interaction in the techniques of new media artist Myron Krueger?

In Chapter 4, I will examine Research Question 2. I will explore and test Dourish's theory by applying it to a case study. The work of artist and technologist Myron Krueger provides us with an example of embodied interaction through his media art work *VIDEOPLACE* (Krueger, 1991: 33-64). Krueger intuitively speculated that this particular work could be used in the service of movement rehabilitation (ibid: 197-198). I will refer to Dourish's five foundations for embodied interaction and apply them to Krueger's *VIDEOPLACE*. By analysing Krueger's design techniques through Dourish, this case study may enable me to develop a design methodology for my project.

Research Question 3: How useful are these theories and techniques to my project?

In Chapter 5, I will examine Research Question 3. I will describe the development and design of my project, the *Elements* upper limb rehabilitation environment. My design will utilise readily available computer technologies, designed to be intuitive and accessible for patients and therapists, and to support current clinical practices. I will describe in detail the design of the user interface, the suite of interactive environments, and audiovisual feedback. I will relate my design to Dourish's five foundations of embodied interaction design and Krueger's techniques. By observing the theories and techniques of Dourish and Krueger, we may explore new possibilities for user interactivity that support human movement and expression for TBI patients. I will also discuss the user's experience of *Elements* as a method of evaluating the design.

To conclude, in chapter six I will reflect on my embodied interaction approach as applied to the design of my project. I will identify the successful characteristics of my design approach that may begin to address the concerns of rehabilitation therapists. I will also discuss the potential of interactive art for hospital-based rehabilitation as a direction for future research. TBI patients may be considered a new audience for media artists. The reciprocal demands of new media art and health science in exploring media art for therapeutic applications may be rich with possibilities for future research.

Chapter 2: Literature Review

2.1 Introduction

In this chapter I will explore design theories that examine user interfaces for human computer interaction. I will pay particular attention to theoretical paradigms in human computer interaction that explore embodiment and user engagement through physical user interaction with computer technology. The aim of my research is to design and develop an interactive artwork titled *Elements* that supports movement assessment and rehabilitation for patients recovering from traumatic brain injury (TBI). The theories identified in this chapter will enable me to lay down a conceptual foundation for the development of my project.

By exploring the relationship between the user interface and user experience I may begin to design an interactive environment for TBI patients that engages them in the relearning of their movement. The literature referred to in this chapter represents a multiplicity of dialogues, methods, and practices drawn from a variety of disciplines. I will survey the field in the following way:

i) In Section 2.2 I will provide an introductory overview of computer mediated interventions for disability. This overview may allow me to identify the limitations and opportunities within the field of traumatic brain injury rehabilitation for enhancing and enabling user interaction. However, a detailed discussion on medical literature and background theory regarding movement rehabilitation is beyond the scope of my exegesis.

ii) In Section 2.3 I will discuss the field of human computer interaction. I will explore theoretical paradigms around the nature of embodied interaction-related design areas in computing.

iii) In Section 2.4 I will provide examples of artists and rehabilitation therapists who explore the experience of embodied user interaction as an aesthetic approach to their work. I will draw on several examples where playfulness and artistic expression is used to motivate patients with disabilities through their physical interaction.

My project is important because there is a need to explore approaches and methodologies to design appropriate user interfaces for traumatic brain injury rehabilitation applications. The theories, approaches, and techniques identified will provide me with a conceptual foundation for the development of my project. By understanding the approaches of human computer interaction designers, new media artists, and scientists, new design strategies for therapy delivery may be explored.

2.2 Virtual reality technology for disability

Over the past decade a community of researchers has been using interactive computer technologies to assist in the assessment and rehabilitation of various disabilities. This is evidenced by the number of new conferences for academic researchers who are creating interactive 'virtual reality' applications for health science.[2] In general, virtual reality is a term that implies a broad range of three dimensional computer simulated environments and associated hardware. The conventionally held view of virtual reality is one where participant-observers can be totally immersed in, and are able to interact with a computer simulated three dimensional virtual environment. Detailed descriptions of virtual reality and related technology have been extensively documented (Rheingold 1992), (Sherman and Craig 2003), (Burdea and Coiffet 2003), therefore only a cursory description will be provided here.

According to Sherman and Craig virtual reality is defined as:

> "a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (a virtual world)." (Sherman and Craig 2003)

A virtual environment is a simulation of a real or imaginary world that is generated through computer software that can be explored and interacted with in real-time. Virtual environments can be displayed via standard desktop monitors, or single screen projection; head-mounted displays which allows viewing via small monitors in front of each eye; or multiple projected room-sized screens. User interaction occurs via hardware devices that can monitor user movement. For example, the Intersense Wand ™ is a hand-held device that tracks the position and direction of the user's hand. Other

[2] For a list of associated conferences see the *International Society for Virtual Rehabilitation, ISVR*, http://www.virtual-rehab.org.

devices can provide simulations of haptic and force feedback to participants. For example, the PHANToM™ haptic stylus interface provides tactile feedback when used to explore 3D data (Burdea and Coiffet 2003).

Sue Cobb and Paul Sharkey review a decade of research and development of virtual reality for disabilities (224 articles in total) (Cobb and Sharkey 2007). The projects described by Cobb and Sharkey range from applications that assist stroke patients with their arm movement using robotics (Louriero, Collin et al. 2004), to semi-immersive interactive simulated environments for children with severe disabilities (Brooks, Camurri et al. 2002). This research community is broad and multi-disciplined, consisting of medical researchers, computer scientists, rehabilitation therapists, educators, and practitioners.

Likewise the range of interactive media, their application, and target user populations is broad. Cobb et al. describe a range of technologies, and examine how they can improve existing methods of assessment, and rehabilitation. A substantial body of evidence suggests that interactive technologies can provide alternative therapeutic solutions that support individuals with disabilities (Cobb and Sharkey 2007).

According to Cobb et al., there is much debate within the rehab community as to what constitutes the term ‘virtual reality’. In their review they identify a subset of other media to which total sensory immersion and simulated three dimensional environments do not necessarily pertain. They note that over the course of a decade of rehab research the definition of virtual reality grew to include ‘associated technologies’. This definition includes mixed reality, augmented reality, tele-rehabilitation, and fully-immersive simulated virtual environments. The definition also includes a variety user interfaces that can track a full range of human body-movements (Zhou and Hu 2004).

How users interact with virtual environments is enabled by the user interface. By user interaction, I mean the relationship between the computer response and the user on each other’s actions. The range and availability of user interfaces and body-movement tracking technologies provide the user with means of interacting with, and experiencing a computer-simulated environment. The computer detects user input and modifies parameters in the virtual environment instantaneously. We may conclude that an analysis of associated technology has enabled the research community to embrace a broader range of hardware offering users interfaces to, and interaction with, multimedia computers, virtual, and real environments.

2.2.1 Virtual reality for traumatic brain injury rehabilitation

According to a number of researchers in motor rehabilitation, virtual reality may assist health-providers accelerate the recovery process and shows great potential in advancing rehab practices for traumatic brain injury (Holden 2005), (Rose, Brooks et al. 2005), (Schultheis and Rizzo 2001). The interest in virtual reality and other associated multimedia technology for brain injury rehabilitation stems from a number of perceived advantages of virtual over real-world training. Maureen Holden's review of virtual reality used for rehab finds that people with disabilities appear capable of learning movement skills using the technology (Holden 2005). Patients learning movement in virtual environments can transfer this knowledge to the real world in most cases. Holden also highlights that virtual reality can provide patients with feedback on performance and can motivate patients to endure extensive practice of movement. In Holden's review no adverse side effects have been reported in impaired populations where interactive technologies have been used to train movement abilities.

2.2.2 The ecological approach to traumatic brain injury rehabilitation

The most contentious statement in Holden's analysis relates to the transfer of movement skills learned in virtual environments to performance of the same skills in the real world. According to Albert Rizzo, the transference of training or 'ecological validity' of virtual reality has often been questioned. 'Ecological validity' means the degree of relevance or similarity that a virtual environment has in relation to the 'real' world. It directly relates to the validity of rehabilitation in improving a patients everyday functioning (Rizzo 2005).

The term 'ecological' in psychology refers to the view that behaviour or action can only be fully appreciated by understanding the nature of the interaction between the individual, the task at hand, and the structure of physical and social environment (Gibson 1979). Rizzo argues that designing virtual environments that incorporate challenges that require real-world functional behaviours may enhance the ecological validity of rehabilitation. Rizzo suggests that virtual reality systems can present patients with visually realistic virtual environments in which patient performance can be tested. This capacity of virtual reality is valuable for retraining tasks that are potentially hazardous for traumatic brain injured patients, such as navigating city streets, or preparing meals in the kitchen (Schultheis and Rizzo 2001). These examples demonstrate efforts to enhance the ecological validity of rehabilitation. Virtual reality can provide detailed, realistic environmental and task simulations that can be transferred to the real world.

However, Rizzo questions whether the audiovisual realism of virtual reality is the only factor that contributes to an ecologically valid training environment (Rizzo 2005). Rizzo points out that much effort could be consumed in improving the audiovisual realism of a virtual environment beyond a level that is really necessary to accomplish effective training. He suggests that the audiovisual realism may be secondary in importance to the way the actual tasks are performed by the patient. According to Heidi Sveistrup, physical actions that reflect real-world movement performed by the patient may have a greater contribution to the desired effect of re-learning motor skills (Sveistrup 2004). This raises the issue of designing user interfaces appropriate for traumatic brain injured patients that reflect real-world actions in ecologically valid ways

We may conclude that simulated virtual environments can represent real-world environments that in turn may enhance learning. This raises the issue how user interfaces might be designed to be comparable to similar action opportunities in the real world and thus enhance learning. If the user interface can replicate real-life movement challenges as opposed to solely recreating realistic looking virtual environments can the ecological validity be enhanced?

2.2.3 Natural interfaces for traumatic brain injury rehabilitation

Albert Rizzo identifies the design of user interfaces as the area that requires most attention in virtual reality rehabilitation research. Rizzo suggests the development of naturalistic interfaces for user interaction is of vital importance to optimise performance and improve access for patients with cognitive and motor impairments (Rizzo 2005). Rizzo notes that developers of virtual reality rehabilitation systems are often constrained to use existing computer interfaces such as joysticks, mouse, and keyboard. Using these conventional interfaces may limit the opportunities for relearning movements for traumatic brain injured patients. Rizzo points out that conventional user interfaces often fall short of the aim to foster natural interaction as they do not reflect how we interact with our environment and manipulate objects in the real world. Put simply, conventional computer interfaces do not represent how we interact with the real world to perform tasks for daily living.

Interaction designer Tom Djajadiningrat et al. criticise interaction design approaches for virtual reality. They suggest current virtual reality interfaces neglect the intrinsic importance of body movement and tangible interaction (Djajadiningrat, Matthews et al. 2007). They suggest that virtual reality interfaces rarely address the notion of motor skill and manual dexterity, or transfer our real-world movement skills into the virtual environment. According to Djajadiningrat, conventional interfaces infer that user interaction should be made as simple as possible (Djajadiningrat, Matthews et al. 2007). For example, keyboard button pushing is perceived to be simple from a perceptual-motor perspective, in so much as learning is shifted almost completely to the cognitive domain.

However, Holden suggests there is great potential for virtual reality interfaces to help traumatic brain injured patients relearn simple perceptual-motor skills (Holden 2005). For example, the movement skills required to lift a cup could be relearned through a specially designed user interface that supports a similar action. In the real world, we gain knowledge about our environment directly through our senses – vision, hearing, touch, smell, and proprioception (awareness of our body). Likewise we can utilise the same senses to obtain information about a virtual environment through the human computer interface. However, designing user interfaces for TBI patients is challenging.

After injury, movement performance in traumatic brain injured patients is constrained by a number of physiological and biomechanical factors including the increase in muscle tone that occurs as a result of spasticity, reduced muscle strength, and limited coordination of body movement (McCrea, Eng et al. 2002). More holistically, the patient's sense of position in space – their sense of embodiment is severely compromised as a result of their injury. There is much research in neuroscience that suggests that under normal circumstances, information from the human body's different sensory modalities is correlated in a seamless manner (Andersen, Snyder et al. 1997). For example, our sense of changes in the flow of visual input is associated with the rate of change in bodily movement (viz. kinaesthesis) (Warren 1995).

In traumatic brain injury, the main streams of sensory information that contribute to the patient's sense of embodiment (visual, auditory, tactile, and somatic) are fragmented as a result of their injury. According to Holden, in order to rebuild body-sense and the ability to effect action, the damaged motor system must receive varied but correlated forms of sensory input during the early phase of recovery; this is seen to maximise the opportunity for recovery (Holden 2005). From this we may conclude that multimedia environments that can help a traumatic brain injured patient correlate a sense of embodiment may assist in the acquisition of movement skills.

In summary, in this section I have provided an introductory overview of computer-mediated interventions for disability and the benefits of virtual reality technology in traumatic brain injury rehabilitation. Rizzo highlights the importance of designing ecologically valid virtual environments. This raised the issue of designing user interfaces for patients to relearn movement skills in ways that can be transferred to the real world. Developers of interactive computer systems for movement rehabilitation are often constrained to use conventional desktop interfaces. These computer interfaces often fall short of fostering natural user interaction that translates into the relearning of body movement for TBI patients. User interfaces that can help the patient to correlate a sense of embodiment may assist in the acquisition of movement skills. For this reason it is important to understand what embodiment is, and why and how it is being applied to the field of human computer interaction. In the next section I will introduce the field of human computer interaction and embodied interaction design approaches.

2.3 Human computer interaction

Understanding how users interact with computers and new technology is representative of a larger research problem in human computer interaction (HCI). The main objective of HCI is to improve the interaction between users and computers through the design of user interfaces for interactive media applications. In my review, I find that most HCI research does not take place under a single, unifying paradigm. Rather, HCI provides many theories developed by a diverse range of related research fields such as computer science, graphic design, industrial design, behavioural science, psychology, phenomenology and art (Ghaoui 2006).

However, according to Shaleph O’Neil, HCI is largely considered from a cognitive science model informed by perception and cognition theory (O'Neil 2008). There is much work in HCI based on models of how the mind works. O’Neil states that the leading theory of perception, which is at the root of the cognitive psychological approach to HCI, is Representationalism, which holds that our perceptual systems operate in similar ways to computers. The cognitive approach to HCI models the human mind and body as information processing systems much like computers. For example, Donald Norman was a great exponent of models of perception and cognition to describe the nature of human computer interaction (Norman 2002). He asserts that, like computers, we have input and output units (the senses and the limbs), a central processing unit (the brain), and memory for storing information that can be manipulated inside the processing unit.

A critique of this view emerged within human computer interaction as it evolved to face new challenges. Winograd and Flores attacked the ‘rationalist tradition’ of cognitive sciences (Winograd and Flores 1987). Winograd and Flores argued that cognitive scientific and rationalist approaches to the computer are fundamentally flawed because they are essentially reductionist in character. By this they mean that cognitive approach defined our reality too narrowly, in order to cope with complexity. As an alternative, Winograd and Flores offered the phenomenological theory of Heidegger’s ‘being in time’ or ‘being-in-the-world’ as an approach to design. O’Neil discusses how this phenomenological approach challenged the dominance of the mind-body split of the rationalist cognitive approaches. This debate is useful as it draws our attention to HCI research based on phenomenology that emphasise human action (including cognition) as embodied actions.

2.3.1 The embodied approach to human computer interaction

According to O’Neil the notion of embodiment in cognitive science has shifted human computer interaction away from modeling complex cognitive mental processes as the basis of understanding interaction. Rather, embodiment has shifted HCI toward reinstating the body as the central site where interaction occurs (O'Neil 2008). This shift has been fundamental to building new theories for HCI from ideas that have developed out of Gibson’s ecological psychology (Gibson 1979), and other strands of phenomenological thought such as Heidegger, Schutz and Merleau-Ponty.

There is much work from the cognitive sciences that shows how spatial and even linguistic concepts are assembled from action or draw meaning by virtue of being grounded by the moving and feeling body (Barsalou 2008) (Glenberg and Kashak 2002). For example, terms like ‘feeling down’, ’on top of the world’, and ‘behind the eight-ball’ all seem to be derived from our previous experience of real-world interactions with objects and environments. According to psychologist James Gibson, the term ’embodiment’ concerns the reciprocal relationship that exists between mind, biology and the environment (Gibson 1979). The central point of Gibson's theory was his explicit refusal of the dichotomy between *action* and *perception.* Gibson states "So we must perceive in order to move, but we must also move in order to perceive" (ibid p.223). Put simply, the notion of embodiment foregrounds the way the human body processes information and makes sense of the world (Anderson 2003). The term 'embodied cognition' is used to capture this seamless relationship between the performer, the task at hand, and the environment (Garbarini and Adenzato 2004). A mental construct or concept gains structure from the experiences that gave rise to it (Mandler 1992). This embodied view of human performance is consistent with trends in human computer interaction.

According to O'Neil the notion of 'embodiment' has grown in influence with respect to the design of interactive systems. This can be seen in the diverse range of research that is contributing to the field of embodied interaction. For example, O'Neil draws on phenomenology, the ecological theory of Gibson, and semiotic theory as a way to understand embodied interaction and meaning in new media (O'Neil 2008). Dag Svanæs promoted the application of phenomenology of Merleau-Ponty to understand interactivity (Svanæs 2000). He notes phenomenology's first-person focus of the lived body and its relation to the environment enables the understanding of interaction from the user's perspective. Eva Hornecker et al. proposed 'embodied facilitation' as a major theme in her framework for the design of tangible interaction systems. She describes how the configuration of material objects and space affects and directs emerging group behaviour (Hornecker 2005) (Hornecker and Buur 2006).

Kinaesthetic aspects of technology interactions have been explored by researchers such as Tom Djajadiningrat et al. (Djajadiningrat, Matthews et al. 2007), and Astrid Larssen et al. (Larssen, Robertson et al. 2007). Their approach to interaction design takes into account a perceptual-motor view of how the human body establishes relationships with computer systems. More recently the aesthetic aspects of human-computer interaction are explored by designers such as (Petersen, Iversen et al. 2004) (Locher, Overbeeke et al. 2009) (McCarthy, Wright et al. 2008). This strand of research describes phenomenon related to user experience termed as 'aesthetic interaction'. According to this view the aesthetics of an artifact emerge out of a dynamic interaction between a user and an interactive system. Aesthetic interaction is conceptualised in terms of a pragmatist aesthetic account of human experience. According to McCarthy et al. the pragmatic approach emphasises the felt-life of the user.

Several researchers in human computer interaction point out that Paul Dourish is particularly notable in his sustained attempt to describe the nature of computer user experience as an embodied phenomenon (O'Neil 2008) (Djajadiningrat, Matthews et al. 2007) (Hornecker 2005). Dourish explores the role of embodiment in the design of interactive technologies (Dourish 2001). He provides a foundational understanding of embodied interaction toward a way to conceptualise a design framework. This design framework is focused on a first-person, lived experience in relation to a computer environment. His framework is used in a practical way to understand the design opportunities of embodied interaction in ways that focus on tangible user interfaces, physical representation, and social interaction.

For example, according to Dourish the ‘tangible computing’ approach to interaction design capitalises on our physical skills and our familiarity with real-world objects. Tangible user interfaces (TUIs), for instance, aim to exploit a multitude of human sensory channels otherwise neglected in conventional interfaces and can promote rich and dexterous interaction (Ishii and Ullmer 1997). TUIs are physical objects that may be used to represent, control and manipulate computer environments. This represented a major transition from the graphical user interface (GUI) paradigm of desktop computers to interfaces that transform the physical world of the user into a computer interface. The Nintendo Wii remote controller could be considered a tangible user interface.

To conclude, in this section I introduced the field of human-computer interaction as a way to explore an embodied view of human performance with computers. Embodied interaction is seen as fundamental to ways of theorising the relationships between embodied actions and technology design and use. We have seen that Dourish et al. share a realisation that the body constitutes our very possibilities for interaction in, and knowledge of, the world. Their research suggests that the basis of interaction design should focus on a first-person, lived, body experience and its relation to the environment. An embodied approach to user interaction may assist me to design computer interfaces that can help traumatic brain injured patients correlate a sense of embodiment. In the next section I will provide examples of artists and rehabilitation therapists who explore embodied interactive user experiences as an aesthetic approach to their work.

2.4 Embodied interaction in new media art & design for rehabilitation

In parallel to the body of HCI research, interactive media artists have made significant contributions to development of physical interfaces and embodied interactive experiences. Rather than celebrate the perceived bodiless existence once supported by virtual reality technology where the user 'disappears' into a virtual environment through a given apparatus, they strive to question the effects of technology by making the viewer question the mediation of user interfaces and their own embodied experience.

According to artist and media theorist Anna Munster, various artists over the years have responded to the appearance of new technology in uniquely concrete and physical ways (Munster 2006). Various artists and designers have engaged embodiment and the technologised body, investigating how technology changes our understanding of the human senses. These approaches are primarily driven from aesthetic concerns which locate how the human body interacts with technology.

For example, this approach is reflected in the work of artist and technologist Myron Krueger, who provides us with an example of embodied performance in media art through his art work *VIDEOPLACE* (Krueger, 1991) pp. 33-64. Krueger speculated that this particular work could be used in the service of traumatic brain injury movement rehabilitation (ibid: pp. 197-198). Krueger developed a computer vision system as an interface to track the body gestures of users interacting with *VIDEOPLACE*. This interface could be programmed to be aware of the space surrounding the user and respond to their behaviour in a direct manner. Participants could move virtual objects around the screen, change the objects' colours, and generate electronic sounds simply by changing their gesture, posture and expression to interact with the on-screen graphic objects. Here, Krueger explored embodiment between people and machines by focusing his artwork on the human experience of interaction and the interactions enabled by the environment.

In recent years, there has been considerable interest in combining media art and interactive technology as a means to engage people in physical therapy (Brooks and Hasselblad 2004). For example, technological and creative elements of Krueger's work can be seen in the genealogy of recent rehabilitation systems that provide playful and creative experiences for disabled participants. Artist Tony Brooks et al. developed an abstract audiovisual art work that aimed to enhance the quality of life for severely disabled children (Brooks, Camurri et al. 2002) (Hasselblad, Petersson et al. 2007).

Simple movements and gestures of the user body are used to control abstract audiovisual virtual environments. Brooks et al focus on playful and creative experiences for disabled participants. Referring to these environments as ‘aesthetic resonance environments’ , they write that “the response to an intent is so immediate and aesthetically pleasing as to make one forget the physical movement (and often effort) involved in conveying the intention” (Brooks, Camurri et al. 2002).

In an analysis of their work, they point to the motivational potential of the medium in the form of novelty and curiosity through self-expression within an interactive environment (Brooks, Camurri et al. 2002). They observe that the audiovisual feedback in their virtual environment is so compelling that the user is motivated to reach new dimensions of expression through curiosity and exploration. The application enables severely disabled patients to become artistic creators of image and sound compositions through user interaction and real-time audiovisual feedback.

In a different approach with impaired children, Sue Cobb et al. (Cobb, Mellett et al. 2007) use computer vision technology to track the beams of handheld flashlight torches to activate audiovisual content and projected special effects. The technology brings to life objects and areas of the environment merely by shining a torch in a desired direction. This form of user interaction provides means for the children to explore their immediate environment through physical and tangible interaction. Their work was shown to effectively support body awareness and movement in children with severe neuro-motor disabilities.

To conclude this section, I have introduced Krueger et al. who explore the experience of embodied user interaction through creativity and play. Krueger et al. suggest that interactive media art has great potential to empower those with disabilities to increasingly engage with the world around them in ways never before achievable. The issue of maintaining user engagement underlines the importance of designing therapeutic tasks and environments that can be presented in an aesthetically meaningful and stimulating way. Maximising a patient’s engagement in relevant and pleasurable activities may complement existing, often tedious, approaches to rehabilitation.

2.5 Conclusions

To conclude, in this chapter I provided a broad introductory overview of interactive computer mediated technologies for rehabilitation. According to Cobb et al., this research community has embraced a broad range of technology offering users' interfaces to, and interaction with, multimedia computers, virtual and real environments (Cobb and Sharkey 2007). A substantial body of evidence suggests that interactive technologies can provide alternative therapeutic solutions that support individuals with disabilities. In particular virtual reality has been shown to improve performance and manual dexterity in patients suffering from traumatic brain injury (Holden 2005).

However, the ecological validity of virtual environments is questioned; that is, the degree of relevance or similarity that a virtual environment has relative to the 'real' world. For example, conventional computer interfaces such as mouse and keyboard do not represent how we interact with real environments. These interfaces may distort the relearning of movement for traumatic brain injured patients. Conventional interfaces shift the interaction from perceptual-motor actions to cognitive decision processes (Djajadiningrat, Matthews et al. 2007).

Albert Rizzo suggests the development of naturalistic interfaces for user interaction is of vital importance to optimise performance and improve access for patients with cognitive and motor impairments (Rizzo 2005). Opportunities for patient interaction with a virtual environment (e.g. body movement, object manipulation) could be designed to be comparable to similar opportunities in the real world and thus enhance learning. However in traumatic brain injury, the main streams of sensory information that contribute to their sense of embodiment are fragmented as a result of their injury. We may speculate the design of user interaction and the user interface that can correlate our sense of embodiment may assist in the acquisition of movement skills that transfer to the real world. In this regard, design that supports an embodied view of performance is of particular interest.

The notion of embodiment foregrounds the way the human body processes information and makes sense of the world (Anderson 2003). We have seen Dourish et al. argue that the basis of human computer interaction should focus on a first-person, lived, body experience and its relation to the environment. The embodied interaction strand of HCI research emphasises human action as embodied actions. According to

O’Neil, this theoretical approach instates the body as the central site where user interaction occurs with computer systems (O'Neil 2008).

Human computer interaction designers are striving to link the user’s physical environment and the body with computer environments through the user interface. According to Dourish, the embodied approach to interaction design capitalises on our physical skills and our familiarity with real-world objects. My challenge is to synthesis an embodied approach to user interaction to create a conceptual framework for the design of my project. An embodied approach may begin to address the ecological concerns of therapists who use virtual environments that aim to foster the relearning of movement in TBI patients.

O’Neil suggests that Dourish’s notion of embodiment is useful to conceptualise design approaches that focus on physical aspects of user interaction (O'Neil 2008). Dourish’s insight opens up the way for how we conceive of user experiences in computer interaction. Therefore in Chapter 3 I will explore Dourish’s five foundations of embodied interaction in more detail to inform the conceptual and critical framework of my exegesis. Dourish’s foundations may provide me with a design framework for my project.

Chapter 3: Conceptual Framework:

According to human computer interaction designer Paul Dourish, how may we define the embodied nature of user experience with interactive media?

3.1 Introduction

One of the more important observations in Chapter 2 was that developers of interactive computer systems for movement rehabilitation are often constrained to using conventional desktop interfaces. These interfaces often fall short of fostering natural user interaction that translates into the relearning of body movement for brain injured patients. This raises the issue of how to design user interfaces that might correlate a patient's sense of embodiment in ways that help in the acquisition of movement skills. For this reason it is important to understand what embodiment interaction is, and why and how it is being applied to the field of human computer interaction. In this regard Paul Dourish is notable in his sustained attempt to describe the nature of computer user experience as an embodied phenomenon. Therefore, according to Paul Dourish, how may we define the nature of embodied user experience with interactive media?

To address this question, I will lay out Dourish's key foundations of embodied interaction. Dourish describes five foundations which he suggests play a central role in understanding embodied interaction: 'ontology', 'intersubjectivity', 'intentionality', 'coupling', and 'metaphor'. Figure 2 outlines Dourish's five interrelated theoretical perspectives informing the conceptual and critical framework of this exegesis.

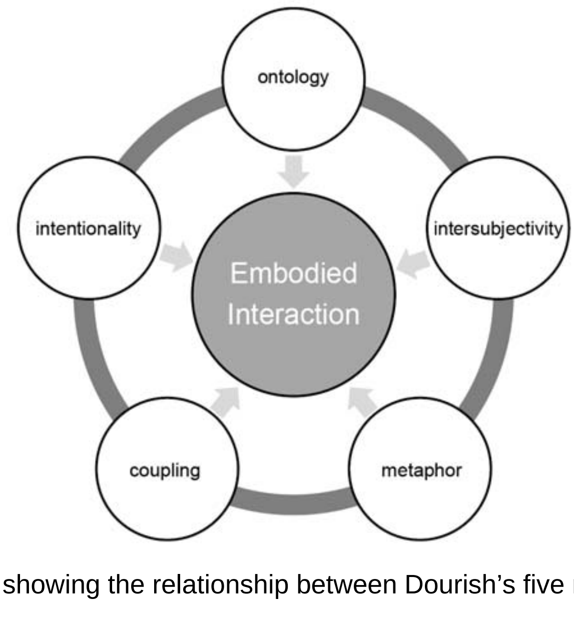

Figure 2: Diagram showing the relationship between Dourish's five main foundations of embodied interaction used to develop my project documented in this exegesis.

In Section 3.2, I will discuss Dourish's notion of embodied interaction. I will introduce two related streams of human computer interaction research in 'tangible and ubiquitous computing'*.* According to Dourish, embodied interaction directly relates to these areas of research*.* In Section 3.3, I will explore each of Dourish's five foundations of embodied interaction in more detail.

3.2 Embodied Interaction according to Paul Dourish

Dourish describes embodied interaction as an approach that hinges on the relationship between user action and meaning. In his book *Where the Action Is: The Foundations of Embodied Interaction,* Dourish asks which sets of human skills computing devices should be designed to exploit. He states "We need new ways for interacting with computers, ways that are better tuned to our needs and abilities" (ibid. p.2). According to Dourish, the only way to make this possible is to better understand the nature of our world, that is, the lived world of our experiences. He explains:

> "As physical beings, we are unavoidably enmeshed in a world of physical facts. We cannot escape the world of physical objects that we lift, sit on, and push around, nor the consequences of physical phenomena such as gravity, inertia, mass and friction. But our daily experience is social as well as physical. We interact daily with other people, and we live in a world that is socially constructed. Elements of our daily experience – family, technology, highway, invention, child store, and politician – gain their meaning from the network of social interactions in which they figure. So, the social and the physical are intertwined and inescapable aspects of our everyday experience." (ibid. p 99)

Here, Dourish draws our attention to the complex ways we make meaning from our everyday interaction with the world around us. This leads him to question whether our daily experience and interactions within physical and social realities could be exploited to make interacting with computers more familiar to us.

Dourish hypothesises that the underlying theme that unifies the social and physical aspects of our everyday life is the notion of 'embodiment'*.* For Dourish, embodiment does not just mean a manifestation of our physical reality, but "being grounded in everyday, mundane experience" (ibid. p.125). By this, he implies that we create meaning by engaging with, and acting in, the everyday world. Our ability to act in and upon our environment is what gives our lives meaning. He suggests the notion of embodiment may provide insight into the nature of user experience and the user's body in relation to interaction with computers.

To clarify the notion of embodiment, Dourish attempts to distinguish between user interactions that occur in the real world from those that are computer simulations of the real world. Dourish references virtual reality to highlight this difference. As previously discussed in Chapter 2, the objective of VR is to immerse the senses of the user in a three dimensional virtual environment. These simulated environments primarily exploit the user's audiovisual perceptions of the real world (Burdea and Coiffet 2003). Head-mounted displays and large wrap-around computer screens direct the user's cognitive and perceptual attention to a virtual environment. A virtual environment exploits our familiarity with the structure of our three dimensional world through computer-generated perspective geometry that simulates a real-world environment.

Dourish suggests virtual reality interfaces make users less aware of the physical world around them. Djajadiningrat et al. agree that virtual reality neglects our embodied view of the world (Djajadiningrat, Matthews et al. 2007). They state:

> "VR environments which generate shared 3D virtual spaces, objects and actors, re-present a re-constructed world that, no matter how intricately detailed, shares only selective and superficial similarity to the world in which we have embodied familiarity. In this sense, they cannot seamlessly enable us to transfer our understanding of the world and its various meanings to our interaction with the system." (ibid. p. 61)

Dourish elaborates further that virtual reality user interfaces do not necessarily constitute how we act in the real-world:

> "… in an immersive virtual-reality environment, users are disconnected observers of a world they do not inhabit directly. They peer out at it, figure out what's going on, decide on some course of action, and enact it through the interface of the keyboard or the data-glove, carefully monitoring the result to see if it turns out the way they expected. Our experience in the everyday world is not of that sort." (Dourish 2001) p. 102

According to Dourish, the difference between our 'inhabited' interaction in the real world and the disconnected user observation and user control of virtual reality is at the centre of his proposition for embodied interaction. He states, “We inhabit our bodies and they in turn inhabit the world, with seamless connection back and forth” (ibid. p 102). Dourish’s central concern of embodiment is that we encounter phenomena directly rather than abstractly, occurring in real time and real space.

Dourish suggests a form of human computer interaction research called ‘tangible and ubiquitous computing’ to reflect this central concern with embodiment. According to Dourish, tangible and ubiquitous computing is dedicated to re-considering the nature and design of computer interfaces, so that we can bring the computer more fully into our world (Dourish 2001). He elaborates that tangible and ubiquitous computing:

> “…attempts to capitalize on our physical skills and our familiarity with real-world objects. It also tries to make computation manifest to us in the world in the same way as we encounter other phenomena, both as a way of making computation fit more naturally with the everyday world, and as a way of enriching our experience with the physical. It attempts to move computation and interaction out of the world of abstract cognitive process and into the same phenomenal world as other sorts of interaction.” (ibid. pp. 102-103)

Dourish notes that his notion of embodiment is particularly effective in understanding tangible and ubiquitous computing where the embodied behaviours of users take place. By this, Dourish means tangible and ubiquitous computing relies on the tangibility of user interfaces and full-body interaction that gives material and spatial form to our experiences with computers. For example, in traditional desktop computing, the screen is merely a window through which we perceive the digital world. According to Dourish, designing user interfaces requires not only the design of the virtual environment, but also the physical, spatial, and social aspects of user interaction in relation to computer environment. Tangible and ubiquitous computing uses real-world objects to direct modes of user interaction. As indicated in the introduction, I will discuss tangible and ubiquitous computing in the next two sections.

3.2.1 Tangible computing

There are several research efforts that link physical user interfaces to applications in virtual environments. Hiroshi Ishii (Ishii and Ullmer 1997), Brygg Ullmer (Ullmer 2002), George Fitzmaurice (Fitzmaurice, Ishii et al. 1995), and Kenneth Fishkin

(Fishkin 2004) are pioneers of tangible computing. Their work seeks to extend and enhance user interaction beyond conventional user input devices such as keyboards and mice. In their seminal paper on ‘tangible bits’ Ishii and Ullmer aimed to design a technology that bridged the gap between the computer world and the physical environment by making digital information (bits) tangible. Ishii et al. sought to create a new form of human computer interaction that they called tangible user interfaces (TUIs).

Ishii et al. defined TUIs as interfaces that “augment the real physical world by coupling digital information to everyday physical objects and architectural environments” (Ishii and Ullmer 1997). Their approach to interface design aimed to exploit a multitude of human sensory channels otherwise neglected in conventional interfaces, and to allow rich and dexterous skilled interaction. They suggested that we may be losing the rich culture and language we have developed in the past when we ignore the aesthetic richness that comes of manipulating physical objects in the real world, and replace it instead with a flood of digital mediating technologies. Counter to this trend, Ishii et al. recognised that computers can be embodied in physical devices that could exist as tangible artifacts of the physical world.

3.2.2 Ubiquitous computing

Mark Weiser and Pierre Wellner pioneered ubiquitous computing in a research program at the Xerox PARC Computer Science Labs (Weiser 1991) (Wellner 1993). Weiser conceived of a new way of thinking about computers in the world. His approach takes into account the natural human environment and places the computer system into the background. Weiser argued for a computer system that invisibly enhanced the world that already exists rather than one that demands high levels of attention focused on a computer screen. Weiser envisaged computing ubiquitously incorporated into many common facets of people’s environment, operating in a transparent fashion, seamlessly integrated into the objects and activities of everyday life. He coined the term ’embodied virtuality’ to refer to the many ways in which computer data could be brought into the physical world.

Similarly, Wellner sought to combine the real with the virtual by augmenting the physical world with computational properties in what later came to be known as augmented reality. Wellner developed the DigitalDesk, which he described as analogous to a physical desktop that includes papers, pens and other office desk items that were used to interface with the virtual environment (Newman and Wellner 1992)

(Wellner 1993). Wellner envisioned making a digital desk analogous to the physical desk. Users could take advantage of their natural hand and arm skills and knowledge of manipulating multiple physical objects to make the computer more familiar, and thus requiring less training to operate.

The implementation consisted of a video projector and video camera pointing downward over the desk. The computer video camera interpreted the user's hand gestures and movement of physical artifacts. The graphical computer desktop was projected downwards onto the desk surface. The user could interact with projected digital documents by manipulating physical documents and office items to control the virtual environment. The result was a computationally enhanced desktop to support interaction with both paper and electronic documents (Figure 3). Digital documents could be moved around and edited using hand gestures tracked by the video camera. Wellner explored the boundaries of direct computer manipulation beyond more common forms of interaction (keyboard and mouse). He investigated the possibilities of manipulating both real and digital objects using tactile manipulation of real artifacts augmented with electronic properties.

Figure 3: Images of Pierre Wellner's DigitalDesk (removed due to copyright restrictions)

In summary, Weiser, Wellner, Ishii et al. believed that to support human activity, computing would move into the environment in which the activity took place. They considered how computing would manifest itself in the physical environment by making the physicality of the computation and interaction central to their research. The result is an approach to human computer interaction that has a direct focus on the interface between physical and virtual environments.

We may conclude along with Dourish that tangible and ubiquitous computing encompasses a broad range of characteristics that synthesises views on embodied interaction (Dourish 2001). He states that 'embodied interaction' is not simply a form of interaction that is embodied, "but rather an approach to design and analysis of interaction that takes embodiment to be central to, even constitutive of the whole phenomenon of user interaction" (ibid. p102). The approach to tangible and ubiquitous computing relates to the tangibility and materiality of the user interface, physical embodiment of data, and the human body as an essential part of user interaction and user experience.

3.3 The foundations of Embodied Interaction according to Paul Dourish

Dourish notes that embodiment is a common theme running through philosophy and in particular phenomenology. To establish a philosophical position, Dourish examines the literature of four phenomenological thinkers – Edmund Husserl, Martin Heidegger, Alfred Shutz, and Maurice Merleau-Ponty (Dourish 2001). The phenomenon of embodiment is concerned with how we make the world around us meaningful in relation to how we act within it. Dourish defines embodiment and embodied interaction as:

> "Embodiment is the property of our engagement with the world that allows us to make it meaningful." (ibid. p. 126)

> "Embodied interaction is the creation, manipulation, and sharing of meaning through engaged interaction with artifacts." (ibid. p. 126)

Dourish identifies that the relationship between 'action' and 'meaning' is central to embodied interaction. He states "The core idea of an embodied interface is the ability to turn action into meaning" (ibid. p. 183). How embodied interaction turns action into meaning is part of the larger system of ontology, intersubjectivity, and intentionality.

Dourish describes five foundations of how meaning manifests itself through 'ontology', 'intersubjectivity', 'intentionality', 'coupling', and 'metaphor'. He suggests these foundations play a central role in understanding embodied interaction*.* The foundations are particularly effective in theorising the relationships between embodied actions and technology design and use. In the next section, I will begin to lay out Dourish's foundations for embodied interaction and their implications for design.

3.3.1 Dourish's first foundation: Ontology

Dourish explains that ontology is a branch of metaphysics concerned with the existence and identification of objects and entities (Dourish 2001) pp. 129 -131. He states "…ontology addresses the question of how we can individuate the world, or distinguish between one entity or another; how we can understand the relationships between different entities or class of entity; and so forth. Ontology deals with how we can describe the 'furniture of the world' (ibid. p.129)*.* According to Dourish, ontology essentially arises from a state of awareness in which we continually assess our relationship to the objects in the world. In short, we uncover meaning in the world through our interactions with it.

Dourish suggests the ways in which we understand the ontological structure of the world relate to James Gibson's ecological term of 'affordance'. As discussed in Chapter 2, Gibson was a psychologist who explored the relationships that exist between the mind, biology, and the environment (Gibson 1979). Gibson was primarily concerned with visual perception; with how living creatures can see, reorganise what they see, and act on it. Gibson posited that 'seeing' and 'acting' are deeply connected. He suggests an affordance is a three-way relationship between the environment, the organism, and an activity. In other words, an affordance refers to opportunities for interaction that meaningful objects provide in our immediate environment and in relation to our sensorimotor capacities. According to Gibson, this relationship is central to ecological psychology in the way we might understand how an organism lives and acts in the world. In short, an affordance is a property of an environment that affords action to an organism.

Donald Norman makes considerable use of Gibson's notion of affordance in the design of everyday products and computer interfaces (Norman 2002). Norman provides many examples of affordances that explore the relationship between form and function drawn from the physical environment. He suggests how affordances can make the use of a device clear to the user. For example, “a chair affords (‘is for’) support and, therefore, affords sitting. Knobs are for turning. Slots are for inserting things into. Balls are for throwing or bouncing” (ibid. p9). Norman suggests that when affordances are taken advantage of, the user knows what actions they can perform just by looking.

Dourish’s understanding of ontology ultimately leads him to question how one might ‘design’ ontology for computer systems (Dourish 2001). There are three terms that become prominent in Dourish’s discussion of ontology; the first is ‘individuate’, the second is ‘tailor’, the third, ‘participate’.

Individuate

According to Dourish to ‘individuate’ in design is to enable the user to differentiate between entities. For example, different shapes could be used to distinguish and differentiate between variations of user interfaces. The user could infer different relationships and meaning from the shape.

Tailor

The second aspect is the ability for the user to ‘tailor’ the environment. Dourish suggests an interactive system should be flexible and capable of being tailored in ways that engage users in interaction and that enable them to create their own meaning. No two people experience the world in exactly the same way. As such, certain aspects of a computer environment could be scaled and adjusted to the experience of the user. For example, a user may be able to reorganise the interface of computer aided design software to suit the commands they might often use to perform their work.

Dourish suggests the ‘configurability of space’ is an aspect of tangible computing that enables users to tailor the environment. Tangible user interfaces can be distributed and rearranged by the user to tailor and adapt a computer environment to their needs and to suit the task at hand (ibid. p. 159). Wellner’s DigitalDesk discussed in Section 3.2 provides us with an example (Wellner 1993). Here, users can reconfigure physical objects, such as pens and paper, to tailor the computer environment to their needs. By reconfiguring the spatial arrangement of objects, users can also reconfigure the computer environment.

According to Rizzo, the ability to tailor an environment to the capabilities of a patient is a key strength of virtual reality technology over conventional movement therapies (Rizzo 2005). For example, a task could be tailored to a level of difficulty most attainable and comfortable for the patient. A gradual progression of difficulty can be introduced by the therapist as the patient improves their performance.

Participate

Dourish suggests that an ontological structure is an emergent phenomenon that arises as a result of user participation with an entity. Users can individuate and tailor an environment through their participation. He states, “Embodiment is not a property of systems, technologies or artifacts; it is a property of interaction. It is rooted in the ways in which people (and technologies) participate in the world” (ibid. p. 189). According to Dourish, user participation and meaning is constantly evolving and subject to revision. Dourish argues that fluid, negotiated boundaries between users and systems rather than rigid, fixed ones are preferable participatory structures.

We may conclude that Dourish’s notion of ontology is concerned with how a user may come to understand and make meaning of a computer environment through their interaction with it. He suggests that a design may reflect a particular set of ontological concerns on the part of the designer, but ultimately it cannot provide ontology for a user. In design, meaning manifests itself as a process of ‘individuation’, ‘affordance’, and ‘tailorability’ of the interface through user ‘participation’.

3.3.2 Dourish’s second foundation: Intersubjectivity

According to Dourish, intersubjectivity is concerned with how users might share meaning (Dourish 2001) pp. 131-134. Dourish notes the problem of intersubjectivity is that, while we might all understand the world from an ontological perspective, we do not necessarily share the same understanding because we do not have access to each others’ thoughts. Dourish suggests that the problem of intersubjectivity emerges in two ways in the design of interactive systems. Both are instances of where the user of an interactive system needs to understand the intentions and motivations of another party.

The first instance concerns communication between a designer and a user, and how it is conveyed through an interactive system. Dourish suggests that an interactive system should reveal how it should be used in ways in which the designer intended it to be used. Dourish states:

> “The designer must somehow communicate to a user a set of constraints and expectations about the how the design should be used. The system can be thought of as a medium through which the designer and a user communicate. The designer’s intentions are communicated through the form of the interactive system itself, and through the ways in which its functionality is offered.” (ibid. p. 132)

The second instance of intersubjectivity for Dourish relates to the communication *between* users, *through* the system. Dourish suggests that this is not about person-to-person communication through email or video conferencing, but rather how people come to develop and communicate shared ways of doing tasks with interactive systems. He suggests that computer systems come to be “‘appropriated’ by their users and are put to work within particular patterns of practice” (ibid. p. 133).

There are three terms that become prominent in Dourish’s discussion of intersubjectivity. They are ‘constraints’, ‘expectations’, and ‘appropriation’. Each of these terms describes how meaning is shared between users and designers.

Constraints

Dourish notes that constraints are an important part of tangible computing design (Dourish 2001). Drawing on Gibson’s notion of affordances, Norman suggests logical constraints are properties of an object that are designed to constrain possible operations (Norman 2002). Norman suggests a logical constraint limits an object’s relationship to other objects, and reduces the number of alternative actions that can be performed by the user in any particular situation (ibid. p. 86). Designers strive to make explicit the functionality of a user interface through its design; a logical constraint directs users away from inconsistent uses of an artifact. A simple example of a constraint might be the physical features of two objects that interlock together in a certain way. The user can only connect them in specific ways that the designer intended in order for the user to perform a certain task or function.

Expectations

According to Dourish, expectations fundamentally reveal themselves over the course of the interaction between the user and a computer system (Dourish 2001). Users can gain an understanding of an interactive environment when the consequences of their actions become expected. In a simple example, a user may come to expect a graphic mouse cursor to move across a computer display when they move the computer mouse. In short, meaning is created when the computer responds in an expected way to the action performed by the user.

Appropriation

Dourish suggests people appropriate technology in the creation of working practices so that the two evolve around each other (Dourish 2001). According to Dourish, how users appropriate a system is shaped by how they select, interpret, share, understand, and put information to use in the course of carrying out their task whereby *meaning* is created *through* shared use of a system. This includes “what decisions people make about when and how to use the system, what expectation they have of when the system is useful and what sort of information it contains, what they know about what other people do with system, and so on.” (ibid. p. 133). Dourish highlights that designers are often surprised at the uses to which their artifacts are put, or incorporated into the activity of users. He suggests “we need to be alert to ways in which systems offer, to their users, the resources that will allow them to adapt and appropriate it” (ibid. p. 171). The designer’s activities should be one “focused on the resources that a design should provide for the users in order for them to appropriate the artifact and incorporate it into their practice.” (ibid. p. 173) However, Dourish points out that the ways users appropriate technology ultimately rest with them, and not the designer.

3.3.3 Dourish’s third foundation: Intentionality

Dourish suggests that intentionality in philosophy proposes that the ‘directedness’ of meaning is a relationship between our thoughts, memories, utterances, and their meaning (Dourish 2001) pp. 134-138. Dourish acknowledges that this is probably the hardest area to understand because there are still continuing debates in philosophy and cognitive science as to what constitutes intentionality. For Dourish, intentionality is central to his understanding of embodied interaction. Intentionality refers to how we create meaning from our action in the world. As discussed in Chapter 2, thoughts or memories gain structure from the experiences that gave rise to it. For example, the intentionality of language is assembled from action, or draws meaning by virtue of being grounded by the moving and feeling body (Barsalou 2008) (Glenberg and Kashak 2002). Terms like ‘feeling down’, and ’behind the eight-ball’ are all intentional references. They are intentional meanings of things derived from our previous experience of real-world interactions with objects and environments.

According to Dourish, interaction with computers carries with it intentional connotations (Dourish 2001). The key feature of intentionality is how we *act through* computer systems to achieve effects in the world. For Dourish, embodied interaction places particular emphasis on user interaction as an activity in the world. “There is no way to talk about action independently from meaning – not simply how action arises from conscious intent, but, more significantly, how intentionality arises from actions in the world” (ibid. p. 137). According to Dourish, intentionality provides a conceptual way to understand how the elements of an interactive system can provide users with meaning in the course of an activity. Through creating opportunities for action in a computer system, the designer must also allow for *effects* on the world that user’s actions are designed to cause. These resulting effects should allow users to create meaning from them.

Donald Norman’s examination of the structure of an action is particularly informative in further understanding the role of intentionality (Norman 2002) p. 46. Norman breaks down the action system of an individual user into three main stages; the goal or task that is to be achieved; executing an action to achieve the goal; and evaluating the results of an action and its effect on the world. Norman suggests intentionality bridges the gap between a goal and the execution of an action by informing how one might plan to execute an action necessary to reach a goal.

Here, I find similarity between intentionality and the term ‘affordance’ in design. As previously discussed, Dourish suggests that making explicit the function of an object relates to James Gibson’s central term of ‘affordance’. An affordance refers to opportunities for interaction that meaningful objects provide in our immediate environment and in relation to our sensorimotor capacities. This relationship is central to ecological psychology in the way we might understand how an organism lives and acts in the world. In short, an affordance refers to the properties of an environment or object that determines how it might be intentionally used. Making the function of an object explicit is intentional.

3.3.4 Dourish’s fourth foundation: Coupling

Dourish brings ontology, intersubjectivity and intentionality together by introducing the notion of ‘coupling’ (Dourish 2001) pp. 138 -142. Coupling is how an intentional reference is made *effective* or maintained. Dourish provides an example:

> “In the physical world, my actions can have a remote effect through a chain of couplings, from one thing to another to another – perhaps from my hand to a lever to a rock I want to move. As far as I am concerned, I am acting on the rock; from my point of view, the rock and the lever are coupled. This idea of coupling is not simply a physical phenomenon but an intentional one too. My actions are outwardly directed, through a chain of associations.” (ibid. p. 138)

For Dourish, the effective use of any tool requires the user to continually engage, separate, and reengage with it. Using his example, this process might involve the decision to start using the lever; pick it up and orient it correctly; adjust the angle of leverage in relation to the rock, perhaps put it down again. This is a process of continual user engagement and reengagement with the lever. The user needs to be aware of the lever, how it sits in their hand, how heavy it is and so forth. Dourish suggests when performing the task, such as moving the rock, the lever should ‘disappear’ into the activity. At other moments, the user would have to be aware of the lever again as they change their position in relation to the rock. According to Dourish being able to continually engage, separate and reengage, that is, being able to control the coupling, makes our use of equipment more effective.

There are two terms that become prominent in Dourish’s discussion of coupling. The first term relates to computer ‘feedback’. Feedback displays information to the user that they have performed some action and is coupled to the actions performed by the user. The second term is ‘visibility’. Visibility of computer feedback provides users with a level of awareness of their actions.

Feedback

To help us understand coupling we may consider computer feedback. Dourish highlights that computer feedback provides augmentations of a user’s embodied activity or practice. Feedback is a relationship between user input and computer output that suggests something has occurred as a result of user interaction. The computer feedback, in turn, can inform how the user responds in performing a subsequent action. For example, moving a computer mouse should move the onscreen mouse cursor in a corresponding fashion. The new position of the mouse cursor informs the user where to move the mouse next. This feedback loop between the computer and the user is a continually evolving communicative action. Dourish suggests that effective communication relies on the ability of the user to control the medium, and that feedback is an essential part of this control.

According to Holden, the provision of computer feedback is central to motor learning (Holden 2005). Scientific evidence suggests that feedback can induce profound changes to the brain at a cellular and synaptic level. Rizzo also reports that feedback can make repetitive and tedious work of physical therapy more compelling and interesting (Rizzo 2005). This suggests that feedback can provide audiovisual rewards that may lead to increased levels of motivation in patients.

Norman states that 'mapping' is an essential part of feedback (Norman 2002) p. 75*.* According to Norman, mapping means the relationship between two entities. This relationship involves an action performed by the user linked to some effect or result in the world. Norman suggests effective mapping which links user action to immediate feedback leads to the user understanding the consequences of their actions. Feedback provides each user action with an immediate and obvious effect.

However, according to Dourish, coupling is not simply a matter of mapping a user's immediate activity at any one moment into some form of computer feedback (Dourish 2001). But rather, "users can select from a variety of effective entities offered to them, the ones that are relevant to their immediate activity and second, can put those together in order to effect action" (ibid. p. 142). For example, the movement of a mouse cursor is not the only representation the user's attention might be drawn to. The user may also direct their attention to other tasks such as opening a file, or sending an email through the mouse cursor. In short, coupling is the action of binding entities together so that they can operate together to provide a new set of functions.

Visibility

Dourish relates visibility to 'feedback' and 'shared feedback' in a collaborative work setting (Dourish 2001). Feedback displays information to the user letting them know they have performed some action. In shared feedback where there is more than one user, all users will see the results of an action as they all see the same artifact. Shared feedback allows groups of people to coordinate their activity together as ongoing feature of their work. Both accounts make the system visible and intelligible to the users, so that they can manage their actions appropriately to the current state of the system.

According to Norman, visibility bridges the gulf between 'execution' and 'evaluation' in performing a task (Norman 2002). Execution relates to carrying out a task. Evaluation relates to the user comparing what happened in the world with what the user wanted to happen in performing a task. Norman suggests visibility acts in two ways (ibid. p 183). Firstly, visibility can remind users of the possibilities for action in execution of a task. Secondly, visibility of effects in the environment can enable users to interpret and evaluate the consequences of their actions. Visibility makes the execution and evaluation of a task visible to the user. In this way, users can learn the causal relationships between actions and outcomes.

3.3.5 Dourish's fifth foundation: Metaphor

According to Dourish, a metaphor may suggest some sort of action that can be performed by the user. Dourish notes that user interface metaphors provide the best uses of coupling in interactive systems. Metaphor and coupling provide ways for how meaning is made manifest from moment to moment and turned to use. For example, we come across metaphors of all sorts that describe the familiar aspects of the real world in many user interfaces, such as windows, desktops, and buttons. Other metaphors in user interfaces suggest actions such as 'dragging', 'dropping', 'cut', and 'paste'. In virtual reality, metaphors are used to guide actions and help users understand how to interact with three-dimensional environments. These might be literal architectural metaphors in the forms of streets, roads, doors, and buildings in a driving simulation. Dourish argues:

> "Metaphor is such a rich model for conveying ideas that it is quite natural that it should be incorporated in the design of user interfaces. The use of metaphor essentially extends the intentional range of systems by providing new ways to conceive of one's actions in the system, and providing new entities for us to be directed toward." (ibid. p. 143)

According to Dourish, "Systems or artifacts supporting embodied interaction need to be designed with an orientation toward the multiple meanings that may be conveyed through them" (ibid. p.167). Dourish suggests that meaning can be conveyed in numerous ways, which can be approximately characterised as aspects of representation of an entity along two dimensions – 'iconic/symbolic' and 'object/action'.

Iconic/Symbolic

The first dimension describes a relationship between a representation, and whatever it is supposed to represent. According to Dourish, a symbolic representation is abstract, and does not necessarily represent the entity itself per se. Using Dourish's example; the number '1' means the number one at a symbolic level. In contrast, an iconic representation depicts the entity it is supposed to represent. For example, an architectural drawing is an iconic representation of a building or structure due to the fact that it is a depiction of the building it represents. The composition of the drawing suggests a recognisable relationship to the planned building.

Object/action

The second dimension relates to the entity to which the representation refers (Dourish 2001). "We distinguish between representations of objects – people and other entities – on one hand, and of actions – events, operations, and behaviours – on the other." (ibid. p. 167). For example, in Wellner's DigitalDesk, the physical user interface, such as a pen, is more suggestive of an action that can be performed (Wellner 1993). I can perform the action of picking up and writing with the pen. In contrast, the paper is more suggestive of an object. The paper is designed to receive my applied action of writing. However, both the pen and the paper can be perceived as both action and object at varying levels.

For Dourish, an embodied interaction approach changes how designers conceptualise the relationship between representation, objects and action (Dourish 2001). He suggests traditional design-approaches maintain clear distinctions between object and action, and representation and object. According to Dourish, an entity can be representational, object, and action simultaneously, carrying different meanings, values and consequences.

> "What embodied interaction adds to existing representational practice is the understanding that representations are also themselves artifacts. Not only do they allow users to 'reach through' and act upon an entity being represented, but they can also themselves be acted upon – picked up, examined, manipulated, and rearranged" (ibid. p. 169).

Dourish highlights the way artifacts can carry multiple meanings for users according to the different ways they might be used, and that some, or all, aspects of meaning might play a role at any given moment. To conclude, Dourish suggests the designer of interactive systems needs to consider how representational effect is embodied within an artifact, how different levels of representation can be manipulated, and how the users control whether they are acting 'on' or 'through' an artifact.

3.4 Conclusions

In this chapter I have attempted to answer my first research question: ‘According to Paul Dourish, how may we define the nature of embodied user experience with interactive media?’ We began this chapter by exploring how Paul Dourish defines the nature of embodied user experience with interactive media. Dourish turns our attention to how we encounter the everyday world. His view of embodiment focuses on facets of meaning and action which play a role in understanding embodied interaction. Dourish recognises that his notion of embodiment is particularly effective in understanding tangible and ubiquitous computing where the embodied behaviours of users take place. Embodied behaviours occur in space (or the environment), through the body, and with sustained engagement with physical artifacts. Tangible and ubiquitous computing relies on the tangibility of user interfaces and full body interaction whereby the computer respond in natural ways to physical user input.

According to Dourish, his perspective on embodied interaction begins to reveal not just how we act *on* technology, but how we act *through* technology. Dourish’s view focuses on facets of meaning which play a central role in understanding embodied interaction. For Dourish, meaning involves a set of related but distinct phenomena, including ontology, intersubjectivity and intentionality.

Ontology is concerned with how users may come to understand and make meaning of a computer environment through our interaction with it. In design, meaning manifests itself as a process of ‘individuation’, ‘affordance’ and ‘tailorability’ of the interface, and through user ‘participation’.

Intersubjectivity is concerned with how users appropriate a system by how they select, interpret, share, understand, and put information to use in the course of carrying out their task whereby *meaning* is created *through* shared use of a system. ‘Constraints’, ‘expectations’, and ‘appropriation’ each describe how meaning is shared between users and designers.

Intentionality concerns the directness of one’s actions and the effects that one’s actions are designed to cause. According to Dourish, coupling is how an intention is maintained and made effective. Coupling relates to ‘feedback’ and the ‘visibility’ of user action possibilities and outcomes. Coupling brings together and manages the relationship, i.e. the connection between individuating an artifact, directing an intention toward the artifact, its effect on the world, and the people who witness the effect.

Metaphor extends the range of intentions by providing ways for users to orient themselves toward an interactive system. Meaning can be characterised in approximate ways as aspects of representation of an entity along two dimensions – ‘iconic/symbolic’ and ‘object/action’.

Each foundation offers design perspectives at an abstract conceptual level and defines broad research concerns regarding the embodied nature of user experience. However, presenting Dourish’s foundations is problematic. They overlap and interact in ways that I find are not distinct. Each foundation generalises conceptual design-approaches but do not provide specific design recommendations. The foundations are not prescriptive, and thus need to be interpreted, expanded, and appropriated for other situations. It is therefore important to examine a case study to further explore the techniques a designer applies as they relate to embodied interaction.

In the next chapter, I will use Dourish’s five foundations for embodied interaction to analyse the techniques of artist Myron Krueger. Krueger provides us with an example of embodied performance in media art through his work *VIDEOPLACE*. (Krueger, 1991) pp. 33-64. Krueger explored embodiment between people and machines by focusing his artwork on the human experience of interaction and of the interactions enabled by the environment itself. I will consider each foundation as a starting point to discuss design aspects of this case study.

Chapter 4: Case Study:

How may we observe Dourish's theory for embodied interaction in the techniques of new media artist Myron Krueger?

4.1 Introduction

One of the key understandings in Chapter 3 was that Paul Dourish defines embodiment as a relationship between action and meaning. His view focuses on facets of action and meaning and how they play a role in understanding embodied interaction with computer systems. Dourish's definitions serve to explain, to relate, and develop an approach to tangible and ubiquitous computing. Therefore it is likely that designers of multimedia environments that link physical and virtual environments may relate to Dourish's notion of embodied interaction. It is important to examine a case study to further explore techniques the designer applies to aspects of embodied interaction. Artist and technologist Myron Krueger provides us with an example of embodied performance in media art through his work *VIDEOPLACE* (Krueger, 1991: pp. 33–64). As noted in Chapter 2, this case study has significant similarities to a number of current researcher projects in the field of movement rehabilitation. How may we observe Dourish's theory for embodied interaction in the techniques of new media artist Myron Krueger?

I will address this question by firstly discussing Krueger's pioneering work *VIDEOPLACE* in more detail. I will then relate to Dourish's five foundations for embodied interaction with Krueger's techniques used to develop *VIDEOPLACE*. Analysing Krueger's design techniques through Dourish's framework may inform my own design approach.

4.2 An artificial reality: *VIDEOPLACE*

Myron Krueger is widely acknowledged for pioneering novel forms of human computer interaction using video capture techniques that interpret full body movement. In his book *Artificial Reality II* he describes an interactive virtual environment called *VIDEOPLACE* (Krueger 1991). In developing *VIDEOPLACE* Krueger explored how users interact with computers utilising a video capture technique that interprets the body's position relative to a computer simulated graphical environment. Krueger coined the term 'artificial reality' that he defines as "a medium of experience":

"An artificial reality perceives human actions in terms of the body's relationship to a simulated world. It then generates sights and sounds, and other sensations that make the illusion of participating in that world convincing." (ibid. p. xii)

The *VIDEOPLACE* installation consists of a large rear projection screen and video camera which the participant faces. Using a high contrast background behind the participant, the live video camera digitises the participant's silhouette, which in turn is projected onto the screen in front of them. The computer system is able to isolate and analyse the body's silhouette to distinguish posture, gesture, and rate of movement in relation to the graphic objects that the user could interact with. By repeatedly stepping in and out of the installation, users could switch between approximately fifty interactive compositions of varying styles. Examples of Krueger's interactive compositions developed for *VIDEOPLACE* include *Critter*, *Medley*, and *Digital Drawing* (Figure 4).

Figure 4: Still images of *VIDEOPLACE*, Myron Krueger (removed due to copyright restrictions)

In the environment called *Critter*, participants can interact with a computer-generated insect or critter (Krueger 1991) ibid. p. 46. The critter reacts to the participant's silhouette in several ways. For example, the critter appears to chase the participant when they move their image around the screen. If the participant stands still the critter will attempt to climb up the participant's silhouette and onto their head. If the user holds out their hand the critter will attempt to float down and land on it. Krueger observed that people reacted to the critter's behaviour as if it were alive.

In the environment called *Individual Medley*, participants can create dynamic images controlled by movements of their bodies (ibid. p. 48). The work captures the participant's eight most recent silhouettes and colours them according to how they overlap. If the participant continues to move, the work will continually update. According the Krueger, the goal of this work is to communicate the pleasure of aesthetic creation.

In the environment called *Digital Drawing*, participants can draw on the computer screen using the silhouette image of their finger (ibid. p. 50). If there are several participants in the environment, each is assigned a different colour. According to Krueger, the goal of this interactive environment is to give the participant explicit creative control over the medium.

Krueger's goal was not to present a single interactive art piece, but rather to allow the users to experience a range of interactive styles so as to demonstrate the potential richness of the medium. Krueger explored embodiment between people and machines by focusing his artwork on the human experience of interaction and of the interactions afforded by the environment itself.

4.3 Embodied interaction in the work of Myron Krueger

As discussed in Chapter 3, Paul Dourish examines the way humans interact with computers in his book *Where the Action Is: The Foundations of Embodied Interaction* (Dourish 2001). Similarly, Myron Krueger asks "What are the various ways in which people and machines might interact, and which of these is the most pleasing?" (Krueger 1991) p. xii.

Krueger's work draws many parallels with Dourish's theory for embodied interaction. For example, Krueger is concerned with the study of computer interfaces that enable user interaction similar to how we act in the physical world. To quote Krueger:" It was clear that the ultimate computer should perceive the human body, listen to the human voice, and respond through all the human senses" (ibid. p. xiv). Krueger is also interested in the relationship between action and meaning. He states:

> "Just as music addresses the intellectual machinery with which we understand sounds – particularly speech sounds – artificial realities can touch the primitive mechanisms through which we apprehend physical reality. The environmental experience can be composed in terms of our abstract sense of space and objects and the expectations we have for the effects of our actions on the world." (ibid. pp. 92-93)

Ultimately, Krueger describes his ideas, techniques and methods for developing his interactive systems. His methods rely on user interactions that occur in space, through the human body, and with sustained engagement with computer environments. In short, there are direct connections between how Dourish understands user interaction as an embodied activity, and Krueger's artistic and often experimental computer implementations. This should be no surprise, as Krueger's work has environmental similarities to the pioneering work in ubiquitous computing discussed in Chapter 3.

Furthermore, Krueger intuitively speculated that *VIDEOPLACE* could be used in the service of traumatic brain injury movement rehabilitation. (ibid. pp. 197–198) To quote Krueger: "Artificial realities have an important implication for the physically handicapped. They provide a powerful medium for translating what is limited physical activity in the real world into full participation in a radically different graphic environment" (ibid. p. 196). Krueger observed that *VIDEOPLACE* may provide traumatic brain injured patients with the motivation to perform otherwise repetitive and often tedious movements of affected limbs. Krueger suggests that the virtual environment could be scaled to respond to the limited movement capacities of users. The patient could be invited to perform some physical action and be rewarded with some form of compelling computer generated feedback.

In the next section, I will refer to Dourish's five foundations for embodied interaction and relate them to Krueger's techniques used to develop his work. This chapter is not a complete analysis of Krueger's work. Rather, I use this case study as a vehicle for suggesting possibilities for design and to further clarify the discussion from Chapter 3.

4.3.1 Dourish's first foundation: Ontology related to Krueger

As discussed in Chapter 3, Dourish explains that ontology is a branch of metaphysics concerned with the existence and identification of objects and entities. According to Dourish, ontology essentially arises from a state of awareness in which we continually assess our relationship to the objects in the world. In short, we uncover meaning in the world through our interactions with it. Dourish's understanding of ontology ultimately leads him to ask how one might 'design' ontology for computer systems.

Here, Krueger's defines this problem as a technological one. Krueger's defines a technique he calls 'perception', which refers not to user perception, but to a computer's ability to interpret and respond to what it perceives (Krueger 1991) ibid. p. 86. The way a computer responds to the user depends on the quality and configuration of its *perceptual system*. Information about the user's behaviour can be obtained from a range of electronic sensors attached to the body or via video cameras tracking the participant's movement. According to Krueger, the configuration of these sensors and the interpreting software constitute the perceptual system. The perceptual system determines what the computer knows and thus what it will respond to. Perception is the degree to which the computer system can interpret which objects are in a physical space and where they are.

In *VIDEOPLACE*, the perceptual system incorporates a video camera that captures the movement-behaviour of a participant performing in the virtual environment. The video camera captures the user's body movements in real time (at least thirty times a second). The computer analyses the video camera feed and perceives dynamic information – such as body posture, rate and direction of participant's movement, and pitch or volume of voice. These attributes can be controlled by the participant and form the basis for user interaction. The perceptual system interprets the user's gestures such as touching, hitting, throwing, kicking, jumping, and pointing. The computer responds to these actions with predefined sets of audiovisual feedback composed by Krueger.

In Dourish's discussion of ontology he identifies how the user 'individuates', 'tailors', and 'participates' in an interactive environment.

Individuate

According to Dourish, to 'individuate' in design is to enable the user to differentiate between entities. In *VIDEOPLACE*, the user sees a silhouette of themselves projected on a video screen. The silhouette reflects their movements as they occur, which are immediately translated into some form of audiovisual feedback. The silhouette becomes the individuated self-image of the user as the key to understanding the environment projected on the video screen. Thus, the projected self-image is the known reference against which all transformations in the virtual environment are registered.

Tailored

According to Dourish the ability for the user to *tailor* the environment informs an aspect of ontology. No two people experience the world in exactly the same way. As such, certain aspects of a computer system could be scaled and adjusted to the experience of the user. Krueger does not deal with this point directly, however he does describe at length how a medium like *VIDEOPLACE* could be tailored for various applications (Krueger 1991) pp. 169-206. These include applications for training, education, and physical therapy.

Participation

User *participation* informs another aspect of ontology for Dourish. In Krueger's work, user participation formed the primary subject of *VIDEOPLACE* (Krueger 1991) ibid. pp. 91-94. By stepping into the installation, users were able to interact with fifty different virtual environments. Transformation of the user's physical body posture created an immediate effect in each of the virtual worlds. Movements of the body elicited a computer response that in turn enabled the user to create a variety of dynamic artistic compositions. The relationship between user participation and computer response enabled the user to become a creator of the artwork. By participating through user interaction, each user has the opportunity to create a unique experience. *VIDEOPLACE* generates audiovisual sensations for the user that, as Krueger notes, make participating in that world both convincing and engaging. By participating in *VIDEOPLACE*, users were able to 'complete' the art work.

Krueger observes that the user's experience of *participation* in *VIDEOPLACE* is playful (ibid. p. 90). He notes that a playful aesthetic allows the participant to explore and experiment with how to use the virtual environments. Through playful interaction, users could seek out new effects, sounds, and visual features with their bodies to see how they work. By doing so, he suggests users might discover new ways of relating to their body. Krueger's personal observations suggest playful user interaction may motivate users to participate and perform movement that they would otherwise feel inhibited to perform.

We may observe the importance of user participation and playful interaction in the therapeutic environments of Brooks et al. discussed in Chapter 2 (Brooks and Hasselblad 2004) (Hasselblad, Petersson et al. 2007). They observed an increase in the participant's level of self-esteem, achievement and behavioural skills as a result of participation in playful and creative activities. They noted that curiosity and exploration were seen to be key values in eliciting user participation.

4.3.2 Dourish's second foundation: Intersubjectivity related to Krueger

According to Dourish, the second term 'intersubjectivity', as discussed in Chapter 3, is concerned with how users might share meaning. Dourish suggests that intersubjectivity emerges in two ways in the design of interactive systems. Both are instances of where the user of an interactive system needs to understand the intentions and motivations of another party. According to Dourish, the first instance concerns how the designer communicates to the user a set of 'constraints' and 'expectations' about how an interactive system should be used. The second instance of intersubjectivity in interactive systems relates to the ways users 'appropriate' technology in the creation of working practices, so that the two evolve around each other.

Expectation

Krueger relates *expectation* to how one might maintain user interest in virtual environments for learning (Krueger 1991) ibid. p. 202-203. The user learns how to interact with the system through a range of pre-composed computer responses. He describes expectation as part of a processing of learning through the way user-actions are verified and *reinforced* by the computer system. If the user's actions are reinforced repeatedly, then the outcome becomes expected. Krueger proposes that the user will likely respond if their actions are followed by a positive outcome, or in other words, reinforced.

Krueger suggests that a general structure for maintaining user interest can be provided by composing variations of the reinforcer: "If the student knows that the response that reinforces each correct answer will be part of a continually interesting pattern, he will be motivated to persist out of curiosity about the next reinforcer. It is the maintenance of interest that is motivating rather than any intrinsic value of the reinforcer itself." (ibid. p. 203) According to Dourish, when media is modulated it transforms how it carries information. For Dourish, modulation is the carrier of embodied meaning that transforms how we might use an interactive system. Here, both Krueger and Dourish describe how varying computer feedback can change a user's action.

Krueger suggests that varying the 'reinforcers' through the course of user interaction assists in maintaining user engagement in activities that would otherwise fail to captivate them. For example, he compares a sequence of reinforcers to that of a piece of music. He suggests each single note of a musical composition could be considered a reinforcer that induces further listening. In this sense, each computer response should encourage further user interaction. Meaning is created for the user through their perception of the computer responses in relation to their interactions. Krueger suggests that a person's expectations are learned through the reinforcement of their actions. Once learned, the user's expectations can be modified over time.

Context

According to Dourish, a design constraint is a method of limiting the options for the user at any one time. It assists the user in deciding how to proceed. For Krueger, the organising principle that governs constraint is 'context' (Krueger 1991) ibid. pp. 154-157. According to Krueger, a context subsumes the user-activities through which an individual interprets the world and controls their responses. A context may include the physical environment, the user body, and the activity the individual is doing.

A context provides constraints to the activities that a user can perform at any one time. If the context can be verified from moment to moment by the user then the user can devote their attention to the task at hand. Krueger suggests context is not a fixed rigid structure but rather one that allows for change. One context should lead to another in expected and even predictable ways. However, he notes that not all situations are predictable and surprises and new situations might occur for the user.

Krueger observes that user interaction will often be unsatisfactory if the context for user interaction is continuously unpredictable, and one in which the user is not prepared for. For example, a user might find it difficult to sense their interactions if an action simultaneously affects all parameters in a virtual environment. In short, both authors agree that constraints provide the user with a frame of reference, a context within which the interaction can be perceived. The relationship between the constraint and the user reveals itself over the course of the interaction between the user and the system.

Appropriation

Krueger does not deal with the idea of user appropriation and shared use directly. However, it is highly likely, given its room-sized configurations, that *VIDEOPLACE* would enable multiple participants to engage with the work at any one time. Perhaps one person would observe another interacting with the system. A person observing another user would learn which actions were predictable, explicit, and effective in the environment. Given the wide range of interactive environments created for *VIDEOPLACE*, it is possible that users may actively and passively engage with the work through observation and direct participation. Krueger observed that each experience would be unique for each participant as they appropriate the system and interact in their own way. In fact, *VIDEOPLACE* was developed and adapted from his own observations of user interactions from a previous work called *METAPLAY* (Krueger 1991) ibid. p. 34.

4.3.3 Dourish's third foundation: Intentionality related to Krueger

As discussed in Chapter 3, Dourish suggests intentionality provides a conceptual way of understanding how the elements of an interactive system can provide users with meaning in the course of an activity. Dourish states that through creating opportunities for action in a computer system, we must also allow for *effects* on the world that our actions are designed to cause, and for users to create meaning from these effects. Dourish suggests that user interaction with designed elements of a computer system (say a user interface) carries intentional connotations.

We may observe examples of intentionality in Krueger's design in the way the system elicits user interaction in *VIDEOPLACE* (Krueger 1991). Krueger composed a variety of user interactions the interface could interpret. Through gestures such as touching, hitting, throwing, kicking, jumping and pointing, the objects in the virtual environment could be controlled.

The graphic object might bear some resemblance to a ball the user can touch and manipulate in some way, for example by lifting, pushing, or throwing it around the computer screen. Krueger states that the moment a graphic object responds to the user's actions, both the object and the experience become real (ibid. p39). The object thus implies some form of intentionality for action, and, when acted upon by the user creates some effect in the virtual environment. The relationship between a performed action and the graphic entities is based on the user exploring how the computer responds and learning the rules governing the virtual environment in the course of their activity. In this way, intentionality arises from actions in the environment.

4.3.4 Dourish's fourth foundation: Coupling related to Krueger

As discussed in Chapter 3, Dourish suggests 'coupling' is the action of binding entities so they can operate together to provide a new set of functions. Coupling is the way our actions are bound to the effects they have in a virtual environment. According to Dourish, being able to continually engage, separate, and reengage with the entities of an interactive system – that is, being able to control the coupling – makes our use of equipment more effective.

Control

We may observe coupling in Krueger's work as it relates to linking user 'control' to the computer 'response' of the interactive environment (Krueger 1991) pp. 95-96. For Krueger, it was important for the user to figure out and understand how they were influencing events in *VIDEOPLACE*. Someone's motives might be aesthetic, playful, or competitive, but regardless, users can only experience a sense of achievement and considerable pleasure if they feel that they are in control of some part of their experience, both directly and indirectly.

Krueger suggests the participant's awareness of their body is a vital part of experiencing his work. The computer system accepts input from the participant, and then responds in a manner that people can recognise as corresponding to their actions. Every user action with *VIDEOPLACE* was accompanied by some form of immediate audio/visual acknowledgement. It was the composition of the relationships between action, control, and response that was of primary importance to Krueger.

Response

Howard Rheingold recalls that Krueger's emphasis from the beginning was that "Response is the Medium" (Rheingold 1992). By this he means that the medium has the potential to elicit new kinds of human behaviour through user interaction in a simulated environment. The user interface could be programmed to be aware of the space surrounding the user and respond to their behaviour in a seamless manner. Krueger observed that users will not see a connection between their actions and the computer's response if the feedback is not consistent.

Dourish states that effective communication relies on the ability of the user to be able to control the medium, and that feedback is an essential part of this control. Feedback provides the user with an indication that something has happened. Krueger suggests feedback has to repeat long enough for the participant to perceive a responsive pattern they can control as a result of their own actions (Krueger 1991) ibid. p. 94.

Krueger notes that if the computer response is not perceived, then user frustration may quickly become apparent. Krueger centered his ideas on coupling user actions to response as a way to focus his artwork on the human experience of interaction. In short, both Krueger and Dourish suggest that coupling action to response provides users with a connection between a sense of the self and their embodied experience of the world.

4.3.5 Dourish's fifth foundation: Metaphor related to Krueger

As discussed in Chapter 3, Dourish suggests that metaphors provide a model for conveying ideas about actions that can be performed by the user. Metaphors may imply user actions such as 'dragging' or 'dropping', or familiar aspects of the real-world in the design of interfaces such as 'windows' or 'trash cans'. Similarly for Krueger, metaphor refers to the actions that are suggested by the juxtaposition of an image with a graphic object. Specifically, Krueger refers to the image of the user as the metaphor for interaction (Krueger 1991) ibid. pp. 115-117. Using his example, if the user's hand appears to be near a graphic representation of a beach ball, then the impression given to the user is that they can move the ball through their physical-participation.

However, Krueger acknowledges that there are limiting issues surrounding the physical-participation metaphor his work so heavily relies on (ibid. p. 116). There are few tasks in the real world that are performed by gesture. Gesture-based systems rely on non-contact based user interactions (body gesture in open space). According to Dourish most tasks require the coupling of physical tools to the effects in the world to mediate action. With Krueger's *VIDEOPLACE*, the vision system effectively replaced the conventional computer mouse and keyboard with an interface almost invisible to the user.

Djajadiningrat et al. note that gesture based systems struggle with meaningful relationships between form, action, and function (Djajadiningrat, Matthews et al. 2007). They suggest it seems unlikely that users have any natural affinity for gestural language. An interface almost invisible to the user provides no 'hooks' for the user's perceptual-motor system to get a 'grip' on a product interface. Rather, Djajadiningrat et al. place an emphasis on the tangibility and materiality of interfaces that users can 'touch' as a metaphor for physical user interaction. They see that the embodiment challenge for human computer interaction is to link the physicality of an interface with motor skills and manual dexterity to create a physical, contactual and dynamic fit between human and product.

Krueger proposes symbolic gestures to work around this problem (Krueger 1991) ibid. p. 116. For example, symbolic gestures in *VIDEOPLACE* enabled users to draw on the screen by extending one finger. Users could erase the drawing by pinching two fingers together, and erase the entire image by opening their hands. However, Krueger suggests that symbolic gestures should be limited in use because they conflict with natural human behaviour.

Metaphors for physical action are often ambiguous, particularly if the user's effects on the virtual environments are conferred by gesture alone. For example, a physical user action such as reaching out to touch a graphic object may result in a variety of potential outcomes. The object may be pulled toward, or pushed away from the user as a result of the interaction. However, there is no way for the computer system to distinguish and interpret between these two intentions, or for the user to predict an expected outcome.

4.4 Discussion and conclusion

In this chapter I explored my second research question: 'How may we observe Dourish's theory for embodied interaction in the techniques of new media artist Myron Krueger?' I addressed this question firstly by describing Krueger's pioneering work *VIDEOPLACE* in more detail, and secondly, I described the techniques and methods he used in relationship to Dourish's five foundations for embodied interaction. Both authors' perspectives explore the relationships between people and computer systems. Both ask similar questions that relate to unifying the physical world and computer worlds. Both suggest that meaning through action should be closely matched to our everyday experiences and abilities.

Krueger suggests user interaction and experience is derived from 'perception', 'participation', 'expectation', 'context', 'control', and 'response'. He suggests these attributes in *VIDEOPLACE* offer the user an environment in which the mind, the body, and the full human sensory world are reintegrated.

There are two aspects of *VIDEOPLACE* that are of particular interest to my research. Firstly, Krueger emphasises an unencumbered mode of user interaction whereby the participant does not have to wear any electronic sensing apparatus to track their movement. According to media critic Howard Rheingold, this runs counter to the general technical developments of the time, in which virtual reality was dominated by wearable interfaces such as data gloves, sensor-laden body suits and vision goggles (Rheingold 1992). Krueger contends that it seems likely people in everyday situations might find it undesirable to be encumbered and tethered with wearable technology which he found burdensome, distracting, unwelcome and costly in most cases (Bermar 1991). In the context of my research project, it may be desirable to minimise encumbrance of TBI patients.

Secondly, Krueger creates a high level of user engagement in *VIDEOPLACE* which enables the user to engage in playful activities. The user can explore and discover relationships between their interactions and the feedback produced by the environment. No two experiences are identical for different users. In this way, Krueger suggests the technology is personalised and humanised. Each user has a dramatically different experience, not only because each user interacts differently, but because the relationships that govern the interaction differ. Each environment offers the user an extended range of activities. Krueger’s strategy here is to maintain and attract user attention.

Krueger’s personal observations suggest playful user interaction may motivate users to participate and perform movement that they would otherwise feel inhibited to perform. Would playful user interactions learned by cause and effect as described in *VIDEOPLACE* stimulate a patient’s level of motivation and engagement? The issue of maintaining engagement in my project underlines the importance of designing therapeutic tasks and environments that can be presented in an aesthetically meaningful and stimulating way. Maximising a patient’s engagement in relevant and pleasurable activities may compliment existing, often tedious, approaches to rehabilitation.

I have identified problematic issues with *VIDEOPLACE* in relationship to my project. Firstly, the user is represented in the environment via a silhouette of their own body. What effect would this have on traumatic brain injured patients to see their own physical disfiguration and impairment reflected in a virtual environment? Would this likely reinforce a negative body image for the patient, or help them adjust?

Secondly, the user's gestures to control computer environments are ambiguous. In *VIDEOPLACE*, the user interface is invisible to the user. In the context of movement rehabilitation it may be preferable to make the user interface direct and explicit in its use. It seems likely that an impaired user will find it difficult to engage and communicate with something that is invisible and isn't there. Dourish suggests such an interface is unlikely to impinge on the embodied perceptions of the user, and is therefore unlikely to be used effectively. He argues that the visibility of a user interface should be a resource to mediate user action.

I would argue that the absence of tactility and touch is a weakness in Krueger's work in relation to my project. User interaction happens through non-contact body gestures in open space. The engagement between the user's body and the invisibility of Krueger's interface places emphasis on the user's cognitive skills rather than perceptual-motor skills and manual dexterity. This point turns my focus to tangible computing and its potential to allow rich and dexterous interaction with physical artifacts.

As we have discussed in Chapter 3, embodied interaction places an emphasis on the relationship between user, the interface, and the environment the interface controls. In the next chapter, I will explore the implications for embodied interaction in the development of my project. I will apply the design techniques of Krueger while cognisant of the limitations in his work. To reconcile these limitations I will draw on Dourish's principles for tangible computing that relate to the configurability of space, the orientation of the human body to the task, physical constraints, and affordances.

Chapter 5: The Research Project:

How useful are the theories of Dourish, and techniques of Krueger to the development of my project?

5.1 Introduction

I have explored the nature of embodied interaction as a framework for designing an interactive art system for movement rehabilitation. In Chapter 2, I identified that developers of interactive computer systems for movement rehabilitation are often constrained to the use of conventional desktop interfaces. These computer interfaces may fall short of fostering natural user interaction that translates into the relearning of body movement for traumatic brain injured patients. This raised the issue of how to design user interfaces that might correlate to a patient's sense of embodiment in ways that help in the acquisition of movement skills. For this reason, it is important to understand what embodiment is, and how it may be applied in the development of my project.

I discussed the nature of embodiment in two primary ways. In Chapter 3, I explored Paul Dourish's foundational theory to understand embodied interaction. Embodied interaction describes the nature of computer user interaction as an embodied phenomenon. Dourish defines embodied interaction through five interrelated theories: 'ontology', 'intersubjectivity', 'intentionality', 'coupling', and 'metaphor'.

In Chapter 4, I analysed the techniques used by Myron Krueger as a case study. I related Krueger's techniques to Dourish's theory of embodied interaction. My findings revealed that Krueger's work has theoretical and conceptual parallels with Dourish. Both authors support embodiment in ways that serve to reintegrate physical aspects of the real world, the user's body, and the virtual world of the computer. Both authors argue for interfaces that encourage a seamless form of interaction between the user and their ambient environment. Therefore, how useful are the theories of Dourish, and techniques of Krueger to the development of my project?

I will address the question by applying the insights derived from my study of Dourish's theory and Krueger's techniques to my project. I will relate my project to Dourish's framework for embodied interaction and to Krueger's techniques within each foundation. I will reflect on my design, intentions, process and development for each constituent part of the project – this includes the overall concept of the system, the user interface, and interactive computer environments. I will conclude with a discussion on the user's experience of *Elements* as a method of evaluating the design.

5.2 The *Elements* project

The *Elements* project is an interactive multimedia artwork that supports movement assessment and rehabilitation for patients recovering from traumatic brain injury. As part of this project I designed the user interface, the interactive multimedia environments, and the augmented feedback (visual, haptic, and auditory) used to help the patients to relearn movement skills. *Elements* is developed to empower traumatic brain injured adults with moderate or severe upper limb movement disabilities.

According to McCrea et al., approximately 85% of traumatic brain injured patients suffer acute impairment to their upper body. Consequently, a majority of patients rate the return of upper limb functionality as a high priority. This is no surprise as activities for daily living and self-care, such as feeding, grooming, toileting, and dressing, all require upper limb interaction with the environment. As discussed in Chapter 1, impairment to upper limb function can include reduced range of motion, accuracy of reaching, inability to grasp and lift objects, or perform fine motor movements (McCrea, Eng et al. 2002). The *Elements* interface is configured to enable the user to reach, grasp, lift, and place physical objects in an interactive environment.

As shown in Figure 5, *Elements* is a custom-made system comprising two desktop display monitors, four tangible user interfaces (TUIs), a stereoscopic computer vision system to track the patient's movements of the TUIs, and computer game software used to present a series of interactive environments to the patient. One horizontal tabletop-mounted monitor displays the interactive environment to the patient, and another is for the therapist to observe and recalibrate the variables of the environment being displayed to the patient. This control allows the therapist to alter the complexity of the environment according to the patient's ability and performance during any consultative period.

Figure 5: Illustration of *Elements* prototype. Image key - 1) Patient; 2) Computer vision camera and mount; 3) Patient display; 4) TUIs; 5) Therapist display; 6) Therapist administrator

The patient interacts with the environment via the tangible user interfaces. Tangible user interfaces are physical objects that may be used to represent, control and manipulate computer environments. The TUIs are soft graspable interfaces that incorporate low cost sensor technology to augment feedback that, in turn, mediates the form of interaction between the patient and the environment. The computer video camera identifies the interface and tracks its position and orientation relative to the computer display. Essentially, the computer tracks the endpoint motion of the patient's arm while the patient is manipulating the tangible user interface.

The *Elements* software consists of a suite of seven interactive applications, each providing patients with tasks geared toward reaching, grasping, lifting, moving, and placing the tangible user interfaces. Audiovisual computer feedback is used by patients to refine their movements online and over time. Patients can manipulate the feedback to create unique audiovisual outcomes. The system-design provides tactility, texture, and audiovisual feedback to entice patients to explore their own movement capabilities in externally directed and self-directed ways.

The complexity of this project necessitated my engagement with other disciplines. There were contributions from a number of researchers in its realisation and is part of a broader study funded by an Australian Research Council (ARC) Linkage Grant. The project is a joint collaboration between RMIT University, Griffith University, the Australia Council for the Arts, and Epworth Hospital, Melbourne. The collaboration fostered a multi-disciplinary approach where the exchange of knowledge and ideas gained strength from others in a process of communication. We all contributed our own insights and working methodologies into the development of the project. Our collaboration became an exercise in sharing knowledge and experience of technology, and discussion around theoretical ideas in which cohesion and consensus could be generated leading to the conception of *Elements*.

Specific to this project, new media art, computer science, and health science contributed to the development of *Elements*. The research collaboration was split into three distinct areas of enquiry. As part of this project I designed the user interfaces, the interactive multimedia environments, and the audiovisual feedback used to assist the patients in relearning movement skills.

Electrical and Computer Engineering PhD student Ross Eldridge developed the software for the multimedia environments and computer video system used to track the patient's movement (Eldridge, Rudolph et al. 2007). Psychology PhD student Nick Mumford designed the clinical tools and protocols to evaluate the patient's performance using the system over time (Mumford and Wilson 2009) (Mumford, Duckworth et al. 2010). Further discussion of the clinical evaluation will be provided in the section 5.4 of this chapter.

5.3 Embodied interaction in *Elements*

As discussed in Chapters 3 and 4, Dourish and Krueger examine the way humans interact with computers. Their approach is concerned with exploring computer interfaces that enable user interactions similar to how we act in the physical world. I am concerned with designing an interface that allows patients to develop the ability to relearn movement skills. I began my design-approach by investigating which re-acquired movement skills traumatic brain injured patients would find most useful in the real world. I identified a set of desired upper limb movements and designed the interactive environment around them.

I identified media that can be configured to interpret the user's upper limb movements, and physical objects that may be used to represent, control, and manipulate computer environments. In Chapter 3 I discussed 'ubiquitous' and 'tangible' computing, where users interact with their bodies through specially designed interfaces that respond to physical body input. These strands of human computer interaction research offer potential design directions for my project.

Pierre Wellner's DigitalDesk was particularly inspirational for my project (Wellner 1993). I envisaged a similar tabletop display that could interpret the patient's physical manipulations of various objects to control elements in a computer graphic environment. However, I identified several practical limitations in Wellner's implementation.

Wellner utilised a front (top down) projection system to display the interactive environment. This system required a large desk to accommodate the projector mount frame and mirrors, and required considerable vertical distance between the desk and the projector to achieve a large display area. Uncontrolled ambient light could interfere with the contrast and brightness of the projected image. The user's upper limbs would also interfere with the projection. For example, their hands and arms would cast shadows, and the environment would be projected onto the patient's limbs if they reached over the desk.

To address these issues, our research group concluded that a large format LCD screen would be preferable to projector technology. In addition, an LCD screen is more portable, can be mounted on any table with ease, and requires little image calibration. In the next section I will reflect on my design in more detail as it relates to Dourish's five foundations for embodied interaction and Krueger's techniques.

5.3.1 Dourish's first foundation: Ontology related to *Elements*

In Chapter 3, Dourish identifies that ontology is concerned with the existence and identification of objects and entities. Krueger identifies this concern from a technological perspective in Chapter 4. Krueger refers to the quality and configuration of the computer hardware and software to perceive and interpret the participant's behaviour. The computer's 'perceptual system' is the degree to which a computer system can interpret which objects are in a physical space and its location.

Perceptual System

Wellner programmed computer software that could interpret symbolic hand gestures and identify physical user interfaces in the environment (Wellner 1993). As discussed in Chapter 4, Krueger suggests that the use of symbolic gestures should be limited (Krueger 1991). Symbolic gestures used to control a computer environment are often ambiguous. I concluded that object identification, and the movement of objects should be tracked via the computer rather than vague hand and arm movements. This practical approach would minimise encumbering the patient with wearable sensors and devices to track their movement.

Our research group trialed a number of vision systems that could interpret the position of objects in space. Electrical and Computer Engineering PhD student Ross Eldridge developed the software for the computer vision system used to track the patient's movements. A technical description of the tracking system is beyond the scope of my exegesis, however the final implementation incorporated a 3D stereo vision camera by PointGrey^{TM} mounted above the display. A technical description of the hardware can be found in Appendix A.

The computer's perceptual system is configured to identify physical objects, and track user movement of objects in real-time. In collaboration with Eldridge, I designed a series of tangible user interfaces that could be identified by the computer's perceptual system. Here, I experimented with the size, shape, and colour of each handheld user interface to enable the computer's perceptual system to track each tangible user interface.

Individuate

According to Dourish, to 'individuate' in design is to enable the user to differentiate between entities. For Krueger, the user's computer silhouette becomes the individuated self-image, which is the user's key to understanding the environment projected on the video screen. Thus, the projected self-image is the known reference against which all transformations in the VE are registered. For the *Elements* system, I designed tangible user interfaces, each of which becomes the known reference against which all transformations in *Elements* are registered.

I designed four unique shaped and coloured graspable, tangible user interfaces: a cylinder, a triangular prism; a pentagonal prism; and a rectangular block (Figure 6).

The shape and physical weight of each TUI offers the patient varying perceptual motor cues for action. For example, how the patient might pre-shape and orientate their hand in the act of grasping and lifting each individual TUI is informed by its shape.

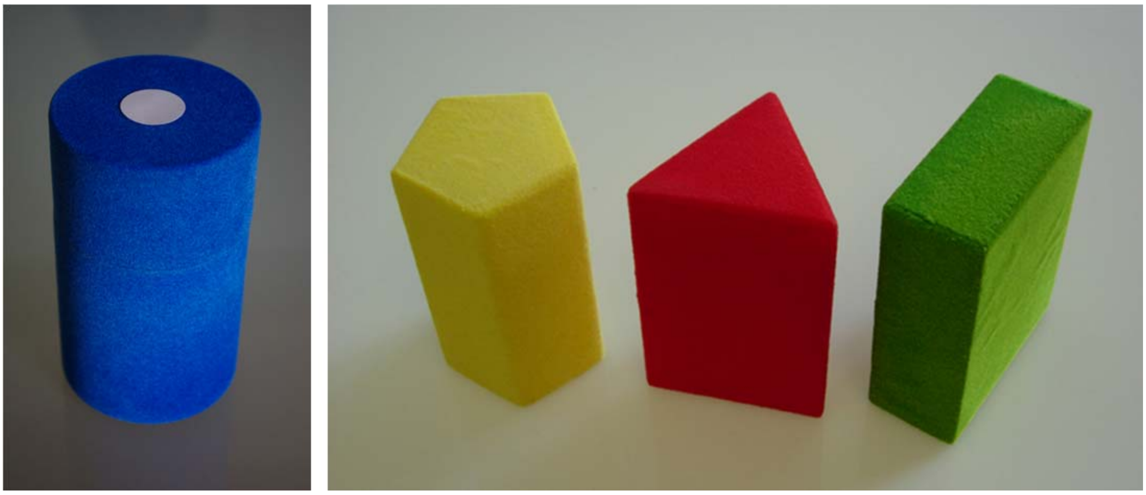

Figure 6: Four graspable, tangible user interfaces.

The use of colour (red, blue, green, and yellow) in my design is practical on two levels. Firstly, it assists the computer to identify each unique colour in order to locate and track the tangible user interface. Secondly, traumatic brain injured patients frequently suffer perceptual difficulties in auditory and visual functions, recognition of objects, impairment of space and distance judgment, and difficulty with orientation. The relationship between the high contrast colours and simple geometric shapes of each TUI is geared toward assisting a visually impaired user individuate each interface.

Tailored

According to Dourish, the ability for a user to 'tailor' the environment informs an aspect of ontology. No two people experience the world in exactly the same way. As such, certain aspects of a computer system can be scaled and adjusted to the experience of the user. Likewise, no two patients will suffer from the same impairments.

I designed a graphical user interface to provide the therapist with options to control the *Elements* tasks, and store data for specific participants (Figure 7). A new patient's details can be entered into a database, or alternatively, the details of an existing user can be loaded. Then, one of seven tasks is chosen. Some of the options for each task include: recording which hand the patient is using to perform the task; the number of times the environment will repeat over a period; the types of audiovisual feedback to be used; audiovisual aesthetic variations to each task; use of single or multiple tangible user interfaces; how near or far away the task appears relative to the patient's arm reach; and the duration of the task.

Once the task is complete, the patient's results can be saved to a Microsoft Excel-compatible spreadsheet for review of performance. The adjustable parameters enable the therapist to tailor the audiovisual complexity of the interactive environments to suit the perceptual and motor capabilities of the patient. The ability to tailor the environment can also be a two-way conversation between the patient and the therapist. The patient can also request adjustments to the environment once they are familiar with the task.

The patient's body location and posture in space are also adjustable. Depending on the activity at hand, a patient may need to be closer, farther away, or continually adapting their bodily orientation to the task. As such, the patient can tailor their actions as the task requires. For example, in Wellner's DigitalDesk, users could move and edit digital documents using hand and arm gestures. The space, the objects, and how the body is configured are determined relative to each other.

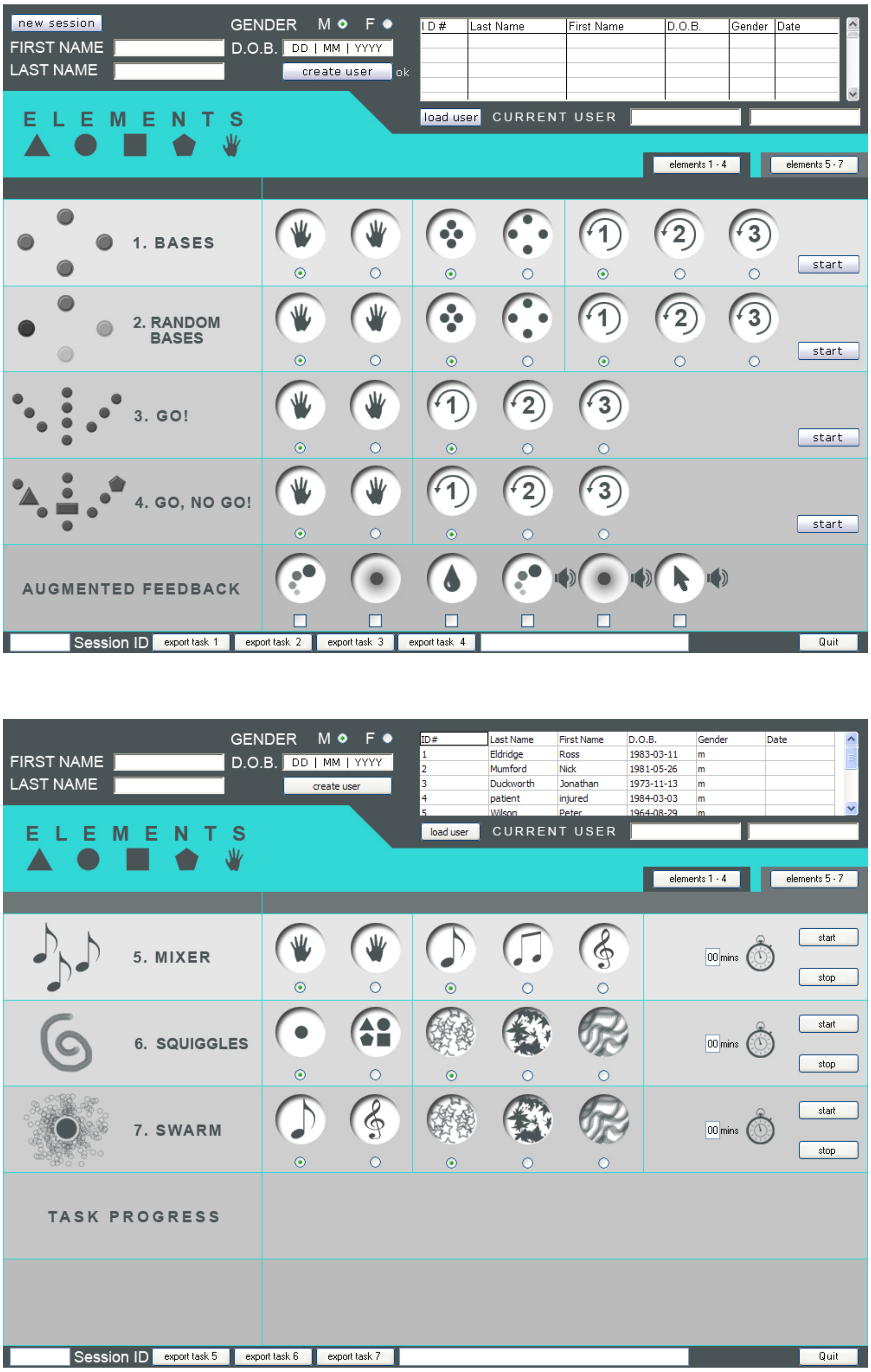

Figure 7: The Elements graphical user interface which enables the therapist to tailor the parameters of each environment.

Participation

Dourish suggests that an ontological structure is an emergent phenomenon that arises as a result of user participation with an entity. Users can individuate and tailor an environment through their participation. For Krueger, user participation was essential to the experience of his artwork. The relationship between user participation and computer response enabled the user to become creators of his artwork. Participation through user interaction enabled each user to create unique experiences. Through participation with their bodies, users could seek out new effects, sounds, and visual features of the environment to see how they work. By doing so, Krueger suggests users might discover new ways of relating to their bodies.

Similarly, I wished to create a series of interactive environments that would enable a patient to explore and experiment with how to use the virtual environments. I designed two modes of user participation that exploited the potential of the *Elements* system. Each of these modes encourages a different style of user interaction and, consequently, has different application potential. A DVD containing video of the *Elements* project can be found in Attachment A.

The first mode of user participation presents four individual task-driven computer games of varying complexity that addresses the competence level of the patient. In each of the four tasks, a patient is asked to place the cylindrical tangible user interface on a series of targets (Figure 8). The four tasks are called ‘Bases’, ‘Random Bases’, ‘GO’, and ‘GO-NO-GO’ respectively.

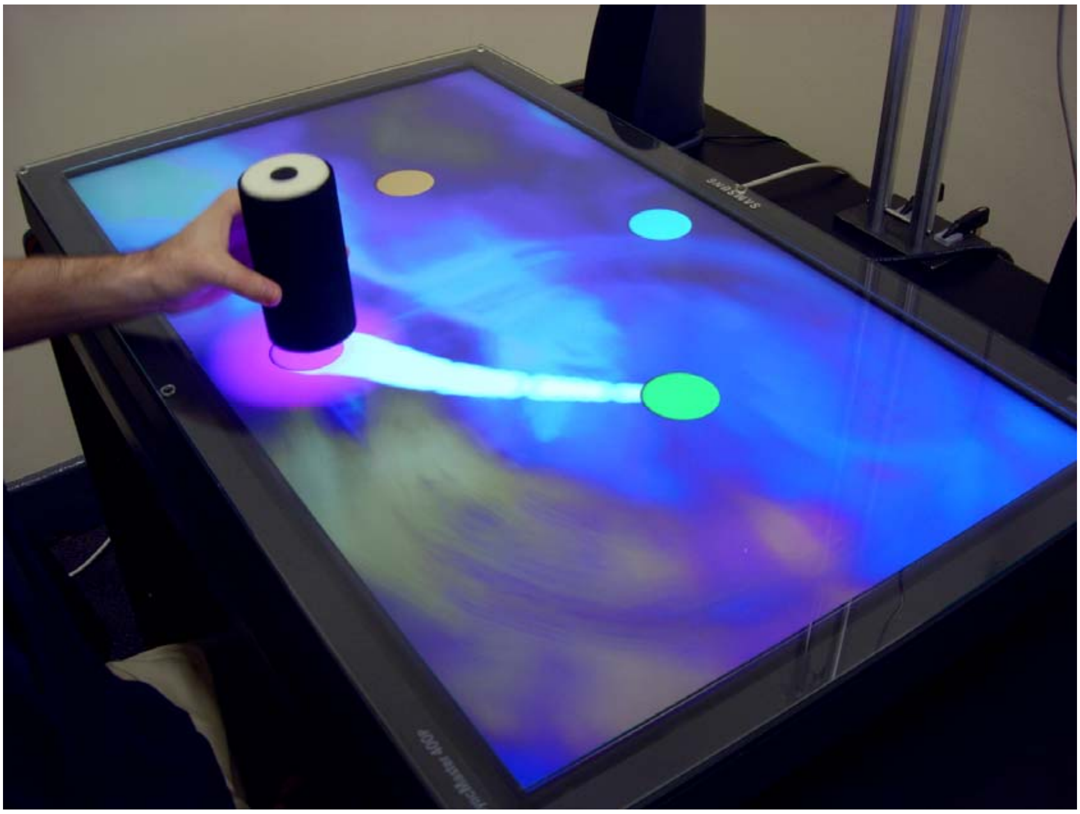

Figure 8: A patient places the cylindrical TUI onto a series of targets.

‘Bases’ consists of a home base where the patients initially place the cylindrical TUI, and three potential movement targets (Figure 9). The circular targets are cued in a fixed order (‘home base’, ‘west’, ‘north’, and ‘east’) using an illuminated border to highlight the next target location.

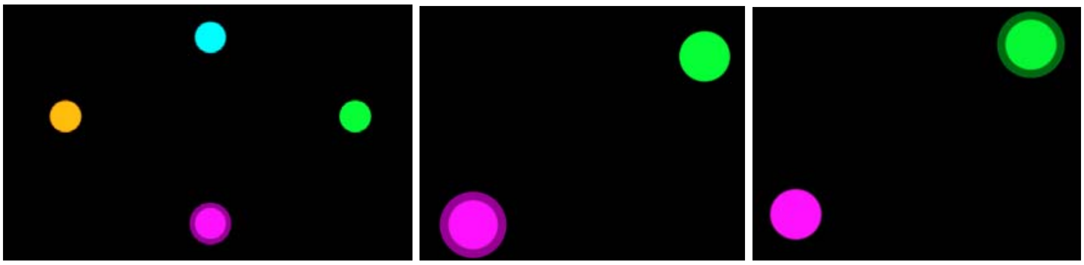

Figure 9: The ‘Bases’ task. Images, left to right – overall layout of target locations; first target is highlighted; second target is highlighted as next location.

‘Random Bases’ has the same configuration of targets, but they are highlighted in a random order (Figure 10).

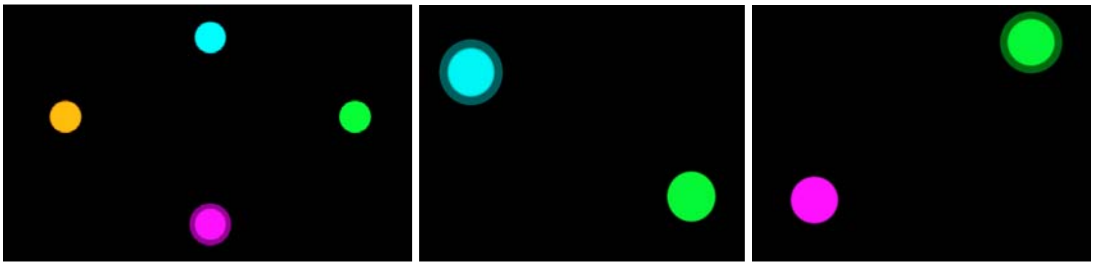

Figure 10: The ‘Random Bases’ task. Images, left to right – overall layout of target locations; north target is randomly highlighted; east target is randomly highlighted as next location.

‘GO’ uses a configuration of nine targets along three radials emanating from the home base (Figure 11). All of the targets are initially hidden from the user. Each target then appears randomly in each of the nine locations. The patient must move the TUI to each of the targets as they are revealed.

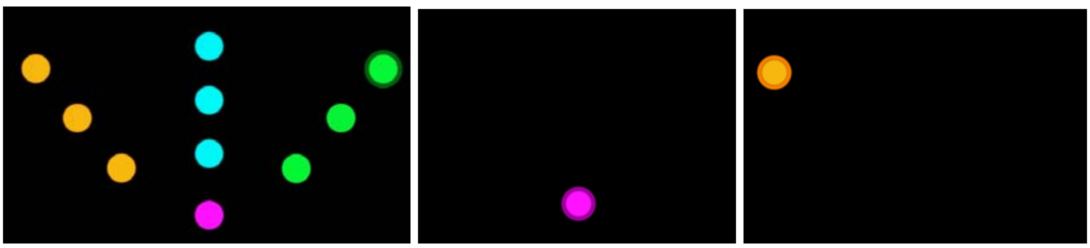

Figure 11: The ‘GO’ task. Images, left to right – overall layout of target locations; first target is randomly highlighted; next target is randomly highlighted as next location.

‘GO-NO-GO’ uses the same target locations as ‘GO’, however, additional targets (viz. a pentagon, triangle, and rectangle) are used to intentionally distract the patient (Figure 12). Patients are instructed to place the TUI on circular targets only, and to resist moving to the other shapes.

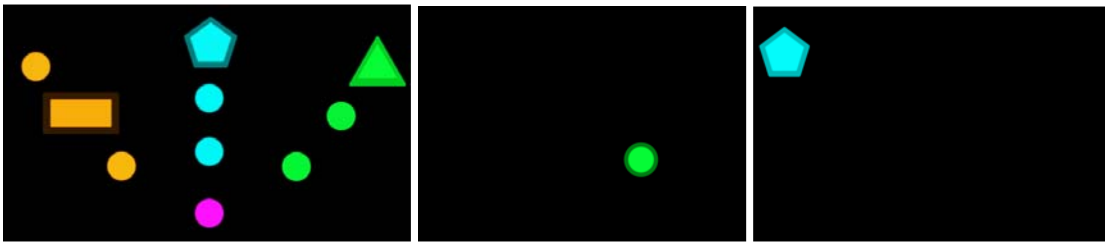

Figure 12: The ‘GO,-NO-GO‘ task. Images, left to right – potential layout of target locations and distracters; first target is randomly highlighted; distracter is randomly highlighted.

In each task, the accuracy of placement, speed of movement, and efficiency of the movement-trajectory to the next target are measured in real time. These scores are presented to the patient as performance graphs. The patient can review their performance and test scores as the therapy progresses over time. The objectives of the performance scores support the participant’s perception of progress and improvement, and encourage self-competitive engagement. In other words, the patient perseveres and strives to improve their performance scores over time.

The second mode of user interaction is a suite of abstract tools for composing with sounds and visual feedback that promotes artistic activity. In these environments there are no set objectives. The patient derives engagement from having the power to create something while interacting with the work. For example, in one environment, the patient might feel pleasure from being able to mix and manipulate sound samples in an aesthetically pleasing way. There is a broad range of experiential outcomes possible in each of the exploratory *Elements* environments. The qualities of the user experience emerge through creative and improvisational interaction. Painting and sound mixing is expressed through the patient’s upper limb control of the tangible user interfaces.

In each exploratory environment, I use curiosity as a characteristic to motivate and engage patients. According to Thomas Malone, curiosity is one of the major characteristics that motivate users to learn (Malone 1981). Malone suggests a learner’s curiosity can enable them to explore and discover relationships between their interactions and the computer feedback produced by the environment. Malone distinguishes two possible modes of curiosity depending on the level of processing involved – ‘sensory curiosity’ and ‘cognitive curiosity’. Sensory curiosity involves using perceptual changes in colour, light, form, and sound to attract attention. By contrast, cognitive curiosity engages the learner by presenting just enough information to let them know their existing knowledge is incomplete.

According to Malone, the learners are motivated to learn more in order to make their cognitive structures better-formed. In this way, a learner’s curiosity can enable them to explore and discover relationships between their interactions and the feedback produced by the environment. Curiosity may offer an important additional characteristic to motivate and engage patients in therapy. In general, an optimal environment will be one where the patient knows enough to have expectations about what will happen, but where these expectations are sometimes unmet. A level of novelty and surprise in an interactive environment may motivate the patient to explore and engage with the environment at a deeper level.

Patients are given full control to play and explore, allowing them to discover how the environment is responding to their movement. Through playful interaction, users can seek out and create new sounds and visual features, exploring their combined effects. Rizzo adds that self-guided exploratory experiences may promote more naturalistic behaviours when patients perform in an independent and autonomous way (Rizzo 2005). By doing so, patients may discover new ways of relating to their body and relearn their upper limb movement capabilities in a self-directed fashion.

The components of the suite of exploratory environments are called ‘Mixer’, ‘Squiggles’ and ‘Swarm’. The mode of user interaction for each environment is designed to challenge the patients’ physical and cognitive abilities, motor planning, and to provoke their interest in practicing otherwise limited movement skills.

Exploratory Task - Mixer

Participants use the Mixer task to compose musical soundtracks by activating nine preconfigured audio effects. Placing a single tangible user interface on any of the nine circular targets displayed on the screen activates a unique sound (Figure 13). Sliding the user interface across the target controls the audio pitch and volume of each sound effect. Changing the proximity of the tangible user interface to the centre of the target alters pitch and volume. The sound can be set to play the desired volume and pitch level when the tangible user interface is lifted off the display surface and away from the target. In this way, participants can activate and deactivate multiple sounds for simultaneous playback.

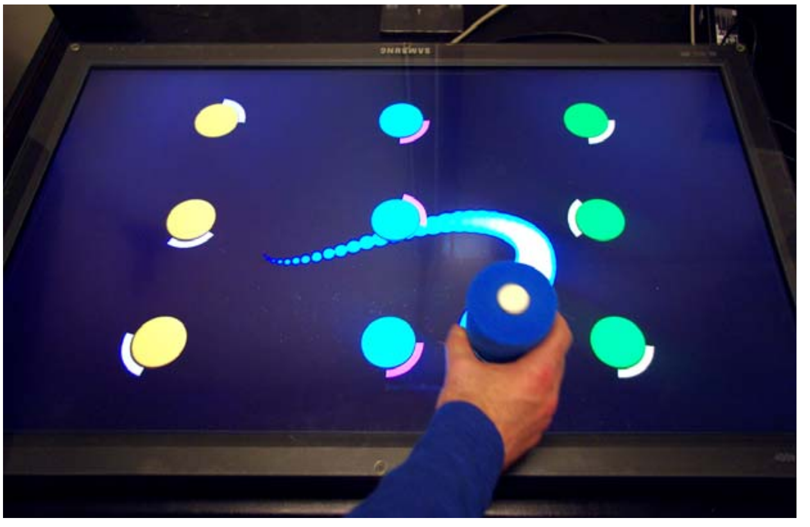

Figure 13: A patient moves a TUI to activate and mix sounds in the 'Mixer' task

Exploratory Task - Squiggles

The Squiggles task encourages patients to draw paint-like lines and shapes on the display using a combination of four tangible user interfaces (Figure 14). Each tangible user interface creates a unique colour, texture and musical sound when moved across the screen. The painted shape appears to come to life once drawn. This animation is a replay of the original gesture, thus reinforcing the movement used to create it. The immediacy of drawing combined with the musical feedback enables participants to create animated patterns, shapes, words, and characters.

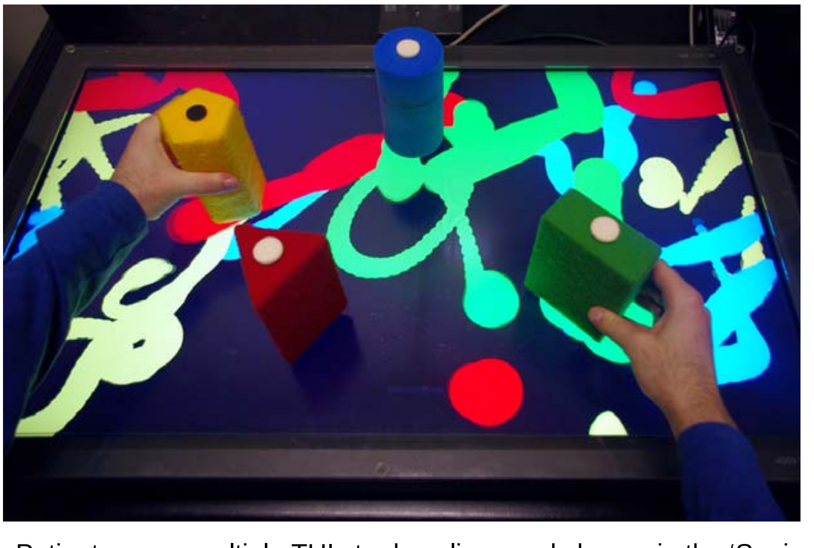

Figure 14: Patient moves multiple TUIs to draw lines and shapes in the 'Squiggles' task

Exploratory Task - Swarm

The Swarm task encourages dual hand control (single hand is possible) to explore the audiovisual relationship between the four different tangible user interfaces. When placed on the screen, multiple coloured shapes slowly gravitate toward, and swarm around, the base of each tangible user interface (Figure 15). As each interface is moved, its swarm follows. The movement, colour, size, and sound characteristics of each swarm change when the proximity between the tangible user interfaces is altered. This relationship encourages participants to create unique audiovisual compositions by moving each tangible user interface across the screen.

Figure 15: Patient moves multiple TUIs to create audiovisual compositions in the 'Swarm' task

To conclude this section, I found Dourish's notion of ontology useful when considering a range of options in the design of the *Elements* project. Dourish defines ontology through three key terms, 'individuation', 'tailoring', and 'participation'.

Firstly, I designed the shape and colour of each tangible user interface to assist the patient. Individuation potentially accommodates the patient's perceptual impairments, and enables the computer's perceptual systems to identify each tangible user interface.

Secondly, the ability to tailor the environment enables the therapist to adjust the audiovisual complexity of the task to suit the perceptual and motor capability of the patient.

Thirdly, the user's participation is essential to the experience of *Elements*, particularly the exploratory tasks. Similar to Krueger's work, participation through user interaction enables each patient to create unique experiences. Through participation, patients can seek out the new effects, sounds, and visual features of each environment. Patients can explore how each audiovisual feature in the interactive environment relates to the position of each tangible user interface.

5.3.2 Dourish's second foundation: Intersubjectivity related to *Elements*

According to Dourish, intersubjectivity is concerned with how users might share meaning. Dourish suggests that intersubjectivity emerges in two ways in the design of interactive systems. The first instance concerns how the designer communicates to the user a set of 'expectations' and 'constraints' about how an interactive system should be used. The second instance of intersubjectivity relates to the communication between users, through the system, in a process of 'appropriation'. Dourish suggests people 'appropriate' technology in the creation of working practices, so that the two evolve around each other.

Expectations

As discussed in Chapter 4, Krueger relates expectation to how one might maintain user interest. He describes expectation as part of a learning process through the way user actions are verified and *reinforced* by the computer system. If a user's actions are reinforced repeatedly, then the outcome becomes expected. Krueger suggests that a person's expectations are learned through the reinforcement of their actions.

In the development of the *Elements* environments, I designed the movement-related audiovisual feedback to reinforce the actions performed by the patient. The audiovisual feedback increases the amount of task- and environmental-information provided to the patient. For example, the feedback may provide the patient with a better sense of the position of their actions, determine what variations in movement are required to realise a goal or action (e.g. speed and placement), and a feel for the unfolding movement-trajectory itself. Each of these parameters is related to one or more of the audiovisual feedback features outlined in Table 1.

Table 1: Descriptions of the audiovisual features of the *Elements* system and their related movement variables.

Audiovisual Feedback (Tasks 1-4)	**Movement variable reinforced by Feedback**
Ripple effect for placement When the TUI is placed on the display, a water ripple animation emanates from that location.	Informs patients that the object has touched the display.
TUI trace of trajectory As the TUI is moved across the display, a fading trail marks the path taken by the TUIs.	Visual representation of movement efficiency and accuracy.
Sound pitch and volume (a) As the TUI approaches a target, a tone increases in pitch and volume. (b) Movement speed is correlated to sound pitch. (c) A 'click' type sound is played when the TUI is placed on a target	Reinforces the speed of movement, placement accuracy and movement goal.
Aura effect As the TUI approaches the correct target, a glowing 'aura' appears around the target.	Reinforces correct movement choices, proximity of TUI to target, and accuracy.
Audiovisual Feedback (tasks 5-7)	**Movement variable reinforced by Feedback**
Mixer	
TUI trace of trajectory As the TUI is moved across the display, a fading trail marks the path taken by the TUIs.	Visual representation of movement, and location of TUI
Aura effect As the TUI approaches a target, a glowing 'aura' appears around the target.	Reinforces the proximity of the TUI to the sound target.
Spinning target circumference As the TUI is placed near a target, the outer edge begins to rotate.	Indicates the playback speed and volume. Faster rotation = TUI is closer to target. Continuous rotation highlights the sound is active.
Sound pitch and volume As the TUI approaches a target, a sound increases in pitch and volume.	Refines movement used to control the proximity of the TUI to the target to control sound playback.
Squiggles	
TUI trace of trajectory As the TUI is moved across the display, a permanent trail marks the path taken by a TUI.	Visual representation of movement.
Animated Trail Once drawn the trail moves according to the gesture used to create it.	Reinforced recall of movement gesture.
Sound A variety of individual sound chords are played when a TUI is moved. Each TUI is associated with a unique set of chords and musical instruments.	A modulation of the movement reinforcer. Induces further movement to create musical composition using single or multiple control of TUIs.
Swarm	
Particle Swarm Geometric graphic shapes gravitate toward the base of each TUI placed on the display. As the TUI is moved the swarm follows.	Locates the position of the TUI on the display.
Swarm Behaviour (a) Colour – The colour of the shapes change according to the proximity of TUIs to one another. (b) Scale – The size of the geometric shapes change according to the proximity of TUIs to one another. (c) Sound – Unique ambient sounds play according to the proximity of the TUIs to one another. (d) Behaviour – The movement characteristics of the swarm alters according to the proximity of TUIs to one another. Each swarm will be repulsed or attracted to one another depending on the proximity of the TUIs	The aesthetics of Colour, Scale, Sound, and Behaviour of the swarm is modulated too induce further exploratory user movements associated with the spatial relationships between the TUIs.
Swarm Dispersal The swarm disperses off the display when a TUI is left unattended after a short period of time. Any movement of the TUI will reinstate the swarm.	Prompts continual movement of the TUI and encourages user engagement to the action possibilities.

During user interaction, patients are instructed to focus on the feedback appropriate to the movement variable that is targeted (Figure 16). For example, if the aim is to improve efficiency, the patient is instructed by the therapist to focus on the fading trail when moving the TUI. The straighter the trail between targets, the more efficient the movement of the TUI between targets. Likewise, a longer trail indicates a faster movement. If the patient's actions are reinforced and verified repeatedly, then the outcomes may become expected in a process of learning.

Figure 16: Examples of audiovisual feedback - Water Ripple, Trail at the base of a prototype TUI, and Target aura

Krueger suggested that once expectations are learned, the feedback can be modified over time. A modification of the audiovisual feedback assists in maintaining user interest by providing compositional variation to the task. For example, varying the sound output on the Mixer task through the course of user interaction may maintain user engagement in movement exercises that would otherwise fail to captivate them. In this way, the audiovisual feedback may change user interaction and encourage new movement solutions to a task.

Constraints

To assist the patient in deciding how to proceed using the *Elements* systems a number of constraints were developed. Dourish and Norman suggest a constraint is a method of limiting the options for the user at any one time. For Krueger, the organising principle that governs constraint is ‘context’. According to Krueger, a context subsumes the user-activities through which an individual interprets the world and controls their responses.

In the *Elements* system, I define constraints as a relationship between the patient, their interactions with the task, and the physical configuration of the *Elements* environment. We may observe the physical configuration of the *Elements* environment constrains user movement within a defined area (Figure 5). The possibilities for user action take place along a single plane of movement within the confines of the horizontally mounted computer LCD display together with the tangible user interfaces to-be-manipulated. The task constraints include the ways in which the tangible user interfaces can be held, moved, and stabilised in relation to the physical terrain of the LCD display and the audiovisual feedback. These constraints provide the user with a frame of reference and a context within which their interactions can be perceived. The task and environmental constraints are designed to increase the patient’s ability to plan and initiate movements within a context that is predictable.

Appropriation

I identified the likely relationship between the patient and the therapist while undergoing rehabilitation therapy. Generally, the rehabilitation process and treatment is conducted by a team of doctors, nurses, dietitians, occupational therapists, physiotherapists, psychologists, social workers and speech pathologists. Family members can also offer vital contributions to the person’s rehabilitation by offering support during recovery and therapy. Traditional therapies usually entail extensive hands-on physical rehabilitation. Such rehabilitation progresses from passive range-of-motion exercises and sensory stimulation during in-patient recovery, to weight training and constraint-induced movement therapy as function improves (Kaplan 2006). These approaches often require one-to-one physical and occupational therapy over an extended period using a variety of props. Our research group concluded that a therapist would provide the patient with one-to-one guidance, and focus their attention to the use of the *Elements* system. The therapist would administer each task, record and observe their progress.

As such, I configured the system so that the therapist has a separate display to control the program located to the side of the main *Elements* display used by patient. The therapist can stop the program at any time to administer individual instructions depending on the patient's proficiency and stage of recovery. The configuration of the design maintains a close visible relationship between the patient and the therapist. The therapist can supervise the patient's activities and provide encouragement and positive instructions.

Patients can appropriate the interactive environment in several ways, for example they can freely choose which tangible user interface they wish to use, the audiovisual feedback they would like to see, and choose the aesthetics of each exploratory environment from a range of audiovisual options. By appropriating the technology to their own capabilities, wishes, and desires, patients can explore new movement solutions and validate these actions in communication with the therapist. Thus, the working practices of both the patient and therapist can evolve around each other.

To conclude this section, I found Dourish's notion of intersubjectivity particularly informative in the development of the *Elements* project. Dourish defines intersubjectivity through three key terms – 'expectations', 'constraints', and 'appropriations'. Krueger's notions of 'reinforcement' and 'context' provide further understanding of the terms *expectations* and *constraints* respectively.

I designed the audiovisual feedback to reinforce the actions performed by the patient. If the patient's actions are reinforced and verified repeatedly, then the outcomes become expected in a process of learning movement.

The physical constraints of the *Elements* environment, and the task that the individual user is performing in relationship to the constraints of the individual's movement were considered. The individual patient, task, and environmental constraints provide the user with a frame of reference and a context within which their interactions can be perceived.

The ways in which the patient and therapist appropriate the *Elements* systems enable their working practices to evolve around each other in an intimate patient-therapist dialogue that addresses solutions and options for movement learning. I have applied all three terms of intersubjectivity in the design toward helping the patient to understand and share how movements can be performed.

5.3.3 Dourish's third foundation: Intentionality related to *Elements*

Dourish suggests intentionality provides a conceptual way to understand how the components of an interactive system can provide users with meaning in the course of an activity. For example, the design of a user interface may carry intentional connotations that suggest how it will be used. Intentionality in design may refer to some element of the real world of human experience. A user interface might imply some form of intentionality for action, and, when acted upon by the user, creates some effect in the interactive environment. In this way, intentionality arises from perceived action possibilities in the environment. I considered intentionality and affordance together as a way to conceptualise the design of the tangible user interaction. The concept of affordance proposed by Gibson has informed the way I conceived of the relationship between the patient and the *Elements* system.

Affordance

The affordances offered by tangible user interfaces have been designed to engage the patient's attention to the movement context and the immediate possibilities for action. More specifically, each tangible user interface affords user actions of reaching, grasping, lifting, moving, and placing them in relationship to the interactive environment. The objective of my design approach is to assist patients to relearn simple perceptual motor skills like lifting a cup, tumbler, or similar-sized object, and to be able to control moving it. These simple actions offer some element of the real world of human experience in ways one might manipulate real world objects. These actions are ones that many of us perform with ease, but offer a real cognitive and physical (often painful and exhausting) challenge for traumatic brain injured patients.

The physical attributes of the tangible user interfaces intentionally reflect the size, weight, and scale of a tumbler. A silicon rubber mould was created from a plastic prototype for each tangible user interface. Each prototype was then cold cast in silicon rubber using the original mould, and coated with a soft adhesive fabric. The softness of each tangible user interface protects the LCD display and TUI from accidental damage, while creating a non-slip tactile outer surface for the patient to grip (Figure 17).

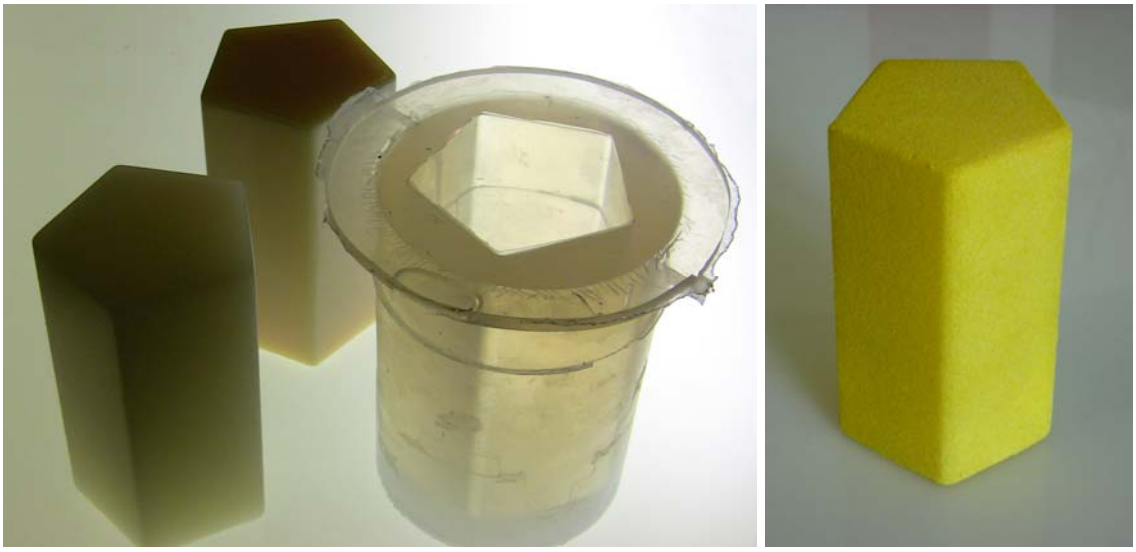

Figure 17: The manufacture process for each TUI; image left - silicon mould, plastic TUI, and cast TUI; image right – fabric-coated silicon TUI.

To conclude this section, I found intentionality and affordance particularly relevant in conceptualising the design of the tangible user interface. Intentionality frames the types of desired actions the designer wants to communicate to the user. The affordance of each interface offers the user actions of reaching, grasping, lifting, moving, and placing. The physical attributes of each tangible user interface implies some form of intentionality for action, and, when acted upon by the user, creates some effect in the environment. Affordances make the action possibilities clearer to the user by virtue of their relationship to the environment, the task, and what the user perceives in relation to their sensorimotor capabilities. The perceptual properties of each tangible user interface are, thus, mapped fairly directly to the action systems of the patient.

5.3.4 Dourish's fourth foundation: Coupling related to *Elements*

Dourish suggests 'coupling' is the action of binding entities together so that they operate together to provide a new set of meaningful user functions. Coupling is the way our actions are connected to the effects they have in an interactive environment. Dourish states that effective communication relies on the ability of the user to control the medium, and that feedback is an essential part of this control. According to Krueger, coupling is the composition of relationships between actions, user 'control', and the computer's 'response'. For Krueger, it was important for the user to determine and understand how they influence events in an interactive environment. If a user understands how they are influencing events, they may feel they are in control of some part of their experience both directly and indirectly. Krueger notes that if the computer response is not perceived, then user frustration may quickly become apparent.

According to Dourish, being able to control the coupling makes our use of equipment more effective. For Dourish, the effective use of any tool requires the user to continuously engage, separate, and reengage with it. In the *Elements* project, this is a process of continual engagement, separation, and reengagement with the tangible user interface and its effects on the environment. For example, how the patient might decide to use the tangible user interface; pick it up and orient it correctly; move it to a different part of the display; perhaps put it down again. This is a process of continual user engagement and reengagement. The patient needs to be aware of the tangible user interface, how it sits in their hand, how heavy it is, and so forth. When performing a task, such as the Squiggles painting application, the tangible user interface should 'disappear' into the activity. At other moments, the patient would have to be aware of the tangible user interface again as they change its position in relation to display.

Feedback

Audiovisual feedback is used to provide the patient with an indication that something has happened as a result of their actions. The audiovisual feedback is closely coupled to the movement actions of the patient (see Table 1). This is not simply a matter of mapping the patient's immediate activity at any one moment to some form of feedback. Instead, coupling the user action to the audiovisual feedback operate together to provide the patient with additional functions that revolve around understanding the nature of their movement. It provides patients with additional knowledge of the outcomes of their actions to aid in future movement planning.

The audiovisual feedback also directs the patient to focus their attention on the external effects of their movement, rather than the internal biomechanics of the movement itself. A recent review of motor learning techniques suggests that internally focused movement can result in slow, consciously controlled movement that disrupts performance (Wulf and Prinz 2001). Wulf et al. emphasise that externally focusing the user's attention on the anticipated effects of movement may enhance learning. They observe that an external focus leads to more rapid, natural, and autonomous actions. However, the precise nature of this effect is in need of further research and beyond the scope of my exegesis.

In addition to the audiovisual feedback, I incorporated tactile feedback delivered to the patient via a small vibration motor embedded in the cylindrical tangible user interface (Figure 18). The patient may feel a short, soft vibration when they are holding the interface. The vibration is triggered when the tangible user interface is no longer tracked by the computer vision system. The tactual feedback indicates two movement errors: if the TUI is moved over the outside perimeter of the visual display; and if the TUI is held incorrectly at an extreme angle so as to be unrecognisable to the computer vision system. This feedback acts as a prompt for the patient to correct their movement in the event these actions occur.

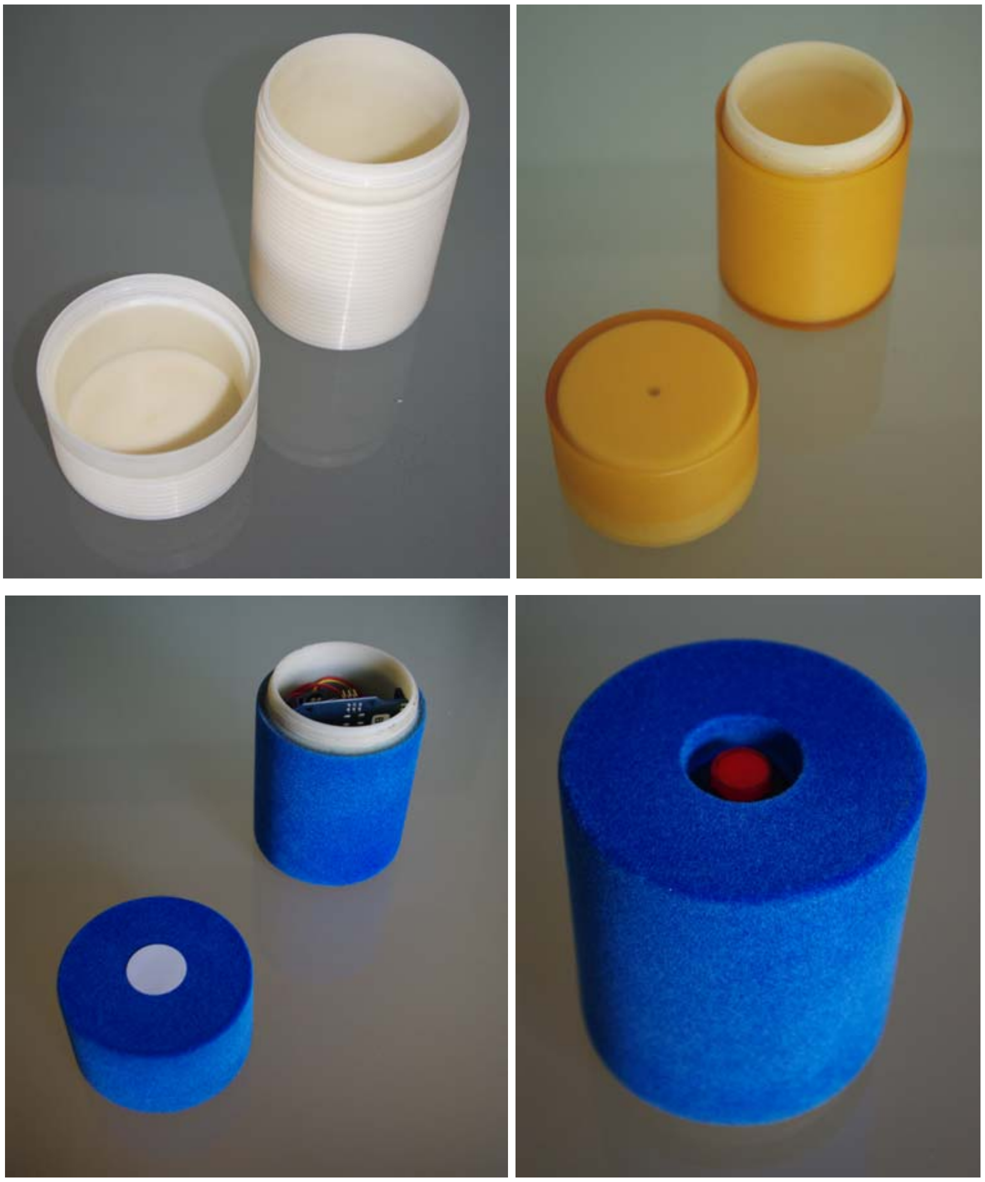

Figure 18: Images of design to accommodate electronics; 1) Plastic shell of cylindrical TUI; 2) Soft polyurethane rubber casing cast onto the outside 3) Bluetooth electronics and vibration motor inserted inside the TUI; 4) Electronic on/off switch located at the base of the TUI.

Visibility

The visibility of the audiovisual feedback is designed to assist the user to interpret and evaluate the consequences of their actions. The visibility of the graphic environment and the user interface may also remind the patient of the possibilities for action in executing a task. I use large graphic elements, very few colours to overemphasise contrast, and similar graphic layout and feedback between tasks to aid recognition and memory.

The audiovisual feedback is shared between the patient and therapist. The therapist and the patient see the results of an action. The therapist observes the feedback produced by the patient's movements and guides them in ways to improve their movement. The visibility of the system enables the patient and the therapist to manage actions appropriate to current state of the system.

To conclude this section, I found Dourish's notion of coupling particularly constructive to understand how a users actions may be bound to the effects they have in an interactive environment. For Krueger coupling is the composition of relationships between actions, user *control,* and the computer's *response.* In this regard I considered how the audiovisual and tactile feedback are coupled to the user's actions. The user actions and the feedback operate together to provide the patient with additional sensory information around understanding the nature of their movement. This additional information (trajectory, speed, accuracy, location, and touch) provides patients with additional knowledge of the outcomes of their actions to assist in planning further movement.

5.3.5 Dourish's fifth foundation: Metaphor related to *Elements*

As discussed in Chapter 3, Dourish suggests that user interface metaphors provide the best use of coupling in interactive systems. A metaphor may suggest some sort of action that can be performed by the user. Dourish claims that coupling and metaphor provide ways for meaning to be made manifest and turned to use from moment to moment. Similarly, Krueger suggests that *metaphor* refers to the actions that are implied by the juxtaposition of an image with a graphic object. Dourish highlights how metaphors can be characterised in approximate ways as aspects of representation of an entity along two dimensions – 'iconic/symbolic' and 'object/action'. Dourish notes that the boundaries between iconic/symbolic and object/action can often be ambiguous.

An entity can be representational, object, and action simultaneously, each carrying different meanings, values and consequences.

In the *Elements* environment I considered how metaphors could be used to inform the design of the tangible user interfaces. According to Kenneth Fishkin, physically afforded metaphors can be used when parts of an interface are made physically tangible (Fishkin 2004). A designer can use the shape, size, smell, colour, and texture of an object to invoke a number of metaphorical links. Fishkin also suggests that metaphor can be useful to constrain the user to imitation. For example, if a tangible user interface is a literal representation of a real world artifact, then the user will refer to the real world artifact as a cue to inform and constrain the type of action they perform.

Fishkin recognises that metaphor has such cognitive power that it should be used with care. The goal of my project is to lower the cognitive overhead required to use the tangible user interfaces, and as such I have made minimal use of metaphor in their design. I designed the tangible user interfaces as an analogy to the shape and size of a tumbler. Thus the operation of the tangible user interface is designed to match the physical actions to those of the analogised object.

The analogy applies to both the shape of the object, and to the likely movement behaviour of the object when used. The physical dimensions of each tangible user interface afford the same graspable actions used to manipulate them. Here, I use metaphor to suggest the sort of physical actions the user might similarly perform in the real world.

In most cases the *Elements* audiovisual feedback does not refer to any real-world analogy to a physical effect (with the possible exception of the water ripple). Rather, the audiovisual feedback serves to reinforce the actions of the user. Each feature is an iconic representation of an action movement it depicts. For example, the fading trail is an iconic representation of the movement path of the tangible user interface.

The audiovisual feedback serves to provide information in addition to the normal flow of visual and movement-related feedback. I deliberately do not connect the aesthetics of the audiovisual feedback to any real-world analogy. For example, moving my coffee cup across my desk obviously does not leave a glowing trail behind it. I use the feedback as a strategy to increase the visibility of the user’s actions, and thus provide opportunities for the patient to interpret and create additional meaning in the way they understand their effects in the environment.

To conclude this section, Dourish's explanation of metaphor raised my awareness to the ways action and meaning might be communicated to the user. Fishkin further emphasises how metaphor might be considered in practice to suggest user actions. I have made simple use of metaphor to inform the physical attributes of the tangible user interface that alert the patient to the likely possibilities for action the object affords. I have made limited use of metaphor to decrease the likely cognitive overhead required to perform actions in the *Elements* environment.

5.4 User evaluation of *Elements*

To conclude this chapter, I will discuss the patient's experience of *Elements* as a method of evaluating the design. *Traumatic brain injured* patients were invited to take part of a study at Epworth Hospital, Melbourne, by the senior physiotherapist. The study was approved by the Human Ethics Committees of RMIT University and Epworth Hospital. All testing was conducted onsite at Epworth Hospital. The study consisted of three, one hour sessions per week over a course of four weeks.

Because the *Elements* system can be scaled to the patient's individual skill level, inclusion criteria were broad. Each patient experienced deficits in upper-limb function and considered the study important. Patients were also required to have cognitive capacity to provide informed consent (Appendices B - E). While there was no specific prerequisite for visual acuity, using the program requires a level of vision equivalent to reading a book or watching television, which all the patients could do.

Twelve patients were introduced to the *Elements* system. A preliminary trial of three patients was recorded on video and a subsequent interview was conducted. My approach was adapted from the video-cued recall method of retrospectively reporting user experience (Suchman and Trigg 1991). The initial trials were a valuable starting point to streamline and simplify the process of evaluation for subsequent patient studies. This rehearsal established the effectiveness and viability of evaluating the patient's experience using the system.

Reporting the user experience of patients using video-cued recall had mixed success. Problems of memory, emotional, and behavioural regulation, combined with physical disability made the process of self-reported user feedback arduous. Patients had problems remembering what they had been doing in detail five minutes prior, had speech impairments that limited their ability to verbalise their experience, and difficulty writing.

In response to these impairments, I developed a qualitative (or self-report) questionnaire as a method of capturing the user's experience in more detail (Appendix F). The questionnaire is adapted from similar questionnaires that characterise and measure user experience with interactive computer environments (Boguslawski 2007) (Chen, Koldo et al. 2005) (IJsselsteijn, Poels et al. 2007) (Kalawsky 1997) (Witmer and Singer 1998). While far from ideal as a method for rigorous qualitative research, this simple survey technique did raise a number of important issues and identify some of the experiences felt by patients. The questionnaire enabled me to assess the usability of the system from the patient's perspective, its aesthetic appeal, and their level of engagement with it.

In a summary of my study, all the patients expressed a desire to interact with the system in a creative capacity. I observed an increased level of motivation, engagement and enjoyment while the patient used *Elements*. The patients indicated that the system was intuitive to use and that the therapy, particularly the exploratory environments, represented a fun diversion from the normal rigours of their physical therapy in rehabilitation. The patients responded well to the technology and to the aesthetic of the therapeutic environments, which are far removed from their normal experience in rehabilitation. The results suggest that creative and game style applications tailored for traumatic brain injured patients were pleasurable and engaging (Appendix G). The audiovisual feedback provided the patients with a sense of agency and control, so that, when one considers that a sense of agency is intimately entwined with a sense of purpose, achievement and happiness, *Elements* may be a means to improve their quality of life in general.

PhD student Nick Mumford devised a series of quantitative approaches to assess the extent to which movement skills were enhanced using the *Elements* interactive environment (Mumford, Duckworth et al. 2010). Mumford's analysis of the patients' performance scores shows significant improvements in movement accuracy, efficiency, and attention to task. He suggests that the performance effects observed may be the result of the audiovisual feedback stimulating a cognitive change at the level of movement planning. However, a detailed discussion of these results is beyond the scope of my exegesis.

In the next chapter, I will conclude with a discussion on the characteristics of embodied interaction design as applied to the development of my project. I will also discuss directions for future research and its broader implications in the rehabilitation field.

Chapter 6: Conclusion:

Project conclusion and directions for future research.

6.1 Conclusion

I have explored the notion of embodied interaction within the context of designing an interactive artwork for movement rehabilitation of traumatic brain injured patients. Embodiment concerns the reciprocal relationship that exists between mind, biology, and the environment (Gibson 1979).

This study indicates that interactive therapeutic treatments that use an embodied approach may improve the rate of recovery and increase the quality of life for patients. A substantial body of evidence suggests that interactive technologies can provide alternative therapeutic solutions that support individuals with disabilities (Cobb and Sharkey 2007). In particular, virtual reality has been shown to improve performance in patients suffering from traumatic brain injury (Holden 2005) (Rose, Brooks et al. 2005). However, we observed along with Rizzo that interactive computer systems for movement rehabilitation are often constrained by conventional desktop interfaces (Rizzo 2005). When used as rehabilitation tools, these physical interfaces are often inappropriate for patients to relearn a wide range of movements associated with daily living and self-care.

This study was motivated by a need to explore the design of user interfaces for specialised rehabilitation applications. Conventional interfaces, such as keyboard and mouse, are designed to be simple to operate from a perceptual-motor perspective (Djajadiningrat, Matthews et al. 2007). This shifts their potential as learning tools almost completely to the cognitive domain. Conventional interfaces may not reflect how we interact with our environment and manipulate objects in the real world. This issue suggests the need to develop user interfaces that can elicit the richness of body movement and help patients relearn basic perceptual-motor skills.

Rizzo suggests that to rebuild a patient’s body sense and their ability to effect action, user interfaces should target specific movement actions in ecologically valid ways (Rizzo 2005). ‘Ecological validity’ refers to the degree of relevance or similarity that activities in a virtual environment have relative to the ‘real’ world, and in its value for improving a patient’s everyday functioning. The main streams of sensory information that contribute to their sense of embodiment (visual, auditory, tactile, and somatic) are fragmented as a result of their injury. Multimedia environments that can correlate a patient’s sense of embodiment may assist in the acquisition of movement skills that transfer to the real world (Holden 2005).

6.1.1 An embodied approach to the design of *Elements*

This study also suggests that Paul Dourish’s theory of embodiment is particularly useful in helping designers focus on user interaction with computer environments (Dourish 2001). Dourish asserts that embodied interaction serves to provide a particular perspective on the relationship between people and computer systems. Dourish’s perspective allows designers to unify the physical world and computer worlds. In this way, designers may create user interactions that are more closely matched to our everyday experiences and abilities. His notion of embodied interaction synthesises views on embodiment in ways that reconsider the nature of user interaction with computer systems.

Dourish explores phenomenological theories to emphasise how human actions are embodied actions. He defines embodied interaction through five interrelated foundational theories relating to ‘ontology’, ‘intersubjectivity’, ‘intentionality’, ‘coupling’, and ‘metaphor’. In Chapter 3, we explore how each of Dourish’s foundation provides a particular perspective on action and meaning and how they play a role in understanding embodied interaction with computer systems. These perspectives support interaction design that focuses on a first-person, lived, body experience and its relation to the environment. In this way, Dourish opens a user-centered design approach to the physical and social realities in which we are all embedded. He implies that we create meaning by engaging with, and acting in, the everyday world. Dourish identifies that the relationship between ‘action’ and ‘meaning’ is central to embodied interaction. Since artists are primarily concerned with meaning, it is precisely here that common ground is opened up for both communities in art and human computer interaction.

In Chapter 4, I discuss the interactive new media art work of Myron Krueger. I explore his techniques and methods for developing *VIDEOPLACE* as they relate to Dourish’s five foundations for embodied interaction. Krueger helps us understand how user interaction and experience are derived from ‘response’, ‘reinforcement’, ‘participation’, ‘control’, ‘context’, and ‘perception’. Technological and creative elements of his work can be seen in the genealogy of recent rehabilitation systems that explore playful and/or creative experiences for disabled participants (Brooks and Hasselblad 2004). Krueger’s work is of particular interest as it employs an unencumbered mode of interaction whereby the participant does not have to wear any electronic sensing apparatus. A high level of user engagement is also observed in his work.

Krueger’s work has been central to the development of my project. I wanted the patient to experience a range of interactive styles so that it might empower them both functionally and creatively. In Chapter 5, I applied the insights of Dourish and Krueger to the design of my project. Their views encapsulated the way I understand, and reflect on, the relationship between the patient, the task, and the interactive environment.

6.1.2 Embodiment and play in *Elements*

As a designer, my goal was to be sensitive to the patient’s sense of embodiment and how the environment might be presented to afford new opportunities for action. *Elements* provides an interaction aesthetic that is coupled to the individual’s perceptual and motor capabilities, building a durable sense of agency. *Elements* enables this by combining variable degrees of audiovisual feedback with the underlying forms of user interaction that provide patients with the opportunity to alter the aesthetics in real time.

Elements relies on user interaction occurring in space, through the body, and with sustained engagement with physical artifacts. These environmental parameters are designed in such a way that individual patients can develop new movement solutions and relearn basic movement skills.

There are three general goals of *Elements*. One was to improve the patient’s general ability to respond to the complexity of various interactive environments. Another was to tailor the environmental constraints of the physical installation to the patient’s needs. Finally, as a designer, I needed to increase the patient’s general capacity to plan and initiate movements, and to transfer these actions to normal physical activities in the real world.

The means of supporting this change is achieved through three main avenues: (i) the process of tailoring the complexity of the interactive environments to the individual patient; (ii) providing audiovisual computer feedback to compensate for the patient's cognitive and sensory limitations; and (iii) presenting aesthetically stimulating and challenging tasks that draw the patient into the learning space and help motivate interaction.

The two aesthetic modes of user interaction provide the patient with many options for movement, ranging from the clear goals of the game-like tasks to the ambiguity of the exploratory artistic environments. The provision of audiovisual feedback served to augment the relationship between the moving body and its effects on the environment. The feedback enabled the user to better predict the changing flow of sensory information that occurred as a result of their movement. This is regarded as a vital aspect of movement control (Garbarini and Adenzato 2004).

I observed how the exploratory tasks tended to heighten the user's sense of agency. Patients' early tentative explorations became perceptual events that were at once curious and compelling. The aesthetic seemed to draw the user into the space, encouraging a cycle of further exploration and play. This sense of involvement in an activity seemed to be characterised by a sense of novelty, enjoyment, and accomplishment. By not making the relationship between movement and its effects as obvious and by removing explicit goals, playful interaction was afforded. We may observe that playful user interaction learned by cause and effect stimulated the patient's level of motivation and engagement. Chapter 5 indicates how this approach to playful forms of embodied interaction exceeded my expectations both in terms of therapeutic effect and user engagement.

6.1.3 A design framework used to develop *Elements*

To conclude my exegesis I have structured a framework based on Dourish's five foundations of embodiment, and Krueger's related techniques (Figure 19). Each foundation is interrelated to form a holistic approach to the design of embodied interaction. My framework may provide an embodied approach to design that begins to address the ecological concerns of rehabilitation therapists. The framework may offer designers and system developers some useful perspectives and themes. The framework may be useful for analysis and conceptual guidance for design of interactive environments for movement learning.

In conclusion, we see that the theories of Dourish and the techniques of Krueger have facilitated an embodied approach to the design of my project. The resulting framework serves to focus my view, providing me with concepts that systematise my thinking and allow for reflection. The framework is organised on two levels of abstraction. Themes on the top level derive from Dourish's foundations for embodied interaction and offer design perspectives at an abstract level. These themes define broad research concerns regarding the embodied nature of user experience. Each theme is elaborated by a set of concepts derived from Dourish and Krueger. They provide analytical design tools for summarising generic issues that may guide the design process.

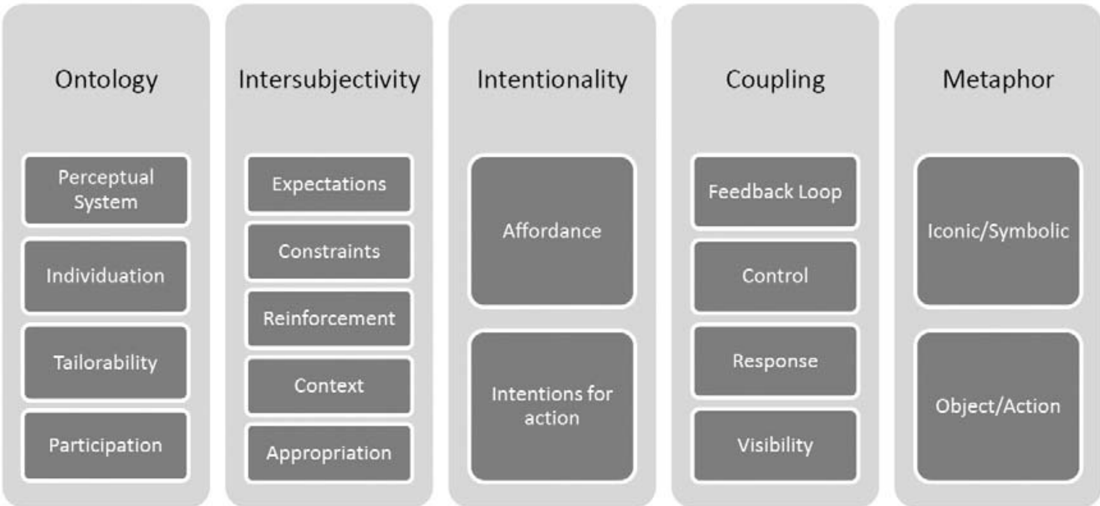

Figure 19: An embodied interaction design framework I used to develop *Elements*.

The framework is not prescriptive, and thus may need to be interpreted, expanded, and otherwise made appropriate for other situations. It may contribute to the larger research agenda of embodied interaction which may assist traumatic brain injured patients correlate a sense of embodiment. My approach relies on user experience of interaction that is tangible, physical, and embedded in space. My original contribution to knowledge is the *Elements* design, an interactive environment that may enable patients to relearn movement skills, raise their level of self-esteem, sense of achievement, and behavioural skills.

6.2 Future directions

I have suggested the *Elements* system allows transformative effects in the patient. These results suggest further opportunity for practitioners in a range of disciplines, especially those involved in art and design for therapeutic environments. As a result of *Elements*, we may identify four main directions for future research.

6.2.1 Moral and ethical obligations

The study raises interesting questions around the moral and ethical implications for patients and therapists. As a researcher directly involved in the application of technology for rehabilitation, I have a responsibility for the promotion and maintenance of health. This is particularly important where research with patient populations require a rational accounting for the potential risks and benefits associated with the deployment of interactive media for rehabilitative treatments.

The neuroplasticity of the human brain is a fundamental scientific finding that supports the basis for treatment of many forms of acquired brain injury. Neuroscience observes that the brain can metaphorically ’re-wire’ itself by creating new nerve cells and reorganise synaptic pathways around damaged brain tissue (Rose 1996). Evidence suggests brain activity associated with given functions, such as limb movement, memory and learning, can move to a different location in the brain as a consequence of normal experience or due to brain damage and recovery. In short, our mind and brain can change with sensory experience.

Rose suggests that physical changes may occur in the human brain when users are engaged with media technology. The consequences of these changes are not yet fully understood (Rose 1996). Krueger adds, “For better or worse, we find that we must foresee the ramifications of every action and be responsible for the consequences” (Krueger 1991) p. 262. Researchers may need to identify and account for how interactive media may potentially facilitate changes to the brain, and the consequences of this sensorial reorganisation.

6.2.2 Computer game design for rehabilitation

Interactive computer games that support an embodied view of performance and play are of particular interest for further research. Computer games provide many instances whereby our sensory perceptions are altered and enhanced. For example, numerous studies reported by Shawn Green and Daphne Bavelier suggest that playing interactive computer games has profound effects on neuroplasticity and learning (Green and Bavelier 2004). Computer games have been shown to increase perception and cognition in gamers compared with non-gamers by heightening spatial and sensory motor skills. These improvements could generalise to a number of real world scenarios, e.g., improved response time when driving a car, or faster performance in sport. The practical therapeutic uses of interactive computer games could be numerous, particularly when in service of individuals with diminished movement and cognitive function.

Rizzo suggests game design may provide linkage to a progressive reward and goal structure that is challenging, engaging, and motivating for traumatic brain injured patients (Rizzo 2005). Hence, the integration of gaming features in interactive movement rehabilitation may prove to be a fruitful research direction. Designers and media artists may consider how to adapt the formulas that commercial game developers traditionally use in the creation of computer games to the focused needs of brain injured patients.

6.2.3 Motivating patients in rehabilitation

This study suggests that interactive computer environments may promote therapy by engaging the patient in creative and playful activities. Future research may explore how the designer may harness these activities to motivate the learning of movement and other human skills. Petersen et al. identify human factors such as curiosity, exploration, and imagination as the key attributes of motivation. They suggest these factors need to be incorporated into the human computer interaction worldview of usability, and user engagement (Petersen, Iversen et al. 2004). As research into interactive rehabilitation progresses, media developers may need to tease out the particular aspects of training and other factors that best elicit motivation and change.

6.2.4 Broader applications

Furthermore, it may be possible to tailor my research for a broader spectrum of people with mobility impairments. A recent study by Dr Dido Green et al. at Guy’s and St Thomas Childrens Hospital, London, suggests the *Elements* system may have benefits for children with neuro-developmental (e.g. cerebral palsy) and acquired brain disorders (e.g. childhood stroke and acquired brain injury) (Green, Lin et al. 2009) (Green, Lin et al. 2010). Her findings have shown profound benefits in children relearning movement skills. This suggests that the *Elements* system could be used to treat a wider range of patients and age groups with neurological upper-limb movement impairments.

In general terms, this study suggests there are benefits to be had when designers and media artists work together with health scientists. Multidisciplinary projects such as *Elements* may help shape the use of interactive technology in rehabilitation practice. As Dourish points out, art and design can make significant contributions to this field. He notes that artists' and designers' perspective on interaction design "…reflects an attempt to make interaction 'engaging' and marks a transition from thinking about the user 'interface' to thinking about the user 'experience'" (Dourish 2001) p. 202. Krueger adds that enriching the quality of user experience with computer media will depend on artists revealing "…new sensations and new insights about how our bodies interact with reality and on the quality of the interactions that are created" (Krueger 1991) p. 265. The positive results of surveys related to *Elements* suggest there is a reciprocal role for media art and health science in developing therapeutic applications that are rich with future possibilities.

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LIST OF APPENDICES

Appendix A: Technical Specifications

Elements was developed using the following:

<u>Software:</u>

Imaging

Photoshop

3D Modelling

3D Studio Max

Interactive 3D Authoring Software

3D VIA Virtools

Database Management

MySQL

Video Tracking

PointGrey™ - Compass 3D

Custom compiled software

<u>Hardware:</u>

PC

Shuttle XPC SN26P

AMD ATHLON 64 X2 Dual Core 4400+

2GB RAM

NVidia Geforce 7900 GT Dual Link

Computer Video Camera

PointGrey™ Bumblebee 2 – 640x480 pixel image @ 48Hz

Display

Samsung 40” LCD display

Audio

Altec Lansing 5.1 surround sound speakers

Tangible User Interface

Arduino™ Microcontroller - Blue Tooth

SparkFun™ Rumble Pack

Appendix B: Plain language statement for TBI participants.

EPWORTH HOSPITAL

Elements: Clinical Design and Evaluation of a Virtual Reality Augmented Workspace for Movement Rehabilitation of Traumatic Brain Injury

Plain Language Statement

Primary Investigator: Dr. Peter Wilson (Associate Professor, Psychology, RMIT University, peter.h.wilson@rmit.edu.au, 9925 2906)

Associate Investigators: Nick Mumford (PhD student, Division of Psychology, RMIT University, nicholas.mumford@student.rmit.edu.au)
Jonathan Duckworth (PhD student, Creative Media, RMIT University, jonathan.duckworth@rmit.edu.au)

Dear Participant,
You are invited to participate in a research project being conducted at Epworth hospital. This information sheet describes the project in straightforward language, or 'plain English'. Please read this sheet carefully and be confident that you understand its contents before deciding whether to participate.

Why is this study being conducted?
The aim of the Elements Project is to design, develop and evaluate an interactive virtual environment that supports movement assessment and rehabilitation for patients recovering from Traumatic Brain Injury (TBI). This part of the project is designed to test the effectiveness of the Elements rehab system using a group of participants with TBI.

Who can participate?
You can participate in the study if you are aged from 18 to 50 years, can provide informed consent to participate in this study, and have a score of 2 or more for muscle activity on the Oxford scale.

If I agree to participate, what will I be required to do?
The training itself will involve 12 1-hour sessions using Elements, an interactive rehab system. Half of our participants will be assigned randomly to a *training* group and asked to use the system three times a week, for 4 weeks, while still doing their normal physiotherapy. The remaining (*waitlist*) participants will first continue involvement in their current physiotherapy but then later be given the opportunity to use Elements. The system involves moving hand-held objects over a large LCD screen, mounted flat on a desk. The screen will display the training environments that you will interact with. These environments and feedback provided by the system are designed to encourage movement in a natural and engaging way. We will track your movements using a special camera and provide feedback to help improve your physical skills. All participants will have their performance on upper-limb tasks assessed twice, immediately before and after the course of training (each assessment will take around 15 minutes). The main assessment tasks are: the *Upper Extremity Functional Index*, the *Action Research Arm Test*, the *Box and Block Test,* a questionnaire the *Neurobehavioural Functional Index (NFI),* and a brief survey on what you thought of the program. Your main carer will also be asked to complete the NFI and a questionnaire; we will ask your permission to do this. We would also like to interview you regarding your experience using Elements. To do this we will film you using the program and later ask you to describe your experience while watching yourself on video. This project will be conducted at the ELIM Building at the Epworth hospital.

Are there any risks or disadvantages associated with participation?
No. This study is testing a program designed to enhance current rehabilitation routines, and will not involve any activities that are more strenuous or risky than your normal rehabilitation therapy. Additionally, the standard Epworth hospital rehabilitation safety procedures will be used.

What will happen to the information I provide?
To maintain your privacy, your results on the *Elements* program will be coded and stored on a computer and secured with password access for 5 years. The scores for the standard evaluations will be stored in a lockable filing cabinet in the Division of Psychology, RMIT City Campus, and later shredded after 5 years. No findings that could identify you will be published. Only the investigators will have access to the research data. All data and results will be handled in a strictly confidential manner, under guidelines set out by the National Health and Medical Research Council. The chief investigator is responsible for maintaining this confidentiality. This project is subject to the requirements of the Human Research Ethics Committee of the Epworth Hospital and the RMIT University. However, you must be aware that there are legal limitations to data confidentiality.

Can I withdraw from the study if I wish?
Since your participation in this study is voluntary, you can withdraw from the study at any time, and have any unprocessed data previously supplied by you removed. If you decline the invitation to participate or decide to withdraw from the study, your current rehabilitation treatment will not be affected. Following the completion of this study, a brief summary of the results will be available to you on request.

What if I have any concerns during the study?
The Investigators will be available throughout the study if you have any questions. This project has been approved by the Human Research Ethics Committee of Epworth Hospital. If you have any complaints you should contact the Human Research Ethics Committee, Epworth Hospital, Ph: 9426 6755.

Whom should I contact if I have any further questions?
Any questions or concerns regarding this study should be directed to the Chief Investigator, A/Prof. Peter Wilson (details provided above). The investigators also encourage prospective participants to discuss participation in this study with their family or physiotherapist, should you wish to.
Yours Sincerely,

____
A/Prof.Peter Wilson - PhD.

____
Mr. Nicholas Mumford - B.AppSc (Psychology) (Hons)

____
Mr. Jonathan Duckworth – BSc Hons, MA (Design)

Appendix C: Plain language statement for the TBI carers.

EPWORTH HOSPITAL

Elements: Clinical Design and Evaluation of a Virtual Reality Augmented Workspace for Movement Rehabilitation of Traumatic Brain Injury

Plain Language Statement

Chief Investigator:	Dr. Peter Wilson (Associate Professor, Psychology, RMIT University, peter.h.wilson@rmit.edu.au, 9925 2906)
Associate Investigator	Mr. Nick Mumford (PhD student, Division of Psychology, RMIT University, s3021329@student.rmit.edu.au) Jonathan Duckworth (PhD student, Creative Media, RMIT University, jonathan.duckworth@rmit.edu.au)

Dear Participant,
You are invited to participate in a research project being conducted at Epworth hospital. This information sheet describes the project in straightforward language, or 'plain English'. Please read this sheet carefully and be confident that you understand its contents before deciding whether to participate.

Why is this study being conducted?
The aim of the Elements Project is to design, develop and evaluate an interactive virtual environment that supports movement assessment and rehabilitation for patients recovering from Traumatic Brain Injury (TBI). This specific component of the Elements Project is designed to gather information from the primary carer of a patient with TBI regarding their views of the Elements program, and any effect it had on the TBI patient in their care.

Who can participate?
You can participate in this study if you are currently the primary carer for a person undergoing rehabilitation for TBI who is participating in the Elements project.

If I agree to participate, what will I be required to do?
If you take part in this study you will be asked to complete a questionnaire regarding the participation of the patient with TBI who is in your care, called the *Neurobehavioral Functioning Inventory* (NFI). This questionnaire relates to symptoms and problems commonly encountered by people who have experienced neurological damage. Completing this questionnaire will take approximately 30 minutes. We will also ask you to complete a brief program feedback questionnaire, which relates to any observations you have made about the participant's behaviour or abilities while they have been involved in the virtual reality training. The patient in your care will also be asked to consent to your participation.

What are the risks or disadvantages associated with participation?
There are no risks or disadvantages associated with completing these questionnaires.

What will happen to the information I provide?
To maintain your privacy, your responses to the NFI and feedback questionnaire will be secured in a lockable filing cabinet in the RMIT Division of Psychology offices at the RMIT City Campus, to be disposed of using a lockable rubbish bin after 5 years. Only the investigators will have access to the data. No findings that could identify you will be published. All data and results will be handled in a strictly confidential manner, under guidelines set out by the National Health and Medical Research Council. The chief investigator is responsible for maintaining this confidentiality. This project is subject to the requirements of the Human Research Ethics Committee of the Epworth Hospital and the RMIT University. However, you must be aware that there are legal limitations to data confidentiality.

Can I withdraw from the study if I wish?
Since your participation in this study is voluntary, you can withdraw from the study at any time, and have any unprocessed data previously supplied by you removed. Following the completion of this study, a brief summary the results will be available to you on request.

What if I have any concerns during the study?
The Investigators will be available throughout the study if you have any questions. This project has been approved by the Human Research Ethics Committee of Epworth Hospital. If you have any complaints you should contact the Human Research Ethics Committee, Epworth Hospital, Ph: 9426 6755.

Whom should I contact if I have any further questions?
Any questions or concerns regarding this study should be directed to the Chief Investigator, Dr. Peter Wilson (details provided above).

Yours Sincerely,

____
A/Prof. Peter Wilson - PhD.

____
Mr. Nicholas Mumford - B.AppSc (Psychology) (Hons)

____
Mr. Jonathan Duckworth – BSc Hons, MA (Design)

Appendix D: Consent form for TBI participants

Epworth

Elements**:** Clinical Design and Evaluation of a Virtual Reality Augmented Workspace for Movement Rehabilitation of Traumatic Brain Injury.

Consent form

I, ..., have read and understood the information contained in the Plain Language Statement regarding the project titled '***ELEMENTS*****: Clinical Design and Evaluation of a Virtual Reality Augmented Workspace for Movement Rehabilitation of Traumatic Brain Injury'**.
I understand that:

- This study is a quality improvement project and is for research purposes.
- My participation in this project is voluntary and that I am free to withdraw at any time, and free to withdraw any unprocessed identifiable data previously supplied.
- I am required to interact with a computer program by performing arm movements. I understand that standardised analyses will be conducted to assess my movement abilities.
- I understand that video footage may be taken during my participation in this project, subject to the participant's consent.
- The results and data will remain confidential and that only the researchers will have access to the information. I also understand that the research results may be presented at conferences and published in journals, on condition that my name is not used. I am aware that there are legal limitations to data confidentiality.
- By checking the box below, I consent to my primary carer completing the NFI: carer form, and program feedback questionnaire.
- I may contact the researchers at any time, and any questions I have asked have been answered to my satisfaction. I also understand that I may contact the Human Research Ethics Committee of Epworth Hospital or RMIT University if I have any concerns.
- I understand that Peter Wilson is the Principal Researcher in conjunction with Nick Mumford and Jonathan Duckworth.
- This form will be retained, once signed, by the principal researcher.

NAME OF PARTICIPANT (in block letters): ....

Signature: ....   DATE: ....
PRINCIPAL RESEARCHER: A/Prof. Peter Wilson

Signature: ....   DATE: ....

Appendix E: Consent form for TBI carers

***Elements*:** Clinical Design and Evaluation of a Virtual Reality Augmented Workspace for Movement Rehabilitation of Traumatic Brain Injury.

Consent form

I, ..., have read and understood the information contained in the Plain Language Statement regarding the project titled '***ELEMENTS*: Clinical Design and Evaluation of a Virtual Reality Augmented Workspace for Movement Rehabilitation of Traumatic Brain Injury'**.
I understand that:

- This study is a quality improvement project and is for research purposes.
- My participation in this project is voluntary and that I am free to withdraw at any time, and free to withdraw any unprocessed identifiable data previously supplied.
- I am required to complete the Neuobehavioural Functioning Index: Carer Form, and program feedback questionnaire.
- The results will remain confidential and that only the researchers will have access to the data. I also understand that the research results may be presented at conferences and published in journals, on condition that my name is not used. I am aware that there are legal limitations to data confidentiality.
- I may contact the researchers at any time, and any questions I have asked have been answered to my satisfaction. I also understand that I may contact the Human Research Ethics Committee of Epworth Hospital or RMIT University if I have any concerns.
- I understand that Peter Wilson is the Principal Researcher in conjunction with Nick Mumford and Jonathan Duckworth.
- This form will be retained, once signed, by the principal researcher.

NAME OF PARTICIPANT (in block letters): ....

Signature: ....   DATE: ....

PRINCIPAL RESEARCHER: A/Prof. Peter Wilson

Signature: ....   DATE: ....

Appendix F: *Elements* Experience Questionnaire

Elements Experience Questionnaire (EEQ)

Age: **Gender:** **Environments Used:**

Please complete the following questionnaire as truthfully as possible. Each of the questions below refers to your experience in using the Elements system. Remember you have the right to leave at any time and any data collected will be kept anonymous and confidential.

Please read the following questions carefully and indicate the extent to which you experienced each item by putting a circle around the number on the following scale:

1 = Not at all
2 = A small amount
3 = A fair amount
4 = Quite a lot
5 = A great deal

To what extent ...

		Not at all	A small amount	A fair amount	Quite a lot	A great deal
1.	... are you familiar with using computer technology i.e. games, internet, etc	1	2	3	4	5
2.	... did you enjoy the visual effects and graphics?	1	2	3	4	5
3.	... did you enjoy the musical sounds and/or sound effects?	1	2	3	4	5
4.	... did the environment hold your attention?	1	2	3	4	5
5.	... did you lose track of time while using the system?	1	2	3	4	5
6.	... were you interested in using the Elements system?	1	2	3	4	5
7.	... did you feel that the task encouraged you to move more?	1	2	3	4	5
8.	... were you disappointed when the session was over?	1	2	3	4	5
9.	... would you like to use the system again?	1	2	3	4	5
10.	... did you enjoy using the system overall?	1	2	3	4	5
11.	... were you able to predict what would happen next when moving objects?	1	2	3	4	5
12.	... were the objects well designed for moving?	1	2	3	4	5
13.	... did you know what to do with the objects?	1	2	3	4	5
14.	... was it hard to learn how to use the system?	1	2	3	4	5
15.	... did the visual display distract you from performing the tasks?	1	2	3	4	5
16.	... did you find the task challenging?	1	2	3	4	5
17.	... did your mistakes frustrate you and make you want to give up?	1	2	3	4	5
18.	... did you learn new ways to improve your movement?	1	2	3	4	5
19.	... did the task give you a sense of achievement?	1	2	3	4	5
20.	... was the environment responsive to your actions?	1	2	3	4	5
21.	... was the audio feedback distracting when performing the tasks?	1	2	3	4	5
22.	... was the visual feedback helpful to performing the tasks?	1	2	3	4	5
23.	... were your test results helpful in assessing your performance?	1	2	3	4	5
24.	... do you see benefit in using this type of system?	1	2	3	4	5

Appendix G: Elements Experience Questionnaire results

Elements Experience Questionnaire (EEQ)

Summary of Results

The questionnaire was completed by eight patients partaking in the clinical study at Epworth Hospital, Melbourne in 2009. Each patient was provided the same questionnaire in each of the final three sessions. The scores below are an average taken from a total of 24 questionnaires.

1 = Not at all
2 = A small amount
3 = A fair amount
4 = Quite a lot
5 = A great deal

To what extent …		**Average Score**
1.	… are you familiar with using computer technology i.e. games, internet, etc	**3.96**
2.	… did you enjoy the visual effects and graphics?	**4.13**
3.	… did you enjoy the musical sounds and/or sound effects?	**3.88**
4.	… did the environment hold your attention?	**3.96**
5.	… did you lose track of time while using the system?	**2.34**
6.	… were you interested in using the Elements system?	**3.71**
7.	… did you feel that the task encouraged you to move more?	**4.21**
8.	… were you disappointed when the session was over?	**2.34**
9.	… would you like to use the system again?	**4.25**
10.	… did you enjoy using the system overall?	**4.33**
11.	… were you able to predict what would happen next when moving objects?	**3.29**
12.	… were the objects well designed for moving?	**4.17**
13.	… did you know what to do with the objects?	**4.09**
14.	… was it hard to learn how to use the system?	**1.38**
15.	… did the visual display distract you from performing the tasks?	**1.19**
16.	… did you find the task challenging?	**2.59**
17.	… did your mistakes frustrate you and make you want to give up?	**1.00**
18.	… did you learn new ways to improve your movement?	**2.96**
19.	… did the task give you a sense of achievement?	**3.05**
20.	… was the environment responsive to your actions?	**3.73**
21.	… was the audio feedback distracting when performing the tasks?	**1.21**
22.	… was the visual feedback helpful to performing the tasks?	**3.72**
23.	… were your test results helpful in assessing your performance?	**4.50**
24.	… do you see benefit in using this type of system?	**4.29**

Appendix H: Australia Council for the Arts, Promotional Material
Artery, Issue 8, 2008, p12

The elemental art of rehab

ELEMENTS' tangible user interface
PHOTO: RAYMOND LAM

A revolutionary three-year art-science collaboration based at Melbourne's RMIT University is unlocking the potential of mixed reality environments in the rehabilitation of patients with traumatic brain injury (TBI).

Early results indicate that the multi-modal interactive workspace, named ELEMENTS, dramatically assists patients seeking to regain upper limb movement following TBI.

The project, funded through the Australia Council's synapse program, and the Australian Research Council (ARC). It aims to stimulate and engage a patient's creative and aesthetic sensibilities throughout the rehabilitation process, according to Jonathan Duckworth, a new-media artist from the School of Creative Media at RMIT and co-leader of the project.

'By raising the aesthetic quality of the stimulus, patients actually forgot they were doing therapy and were excited about coming in for their sessions,' said Jonathan.

While TBI directly affects about 2 per cent of the population, it is also the main cause of death and disability in adolescents and young adults. It costs the community in excess of $3 billion annually, not to mention the incalculable social, emotional and mental health costs.

The ELEMENTS system consists of a large horizontal tabletop graphics display, a stereoscopic vision-based tracking system, and tangible user interface.

The interface is a graspable system that incorporates low-cost sensor technology to augment feedback to the patient about the effects of their movement. The combination of 3D non-invasive technology is designed to help patients re-train movement, their sense of embodiment, and self-efficacy.

Jonathan has been practicing as a new-media artist and designer since 1999, developing interactive 3D environments both through the Virtual Reality Centre at RMIT and his multimedia practice ZedBuffer.

He became interested in TBI rehabilitation after being approached by a patient who had read about virtual reality rehabilitation on the internet.

'Having previously worked with the Australia Council and being aware of the synapse program, I took the idea to them and we had a positive series of meetings to flesh the idea out,' he said.

The Australia Council's synapse program acknowledges that artists and scientists approach creativity, exploration and research in different ways and from different perspectives and that new ways of seeing, experiencing and interpreting the world can result from such collaborations.

Fellow project leader and associate professor in psychology at RMIT, Peter Wilson, is thrilled at the project's results so far.

'The marriage of art and science, as seen in the ELEMENTS project, is a significant step forward in rehabilitation,' Professor Wilson told *artery*.

In what is a truly multi-disciplinary effort, the duo is working closely with RMIT's Nick Mumford (psychology) and Ross Eldridge (electrical and computer engineering) while collaborating with Mark Guglielmetti (new media artist, Monash University), Pat Thomas and David Shum (psychologists at Griffith University), and Dr Gavin Williams (senior physiotherapist at the Epworth Hospital in Melbourne).

Jonathan is currently developing two aesthetic styles for ELEMENTS – a task-based game-like program and a creative aesthetic program that engage patients on two different levels. According to Jonathan, one of the key benefits to the system is its ability to stimulate more life-like sub-conscious movement in patients. 'To make intentional movements is a difficult process in rehab so ELEMENTS allows patients to learn like they would in real life,' he said.

The team's early results have already exceeded expectations. Significant gestural improvement was observed in patients using the system for even a short period of time while patients reported a high level of motivation, engagement and enjoyment in the therapy.

Their results also attracted considerable oversees interest at this years' Virtual Rehabilitation Conference in Vancouver, Canada and the International Symposium for Electronic Art held in Singapore in August.

>> www.zedbuffer.com

Appendix I: RMIT University, Promotional Material
The Australian Financial Review Supplement
Making the Future Work, RMIT, 2009

RMIT researchers have developed an interactive console to help brain-injured patients.

THE GAME OF LIFE

by Robyn Anns

For anyone unfortunate enough to suffer a Traumatic Brain Injury (TBI), the road to recovery is slow, painful and often challenging.

Brain-injured patients must re-learn basic tasks using repetitive mobility training, gestural practice and rehearsal of basic, everyday tasks. Now, thanks to the efforts of an artist and a psychologist at RMIT, rehabilitation for TBI patients may be swifter, more effective and far more enjoyable.

New media artist Jonathan Duckworth, Associate Professor of Psychology Peter Wilson and their collaborators have produced a unique device that uses colour graphics, psychology and technology to help brain-injured patients regain their motor skills.

The interactive, screen-based graphics display, called Elements, provides users with progressive challenges to cognition and coordination, and immediate feedback on their performance. The arts-science design project was supported through the Australia Council's interdisciplinary arts initiative, Synapse, and the Australian Research Council.

The prototype has been trialled at the Brain Injury Clinic at Melbourne's Epworth Hospital, with a total of 10 patients, during the past year. "All the patients were very keen to interact with the system in a creative way, and they showed increased motivation, engagement and enjoyment while using the system," Wilson says.

A trial involving three patients showed improvements in movement accuracy, efficiency and attention to tasks at hand. "The Epworth trial results strongly suggest that creative applications improve TBI patients' motor and cognitive skills," Wilson says.

The Elements system looks rather like a game console with a 42-inch LECD horizontal glass surface, but it also has an overhead camera and 3D tracking system.

As patients move hand-held markers containing sensors across the screen, they can see the effects of their movements on the coloured patterns displayed on the glass.

"We can scale up in complexity as patients become more dextrous. We can also track how accurate and quick they are," Wilson explains.

For Jonathan Duckworth, an artist, designer and PhD student at the School of Creative Media, helping to create Elements was an unexpected artistic challenge.

"It encourages patients to play and explore. It can be used as a game-like environment where it is goal-directed, or in an exploratory play using emerging goals where users can explore what they can do," Duckworth explains.

"With Elements, patients can play interactive, screen-based exercises and games, which is something they are probably comfortable with," Wilson adds.

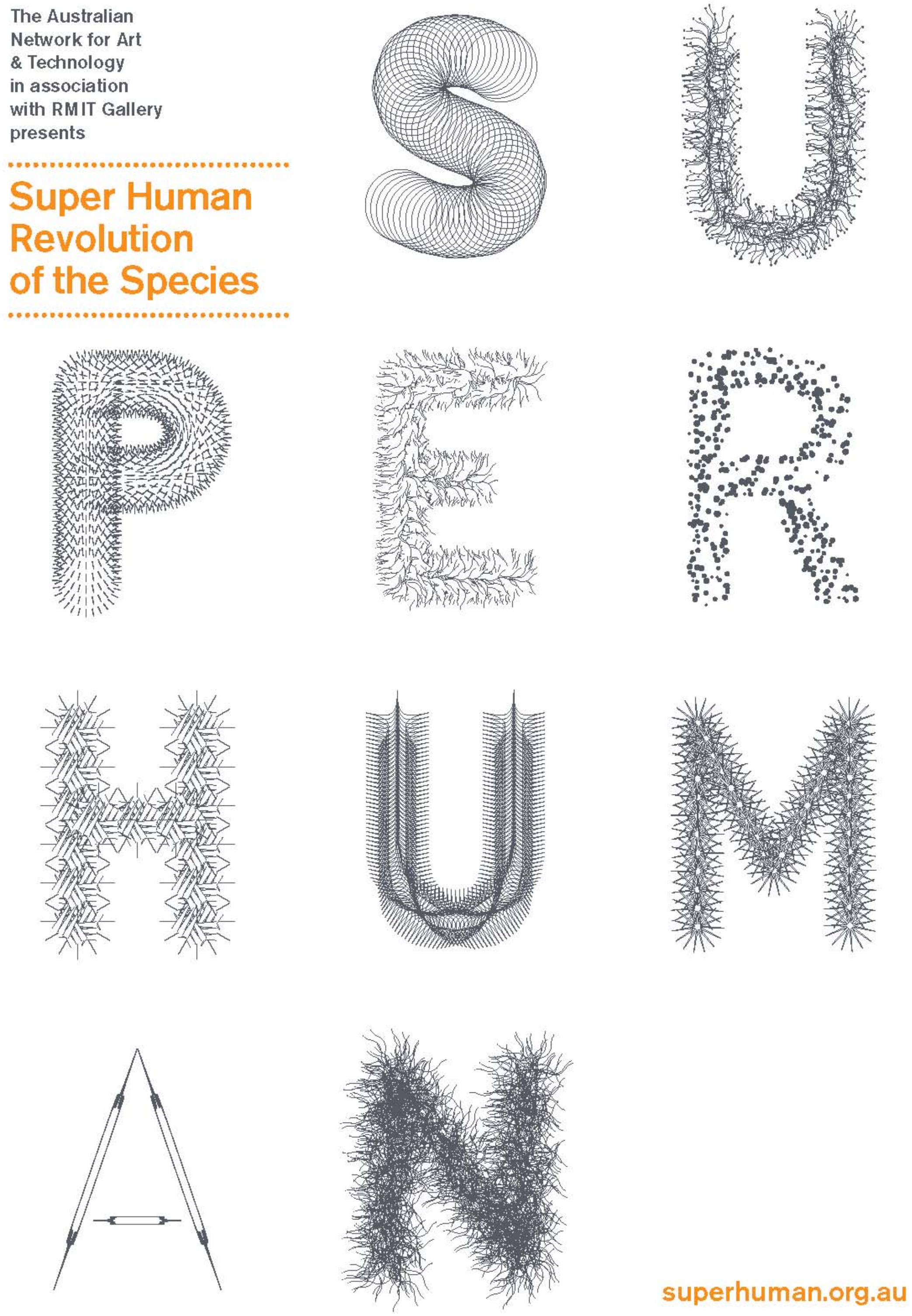
"They can compete against themselves and improve on their previous efforts. It's something they can relate to and it provides instant feedback; it's sort of fun and not intimidating.

"With conventional therapy, clinicians track recovery and this provides feedback to the patient. But with this system we can assess very accurately and provide augmented feedback in real time so they learn or re-learn motor skills more quickly," Wilson says.

Senior Physiotherapist with the Brain Injury unit at Epworth Hospital, Dr Gavin Williams, describes Elements as the way of the future.

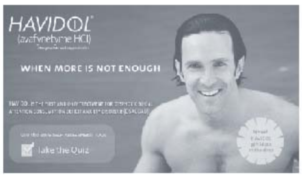
"The more specific, immediate and accurate feedback you get, the better you learn. This system gives them all that. The learning side of things is immediate and in context that is best for the patient."

Appendix J: Super Human 2009, Exhibition Catalogue
Australian Network for Art and Technology (ANAT)



Super Human
Revolution
of the Species

Inspired by the 150th publication anniversary of *The Origin of Species*, Darwin's evolutionary treatise, Super Human: Revolution of the Species turns the spotlight on collaborations between artists and scientists and the impact these have on what it means to be human, now and into the future.



Appendix J: Exhibition Catalogue Continued…

Exhibition
5 November – 5 December
Artist's Reception
22 November

Showcasing works by leading Australasian artists, the Super Human exhibition reframes the Cartesian body within contemporary culture. Focusing on Cognition and Neurology (Mind), Augmentation and Biological Manipulation (Body) and Nanoscale Interventions (the Soul, the 'not visible'), the exhibition exposes our aspirations and fears about our bodies and their extraordinary functions.

Clockwise from top left: *Havidol*, Justine Cooper; *Chameleon*, 2007, Tina Gonsalves; *The Heart Library*, 2004–2009, George Khut; *Electric Retina*, 2009, Jill Scott; *Midas*, Paul Thomas; *Embracelet*, 2007, Jonathan Duckworth; *Machine Gun Walker*, 2004, Brad Nunn; *Metazoa*, 2008, Angela Main; *Fragile Balances*, 2008–09. Mari Velonaki in collaboration with David Rye and Steve Schending; *Drift*, 2009, Leah Heiss; *Fibre Reactive*, 2004–2009, Donna Franklin; *NoArk II*, 2009, The Tissue Culture and Art Project






Appendix J: Exhibition Catalogue Continued…

Artists

The artists in the Super Human exhibition practice at the leading edge of creative research and their resultant works are testament to the value and importance of contemporary collaborations between the arts and sciences

Justine Cooper

justinecooper.com

Cooper's artwork investigates the intersections between culture, science and medicine. She works across various media – animation, video, installation and photography, as well as medical imaging technologies. Justine was the first Artist in Residence at The American Museum of Natural History.

HAVIDOL®
havidol.com
Consumer advertising for prescription medications was legalised in the United States in 1997. Since then, more and more prescription drugs are being developed and sold that are lifestyle enhancing, rather than life-saving. Cooper's work invents a new disorder and associated marketing campaign to launch the fictional magic-bullet pharmaceutical *HAVIDOL®*, which treats Dysphoric Social Attention Consumption Deficit Anxiety Disorder (DSACDAD).

Acknowledgements: *HAVIDOL®* **was funded by the Australia Council of the Arts, Greenwall Foundation and New York State Council for the Arts.**

Jonathan Duckworth

zedbuffer.com

Duckworth is an artist, designer and PhD candidate at the School of Media and Communication, RMIT University. His creative work is informed by his research into technologies, designs and materials that offer unprecedented scope for modifying spatial experiences in engaging and innovative ways.

Embracelet and Elements
These works investigate physical interaction and augmentation in the service of movement rehabilitation for people with a Traumatic Brain Injury (TBI). *Embracelet* is a conceptual bracelet that provides tactility and augmented visual feedback based on grip strength; *Elements,* developed in collaboration with Assoc Prof Peter H Wilson, is a desktop virtual environment that affords movement. Combined, they provide a tangible (and psychological) bridge between therapeutic and daily environments and challenge assumptions surrounding clinical environments and the recovery process.

Acknowledgements: *Embracelet*: Developed at the ANAT reSkin workshop hosted by the Australian National University School of Art, the Centre for New Media Arts (CNMA) in association with Craft Australia. Supported by RMIT, Australia Council for the Arts and Nanotechnology Victoria. *Elements:* Supported by a Synapse/Australian Research Council (ARC) Linkage Grant through the Australian Government through The Australia Council, its Arts funding and advisory body and RMIT University.

Donna Franklin

bioalloy.org

Franklin teaches at the School of Communications and Contemporary Arts, Edith Cowan University. In 2005 she undertook a residency at SymbioticA – Centre of Excellence in Biological Arts and since then has exhibited internationally. She is currently developing a research project *Micro'be'* with Gary Cass.

Fibre Reactive
Fibre Reactive uses living fungi (Pycnoporus coccineus – orange bracket fungus) to question the manipulation of living entities as commodities. Humankind is unique in its separation of self from the environment through the use of technology grounded upon anthropological narratives. Such mediated experience can lead us to forget that our very survival is dependent upon even the smallest elements of our ecosystem.

Acknowledgements: Elizabeth Halladin, Gary Cass at FNAS, Pr. K. Sivasithampraram at SEGS; Jane Coakley, Dr Ionat Zurr, Oron Catts at SymbioticA, UWA, Dr Nicola Kaye and Dr Chris Crouch at SCA, ECU.

Tina Gonsalves

tinagonsalves.com

Gonsalves integrates art, science and technology to produce interactive works offering new ways of experiencing the connection between our 'internal' body and its external environment. She is currently honorary artist at the Institute of Neurology UK, the MIT Media Lab, USA and Nokia Research Labs, Finland.

Chameleon – Prototype07
Chameleon merges art, neuroscience and technology into a poetic interactive installation driven by the emotions of the audience. The work investigates emotional contagion, highlighting how we innately and continuously synchronize with the facial expressions, voices and postures of others. Created between 2008–2010, the various prototypes resonate with scientific and artistic research, fostering new models for scientific inquiry and immersive artistic experiences.

Acknowledgements: Developed in collaboration with Prof Hugo Critchley, Prof Chris Frith, Prof Rosalind Picard, Dr Rana El Kaliouby, Nadia Berthouze. Curated by Helen Sloan of SCAN. Supported by the Wellcome Trust, Australia Council for the Arts, Arts Council England, ANAT, Banff New Media Institute, MIT Media Lab, Brighton and Sussex Medical School, Lighthouse, Dana Center, Institute of Neurology UCL.

Leah Heiss

elasticfield.com

Heiss is an artist, designer and academic who engages in collaborative research projects to produce innovative technology applications that reveal an enduring fascination with the potential of communications' modalities to transcend physical limitations in a meaningful, embodied way.

Drift
A series of handheld interactive objects that investigate social behaviours, *Drift*'s luminescent pods pulsate softly, engaging our curiosity, beckoning us to pick them up. When the pods are held in hand they react in playful, confronting and unexpected

ways, reflecting how, by imbuing our artefacts with interactivity, we may actually be ascribing them personality traits – the capacity to behave in erratic, complex and unforseen ways.

Acknowledgments: *Drift* is supported by the Customising Space Program – RMIT Design Research Institute and by RMIT School of Architecture & Design through the SRC Funds.

George Poonkhin Khut

georgekhut.com

Khut's practice focuses on biofeedback interactions and ethnographic research processes, inviting us to experience and re-imagine notions of embodiment and self-hood. The exhibition of his works reaches beyond the gallery and into hospitals and science centres, evidence of the broad resonance of his approach.

Alembic and Retort

Alembic and Retort is an interactive work inviting us to explore and reflect on the relationships between our thoughts, feelings and physiology. Sensors enable us to navigate layers of electronic sound using emotionally-mediated changes in our heart rate patterning. Alluding to alchemical notions of slow-burning psychological ferment and distillation, the work reframes our psycho-physiology as a space of poetic, elemental transformations using the sounds of heat, condensation, air and stone.

Acknowledgments: Jason McSweeney (analysis software), Greg Turner (Max-MSP); and Sean O'Connell (electrode fabrication). Parts of the work were developed with support from the Australian Government through The Australia Council, its Arts funding and advisory body.

Angela Main

metazoalive.com

Main is a NZ artist who creates large-scale performative and multi-disciplinary events hinged around the ideas of participation and play. Since 2006, in collaboration with HITlabNZ, she has developed multi-user works that appropriate augmented reality software within large-scale environments.

Metazoa

Metazoa weaves cross-cultural narratives into an interactive game, blurring scientific, spiritual and socio-politicial evolution mythologies through the player's experience as a digital avatar. 500 million years is distilled into five minutes, with players required to physically engage with the character their bodies are mobilising on-screen. We begin as protozoa and progress through seven ages and seven forms before being propelled back via cataclysmic events mimicking the evolutionary cycle.

Brad Nunn

synapse.net.au/people/brad_nunn

At the age of 28, Nunn suffered a brain haemorrhage, leaving him physically and neurologically 'damaged'. Since then, his artistic practice has focused on interrogating the two prevailing narratives of prosthetics: as compensation for the so-called 'disabled' body and as enhancement of the 'normal' body.

Machine Gun Walker

Attached to the frame of the walker is a representation of the archaic Vickers machine gun, a weapon used by Australian troops in WWI, WII and the Korean War – wars in which those who fought are now reaching the age when walking frames will have taken the place of guns. By empowering the walker in such a way, patriarchal identity can be restored and the image of the frail, defenceless returned soldier overturned. The machine gun is fantasy, the walker, reality.

Jill Scott

jillscott.org

Scott is Professor for Research at the Institute of Cultural Studies in Art, Media and Design, ZHDK University of the Arts, as well as Co-Director of the Artists-in-labs Program, Zurich. She has exhibited extensively

Appendix J: Exhibition Catalogue Continued…

and is currently creating interactive works based on neurobiology, which she calls 'Neuromedia'.

The Electric Retina
The Electric Retina combines retinal research and interactive media art with metaphorical associations about visual perception. The work, a media-sculpture based on the study of photoreceptors and their neural behaviour, enables us to gain a greater understanding of how our visual and cognitive reactions are affected by genetics, disease and degeneration.

Acknowledgements: The Neuhauss Lab: Prof. Dr. Stephan Neuhauss, Corinne Hodel, Melody Huang, Oliver Biehlmaier, Colette Maurer, Markus Tschopp, Marion Haug. Editing Support: Marille Hahne. Programming and Sensoring: Andreas Schiffler and Marcus Dusseiller. Construction helpers: Simone Lüling, Beat Schlaepfer, Christian Tanner.

Paul Thomas

In collaboration with Kevin Raxworthy

visiblespace.com

Thomas is an artist, curator and academic researcher. He is currently Director of the Centre for Research in Art, Science and Humanity at Curtin University of Technology and prior to that was the founding director of the Biennale of Electronic Arts Perth (BEAP). His work is exhibited internationally.

Midas
Midas is a visual and sonic installation that amplifies aspects of experience at a molecular level. It is based on research developed at SymbioticA, Centre of Excellence in Biological Arts and the Nano Research Institute at Curtin University of Technology. The work examines the transition phase that occurs at the nano-level between skin and the materiality of gold.

Tissue Culture and Art Project

Oron Catts & Ionat Zurr

www.tca.uwa.edu.au

Catts and Zurr's use of tissue technologies as a medium for artistic expression leads us to question perceptions of life, identity and the position of the human in relation to other living beings and the environment. Their work has shown internationally, including at Ars Electronica (2007) and MoMA (2008).

NoArk II
NoArk II explores the taxonomical crisis resulting from life forms created using biotechnological means. The work takes form as an experimental vessel designed to maintain and grow a mass of living cells and tissues originating from a number of different organisms. The vessel serves as a surrogate body for a collection of living fragments and is a tangible as well as symbolic 'craft' for observing and understanding a biology combining the familiar with the other.

Acknowledgements: The Tissue Culture & Art Project is hosted by SymbioticA, School of Anatomy and Human Biology, University of Western Australia. The project was assisted by the State of Western Australia through the Department of Culture & the Arts. Bioreactor supplied by Wave Products Group/GE Healthcare.

Mari Velonaki

In collaboration with David Rye & Steve Scheding

csr.acfr.usyd.edu.au

Velonaki's practice engages with digital and robotic 'characters' in interplays stimulated by sensorially-triggered interfaces. Her work has been exhibited in major museums internationally and, 2006, she cofounded the Centre for Social Robotics at the University of Sydney's Australian Centre for Field Robotics.

The Fish-Bird Series (2004–09
The Fish-Bird series started with Fish and Bird, two characters who fall in love but cannot be together due to 'technical' difficulties. The characters – two autokinetic robotic wheelchairs – communicate with each other and with the audience through movement and written text.

Circle D: Fragile Balances
Circle E: Fragile Balances
In *Circle D*, two luminous cube-like objects display personal messages that flow between the virtual characters, Fish and Bird. The objects can be lifted and, if handled gently, reveal intimate messages. Sudden or abrupt movements, on the other hand, make the text illegible and terminate the communication. In *Circle E*, we are invited to write intimate notes to our loved ones and donate them to the project by 'posting' them in a revolving brass machine.

Acknowledgements: Centre for Social Robotics, Australian Centre for Field Robotics (ACFR), The University of Sydney, Iain Brown, Mark Calleija, Bruce Crundwell, Andrew Hill, Craig Rodgers, David Silvera, Geoff Tonkin, Dave Wood.

Appendix J: Exhibition Catalogue Continued…

Credits *Original Curatorial Concept* Melinda Rackham *Producer* Vicki Sowry *Communications & Marketing* Amanda Matulick *Graphic Design* Aaron Seymour *Coordinator* Gillian Morrison

Thanks *RMIT Gallery* Suzanne Davies, Vanessa Gerrans, Sarah Morris, Evelyn Tsitas, Peter Wilson *ANAT* Gavin Artz, Ruth Cross, Juili Kwan, Simon Tropeano, Louise Vlach

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