Discovering Physical Visceral Qualities for Natural Interaction

Submitted for the degree of Doctor of Philosophy

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Abstract

As the technologies of computing have advanced to become ubiquitous and pervasive in our everyday life, our way of interacting with computers is also changing. Most existing research, particularly on Tangible User Interfaces (TUI), has focused on enhancing and augmenting physical artefacts to be digitally-linked to underlying computational functionalities. This research focuses on physical devices and reports an investigation into what makes interaction natural and fluid.

We believe the knowledge of today can benefit the design of tomorrow. A wide range of home appliances and devices are examined. Attention during the analysis is given to the mappings between the physical and digital states and the design features that make them appealing and natural to use. A set of physical design features and a collection of implicit design characteristics are introduced. These are further analysed and elaborated from a cognitive point of view, which takes into account mental requirements and cultural influences. Tangible devices that embody the design principles are then examined and these principles are related to existing TUI framework.

The design principles were incorporated in the study of the Cubicle – an existing tangible input device. Despite breakdowns in the users' ability to create explicit mappings, users still could complete tasks, and found the whole experience enjoyable. *Inverse action* (one of the design principles) enabled users to construct *momentary mappings* which helped them to overcome breakdowns. We call the momentary knowledge that embeds within the flow of interaction; *visceral interaction*. We further explored the notion of *inverse action* in a second user study: 'Cruel Design', where the mappings between two joysticks and their functionalities were swapped around.

In this thesis, we learned there are more to natural interaction than just good mappings. It was particularly surprising to discover where mappings are not explicit and deliberate, physical visceral qualities in artefacts, together with human innate abilities, helped users in interaction.

Declaration

I declare that the work presented in this thesis is, to the best of my knowledge and belief, original and my own work. The material has not been submitted, either in whole or part, for a degree at this or any other university.

Excerpts of this thesis have been published in conference and workshop articles, most notably (Ghazali and Dix, 2006), (Ghazali, 2006), (Dix et al., 2005), (Ghazali and Dix, 2005a), (Ghazali and Dix, 2005b), and (Ghazali and Dix, 2003).

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Masitah Ghazali

Acknowledgements

"To be working in the area of Human-Computer Interaction is something that she always wanted to do. Together with her interest in both homes and designs, and, the emergence of ubiquitous computing technology, she started her research on ***engaging user experience****,* ***physical-tangible interaction*** *and* ***domestic technology settings.****"*

The above excerpt was written in the early days of my PhD. For this, I would like to thank my supervisor, Professor Alan Dix, for giving me the opportunity to realise my dream and taking me under his wings. Because of his beliefs in me, his kind patience, his continuous support and his constructive criticism, I was able to do this from day one to the production of this thesis.

Special thanks to Kiel Gilleade for the great collaboration in the Cruel Design study, and for being such a good colleague and officemate. Special thanks also go to Florian Block and Jennifer Sheridan (who is now a Dr.) for the stupendous teamwork in the Cubicle study. My thanks also go to Dr. Boriana Koleva and Marina Ng, from Mixed Reality Lab Nottingham University, for their input in TUI framework. Invaluable thank you goes to Dr. Corina Sas for providing valuable feedback on my thesis. And to Pete Dawson, for doing me a huge favour by proof-reading this thesis.

I never imagined how hard, difficult and lonely the PhD journey was, especially in the process of writing-up. But like other journeys in life, loves, supports and encouragements had helped me through the rough times. Thank you to all my wonderful friends whom I have made over the years for the kindness, laughter and friendships. Particularly, my past and current housemates, Edaroyati, Azean and Idlan, for keeping me fed with good food and in good spirits. And also to Novia and Rafidah for taking me in and giving me a home when I was home-less. Thank you!

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I would like to express my deepest gratitude to my mom and dad, and my siblings, for their unfailing prayers. Despite the distance, they are always close to my heart.

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Dedication

To my parents

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Chapter 1

Introduction

The advent of Ubiquitous Computing has gradually moved people away from the desktop environment, only to find themselves interacting with a plethora of computational devices in their surroundings. The subject of interaction with computing has never been dull especially in the past decade and obviously is not going to be so in the decades to come. The uniqueness of this subject is the fact that it has successfully become inter-disciplinary in nature, belonging not only to the computer scientists, but also to people from different backgrounds, such as psychologists, sociologists, artists, architects, engineers, product designers and many more. These people come together with one thing in common: to improve the quality of interaction.

This thesis attempts to discover what makes interaction natural and fluid. By investigating the way we interact with everyday artefacts and appliances, this thesis explores the design characteristics that make these interactions successful, and outlines how they can be applied in the design of tangible controls.

1.1 Interaction in Ubiquitous Computing

Ubiquitous Computing was first articulated and introduced in 1988 by Mark Weiser (Weiser, 1996). In his paper, which he co-wrote together with John Seely Brown, they envisioned the third wave of computing is that of ubiquitous computing: a number of devices being associated to one person, will be around 2005-2020, which also marks the beginning of the age of calm technology (Weiser and Brown, 1996). According to Weiser (1996), the major trends in computing began with the wave of mainframes, where each machine was shared by lots of people, and then with the wave of personal computing, where one person works closely with one machine or desktop.

The birth of the third wave, is a work of integration of computer science, engineering, human factors and social sciences. The idea of ubiquitous computing, is for computing to be embedded into the environment where people should interact with computing devices more naturally. The condition where computing is pervasive within the surroundings gives an additional name to ubiquitous computing – pervasive computing. One way of realising this is by producing more sensor-riched computing appliances which can sense any changes in the environment in order to enable interaction between indirect users and pervasive devices. This is normally known as context-aware computing.

Interaction in ubiquitous computing covers such a vast area, from ambient environments that allow communication to take place on the periphery of human perception, to embedded technologies that normally augment the existing devices to be more robust and compatible in almost any situations, or to context-aware computing, in different types of settings, for example, home, office, classroom, cities and museums.

As described above, the third wave of ubiquitous computing is imminent. The transition has inevitably necessitated a change in conceptual models, i.e. how users' roles play out in the new era. Research in this area also takes considerable input from groups of users like the elderly, and people with disabilities, who previously were not regarded as dominant users.

The vision of the creation of tangible devices in the era of ubiquitous computing, linking the physical-digital worlds, is shared by many these days. The term “Tangible User Interfaces” (TUI), first proposed by Ishii in 1997 (Ishii, 1997), introduced the world of computing to the possibility of linking physical artefacts with digital information; and the research work on TUI has grown much since.

Interacting with tangible artefacts is always exciting, fascinating and inspiring. The behaviour of physical objects which have been augmented and computationally-linked to their digital space never fails to mesmerise users to interact with them. When the tangible artefacts are closely or exactly designed in the form of things or devices which we normally see, interaction creates a wonderful experience, but when the artefacts are not as straightforward as they seem, interaction can get lost in the exploration.

1.2 Interaction with Everyday Appliances

There are objects, artefacts, machines, devices and appliances in every corner of our space. And undeniably, we are now living in a world that is suffused with computation, which results to even richer interactions, and some times more exciting and enjoyable.

The way each and every object is designed does influence the way users understand, or how a user can immediately know of what or how to manipulate these objects. Bridging what an object could offer – both its meaning and its functionality, and how a user can make full use of an object, is very crucial. On one part, we could have the affordance to help the designers to design an artefact to its full potential, and on another, users may rely on their past and existing knowledge, their bodily movement, and even their intuition, to interact with objects, or specifically to manipulate the physical controls of these objects. These two key points are inextricably related as both points should be considered by both the designers and the users to ensure the bridging of understanding takes place.

As ideal as the objects and devices may be, some issues are still lingering and circulating especially in the design aspect. Even until today, it has always been a difficult decision in determining what should be more important when it comes to usability and usefulness vs.

aesthetic, and manual leaflet and instructions vs. pick up and use.

Despite these, there are plenty of good design values coming from the existing devices and appliances. And this is exactly what should be understood and be adopted in designing novel devices.

1.3 Understanding Physicality

Today's interpretation of physicality has evolved significantly with the invention of mechanical and electrical devices, objects and appliances. With these kinds of artefacts, our understanding of physicality has gone beyond that just one thing, i.e. the appearance of physicalness, as these artefacts now have something else associated with them, and at most of the time, they have designed purposes (Ghazali, 2006). And these are also true for almost every single computing device, including tangible objects, we see today.

One thing that tangible artefacts and everyday appliances have in common is the physicality attributes of the objects. When all the functionalities which are associated with them are stripped off, perhaps the process of interaction is not so different after all.

This thesis focuses on some of the issues outlined above. The question on what makes the interaction with everyday appliances successful, or unsuccessful, was first addressed. This results to a set of physical design characteristics that incorporates mainly the views and concepts of affordances and mappings that illustrate the innate ability and understanding that humans have when interact with devices.

The assessment is done in two ways:

i) by implementing or applying the physical design characteristics in experimentations, followed by a conceptual analysis
ii) by assessing further its implications on the existing TUI frameworks

The former addresses the issue of physical-digital mappings and at the same time, takes into account the issues of its application within domestic settings, as well as enjoyable and playful experiences. Further assessment is carried out to address issues of visceral interaction and the relationship between the cognitive and physical mappings. Finally, ways are addressed in how the tangible interface design can benefit from the findings.

The motivation of this research comes from the idea of human centred approach to Ubiquitous Computing, and in particular, interactions with regards to objects and devices, as elaborated in the following sections.

1.4 Motivation

Why do we consider day-to-day devices at all? These are typically independent devices with low computational power and very traditional technologies. In contrast research in tangible and ubiquitous technologies seems to be technologically far removed. This radical view of the future has captured the media's imagination, for example ubicomp researchers contributed strongly to the film *Minority Report* (Spielberg, 2002) which has popularised the ubiquitous vision of the future first articulated by Weiser (1993). This science fiction world seems far removed from the devices we see today, but perhaps they are not so different after all.

1.4.1 The Vision

Ubiquitous computing paints a world where the day-to-day activities of our lives are suffused with computation. Each item from briefcase to breakfast-cereal packet becomes a locus for interaction. Some of this is incidental to the activities we are doing (Dix et al., 2004b): the briefcase keeps track of its contents and talks to the wall calendar so that it can warn if an important document for today's meeting is missing. But other actions require more intentional although still implicit interactions (Schmidt, 2000): tipping the breakfast place-mat from side to side to turn the pages of the morning paper displayed on it. Others are more explicit still, the magic wand that acts as universal control (Fails & Olsen Jr., 2003).

We are focusing in this thesis on the latter two categories: the intentional but implicit and the more explicit interactions. Both involve physical objects or controls. However, as the world fills with physical objects that have meaning in the electronic world, then how do we understand those meanings? How do we turn the device that is a wonderful demonstration when you know how it works into an object that is "pick up and use"? And even when you know how it works, what are the affordances of the object and the properties of the physical–logical relationship that allow the use to become natural?

1.4.2 The Mundane

In the *current* world our lives are suffused with computation. Many items from Walkman to washing machine are a locus for interaction. Some of this is incidental to the activities we are doing: the set-top box that monitors your watching habits and consults the electronic TV guide so that it can pre-record the programmes you may want to see later. But other actions require more intentional although still implicit interactions: the volume control on the phone that naturally sits under your thumb. Others are more explicit still: the dial and switches on the washing machine control panel.

Focusing again on the latter two categories, designers of day-to-day products are constantly faced with the issue of how to make these devices comprehensible to ordinary people. A MiniDisc controller that makes a wonderful demo to a group of fellow designers, or even computer scientists, could win you a design award, but will be a market flop if people cannot pick it up and use it. A 27 page manual is not acceptable whilst jogging.

1.4.3 Harvesting the Experience in the Ordinary

So, we can see that the novel interactions envisaged in ubiquitous computing, although different in detail, do share much with more mundane day-to-day appliances. By studying these appliances we can learn much that would be hard or impossible to learn by extensive experimentation with novel devices.

First, we all have an extensive first and second hand knowledge of these devices and their use. Of course we have to be careful as researchers and designers when generalizing from our own anecdotal experiences; however, neither should we ignore this rich resource.

Second, these devices are only popular if they ‘work’ for people. Although little-used controls may not be optimal it will generally be the case that the more heavily-used aspects will have designs that have been found to be usable otherwise the products would not sell. Obviously this second argument does not hold where there is an effective monopoly, as is the case with certain software goods, but for most consumer appliances there is considerable competition and also consumers will have seen them in friends’ houses, or for personal products perhaps borrowed them and tried them out.

Finally, these products embody the knowledge of their designers. Some are successful because they happen to be, but many are successful because they are designed to be. Because of the different styles of the disciplines, much of this design knowledge is communicated through exemplars rather than abstracted principles. However, this community knowledge, as well as individual skills, are evidenced in the products we find.

Of course not all appliances are well designed; in particular, aesthetics may dominate usability. However, this should not detract from the overall ease with which we conduct most of our technological use of artefacts.

1.5 Thesis Statement

The objective of the research is to understand the features of physical interaction and of the physical-logical mapping that make them comprehensible and natural. Our aim is to use rich, implicit knowledge in the design of day-to-day artefacts to uncover principles that can be used in the design of novel tangible interfaces.

The prime interest is the detailed physical aspects of devices and the way in which these can recruit our innate human abilities. The further goal is to understand the cognitive aspect in an interaction and the relationship it has against the physical aspect within an interaction.

The methods used include surveying literature and available information, analysing information at hands, designing and carrying out case studies to prove the feasibility of the proposed ideas, creating concepts that generalise what was learned from the studies, and analysing the solutions.

1.6 Method

This research adopts two types of research methodology: exploratory approach and experimentations. The structure of this research work was mainly influenced by the exploratory nature that arose as the research progressed. What could be useful to be brought forward was analysed using analytical methods such as the State Transition Network (STN) diagrams (Chapter 3) and the status–event analysis (Chapter 5). Experimentations or user studies, meanwhile, were carried out to test the hypotheses, which mostly derived from the findings (Chapter 4 and Chapter 6). The large part of this work is to do with the implication of the understanding in a bigger picture (Chapter 7).

Instead of having a descriptive and elaborative section on methodology in this chapter, we decided to have the methodology section at the end of this chapter (Chapter 8). By doing so, in our opinion, we will be able to see and understand more clearly the exploratory nature of this research.

1.7 Novel Issues and Contribution

The thesis raises several novel issues in the field of Human–Computer Interaction and Tangible Computing. The main area of work is on interaction between physical, cognitive and logical, and design theory. The major contributions are:

- deeper understanding of everyday things, i.e. focusing on the use of physical design and identification of physical design characteristics

- the concept of natural interaction, with regards to physicality, how these recruit our innate human abilities

- theoretical grounding for tangible design, which also includes an overview of design guidelines for tangible controls

1.8 Thesis Outline

The thesis consists of eight chapters and is structured in the following way.

In Chapter 2, a background of this thesis is outlined and related work is presented. An outline of different interpretations of affordances is presented, as well as the related existing design models and framework with regard to design usability and tangible design. Literature review also covers topics such as interaction design theory, engaging experience and human performance to widen our perspectives on the cognition side of human. How these can be exploited in the thesis are also outlined.

Chapter 3 focuses on the study of the real physical controls on really-used artefacts in order to understand the features of physical interaction and of the physical-logical mapping that make them comprehensible and natural. The relationship of the physical objects with their underlying logical state is examined, and the results of studying a range of consumer appliances and the ways in which explicit natural physical interactions are presented. Based on these results, a set of principles and issues of physical interaction is produced.

Chapter 4 presents User Study I: The Cubicle, which describes how the concept of physical-digital interaction is applied to the experimental Cubicle as a particular novel input device. The device was designed to investigate whether users are able to understand 'soft', re-programmable mappings and also the playfulness of the Cubicle. The design principles were evaluated and users' behaviours were observed.

Chapter 5 focuses on the interaction process, in which it brings in and highlights the user entity in the physical-logical mapping relationship that has been discussed in chapter 3. In particular, this chapter describes the two relationships: user–physical and user–logical, from these two aspects: cognitive and feedback. At the end of this chapter, the term of

Visceral Interaction, which emerges from the Cubicle study from the result of incoherency in mappings is introduced.

A second user study, The Cruel Design, is presented in chapter 6. This study was inspired by the phenomenon where *natural inverse* assisted in situations where incoherency did not occur in the mappings. The study further observes the physical and cognitive performance of users in conditions where the mapping relationships are incoherent.

Chapter 7 uncovers how the successful physical interaction can be applied in the tangible design. This chapter looks at several examples of tangible devices that embody the design principles. The analysis on these several existing tangible devices exposes in what way they exhibit natural interaction. Next, an impact of the principles on the TUI framework is examined, and some of the broad guidelines for tangible controls are presented. The critical design characteristic of reversibility and its essential feature in the design of tangible interaction is discussed.

Chapter 8 begins with a reflection of the whole process of methodology that was carried out throughout the research work. This is then followed by conclusions which summarises the findings and contributions made in the thesis. Future research is also presented, which also includes the ways to improvise the work and the possible research areas.

The following illustrates the thesis chapter-flow which should assist in understanding the flow of work of this research.

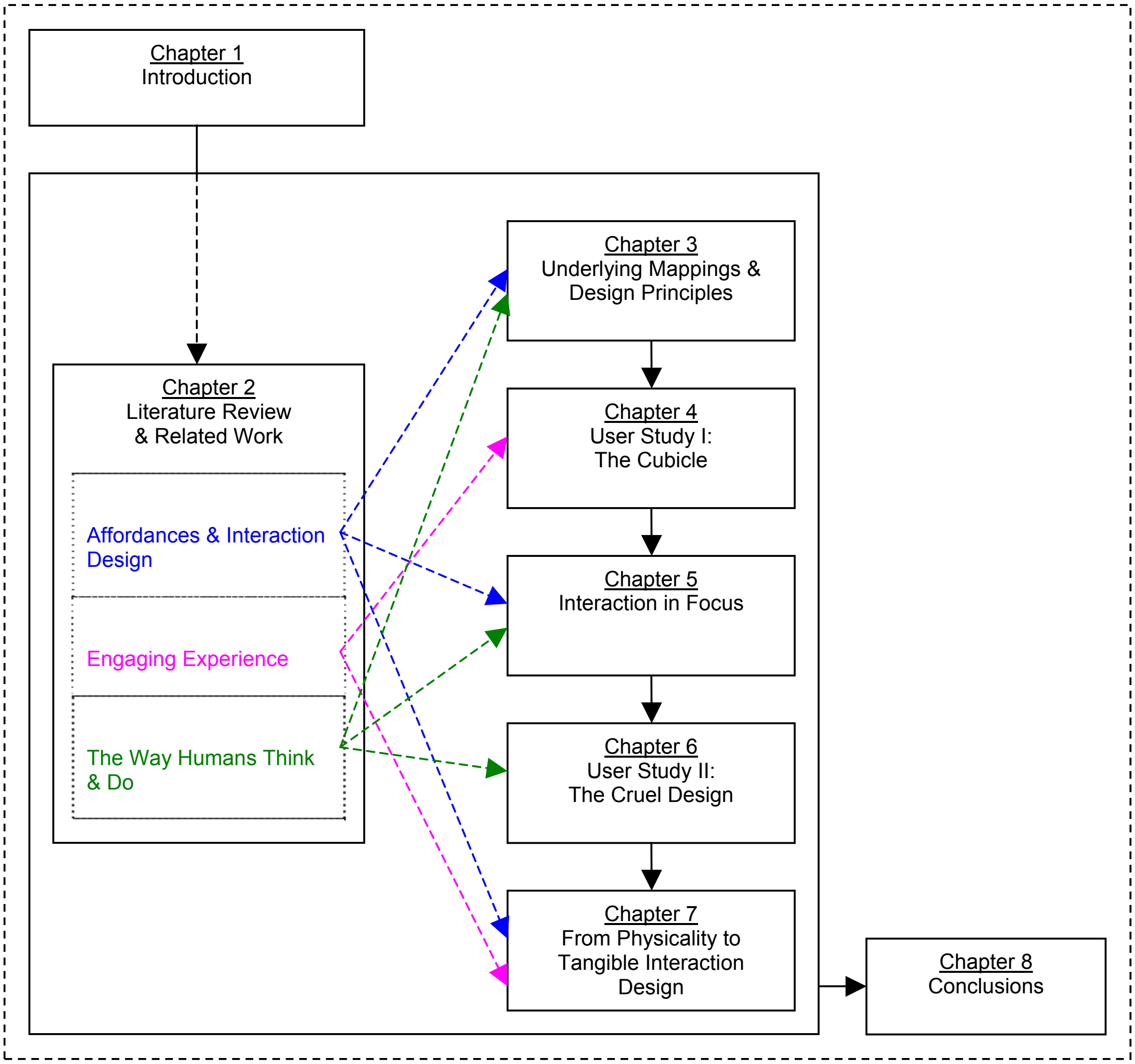

Figure 1.1 Thesis chapters flow

Chapter 2

Literature Review and Related Work

This chapter reviews some of the interaction design and cognitive psychology literature to provide the underlying theoretical support in our quest of understanding natural interaction based on physical visceral qualities.

We begin by presenting the most trivial topic when it comes to design: the concept of affordances (section 2.1.1). The many interpretations of the affordances, widen our perspectives on this topic as they extend and expand the definitions given by Gibson's and Norman's. We then review literature on what constitutes meaningful interaction in section 2.1.2. These two topics would be the basis to how we embark our research work. With this reason, we present a theoretical framework to equip us upon our own research study in separate section, section 2.4.

Next, in section 2.2, we present the elements that can make of an engaging experience. We see this notion as an essential concept in an experience and interaction to keep the interaction with the users flowing, and most importantly, engaging. In section 2.3, we show the cognitive psychology side of human, by presenting the way humans think and do. At the end of every section, we briefly describe how we exploit the understanding that we have attained from the literature review later in the thesis. Discussion and conclusion then end this chapter.

2.1 Interaction Design

2.1.1 The Role of Affordances in Design

People always associate good design to good affordance, which claims the result in some sense of natural. The classic example of good affordance is the door handle, which when it is designed properly, the door affords pulling. Another common example is the way a GUI button is designed on the screen which looks like an actual button, hence it is said to afford clicking. As it seems to be a simple idea, there are many definitions and interpretations to what affordance means, in an attempt to make it more objective rather than subjective.

Affordance concept popularised by Norman (1988) in his book “The Psychology of Everyday Things” brought the concept to the attention of designers. This concept is originally a work by a psychologist named Gibson who introduced affordance in his book entitled “Ecological Approach to Visual Perception” (Gibson, 1979). These two definitions of affordance, to a degree, are a different idea altogether.

According to Gibson, affordance as attribute of an interaction design feature is what that feature *offers* the user, what it *provides* or *furnishes* (Gibson, 1979). He illustrates his definition by giving an example of how a horizontal, flat and rigid surface affords support. In his perspective, affordance is reckoned with respect to the user. Furthermore, Gibson points out affordance as physical properties, which it as a physical relationship between actor and physical artefacts in the world reflecting possible actions on those artefacts. We can clearly see this type of affordance does not have to be visible, known, or even desirable.

Gibson’s affordance is referred to as real affordance by Norman (Norman, 1999), which he says this unqualified term affordance is merely about physical characteristics of a device or interface that allow its operation. Norman introduces another type of affordance: the perceived affordances. Perceived affordances are the characteristics in the appearance of a device that give clues for its proper operation. He emphasises on the point that we must understand the difference of the two, and not to use the term affordance alone. Although Norman says much of the examples in his Design of Everyday Things (DOET) book, are about perceived affordance, the two affordances have become somewhat lost due to lack of emphasis of the two affordances. Following is a table that briefly illustrates the differences of affordance concept by both Gibson and Norman.

Gibson's Affordances	Norman's affordances
• Offerings or action possibilities in the environment in relation to the action capabilities of an actor • Independent of the actor's experience, knowledge, culture, or ability to perceive • Existence is binary – an affordance exists or it does not exist	• Perceived properties that may or may not actually exist • Suggestions or clues as to how to use the properties • Can be dependent on the experience, knowledge, or culture of the actor • Can make an action difficult or easy

Table 2.1 Gibson's and Norman's Affordances (adapted from McGrenere and Ho, 2000)

Although we often refer to affordance concept, especially in our design work, be it by Gibson or Norman, ambiguity does appear somewhere along the line even within the HCI community itself. Gaver (1991), McGrenere and Ho, (2000) and Hartson (2003), are amongst those who have attempted in clarifying the ambiguity that exists in affordance.

Gaver (1991) refers affordances in design as a way of focusing on strengths and weaknesses of technologies with respect to the possibilities they offer to people who use them. He separates affordances from the perceptual information that specifies affordances (see figure 2.1), which allows us to consider affordances as properties that can be designed and analysed in their own terms. Referring to figure 2.1, if the user has the perceptual information, the affordance may be perceived to exist. He extends the concept of Gibson and Norman by showing how complex actions can be described in terms of groups of affordances, sequential in time and/or nested in space, showing how affordances can be revealed over time, with successive use actions, for example, in the multiple actions of a hierarchical drop-down menu.

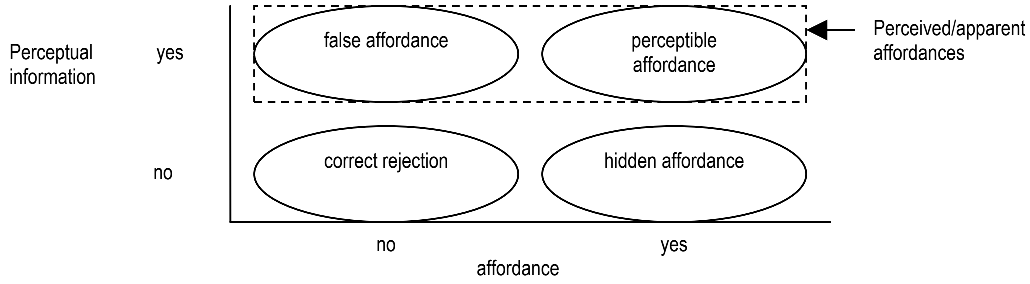

Figure 2.1 Separating affordances from the perceptual information that specifies affordances (adapted from Gaver, 1991)

McGrenere and Ho (2000) aim to clarify the affordance concepts for effective communication among researchers and practitioners and make a connection to usability design. McGrenere and Ho first analyse both Gibson (1979) and Norman (1988) work before discussing the importance of affordance in terms of design, and specifically in the area of software design. Both of them disagree to a claim that Norman made about a scrollbar is a learned convention and implies that it is not an affordance. They also make a clear distinction of usefulness versus usability when it comes to designing affordances and designing the information that specifies the affordances.

According to McGrenere and Ho (2000), usefulness of a design is determined by what the design affords, whilst the usability of a design can be enhanced by clearly designing the perceptual information that specifies these affordances. Figure 2.2 is an illustration of a framework of affordances for design that both McGrenere and Ho propose, in which by moving along the diagonal line could support design improvement.

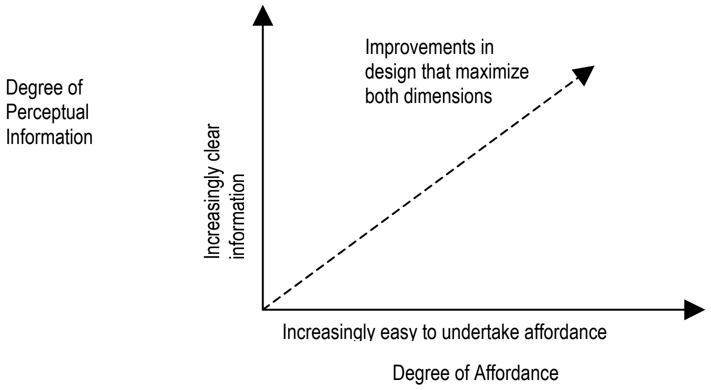

Figure 2.2 Representing the affordance and the information that specifies the affordances on a continuum (adapted from McGrenere and Ho, 2000)

Another attempt in clarifying the concept of affordance has been carried out by Hartson in his paper Cognitive, Physical, Sensory and Functional Affordances in Interaction Design (Hartson, 2003). In brief, Hartson refers Cognitive affordance to what Norman described as Perceived affordance: that helps users with their cognitive actions. Physical affordance refers to what Norman defines as real affordance, which is about helping users with their physical actions. Helping users with their sensory actions illustrates the sensory affordance, whilst functional affordance ties usage to usefulness. Hartson, in his paper, emphasises on the design of physical affordances, as he says almost no one mentions of this type of affordances.

Design of physical affordances is about design of physical action part of usability, easy-to-use in the form of high performance and productivity for experienced users, as well as to help less-abled users to achieve maximum efficiency in physical actions. And this is why Hartson introduces 'sensory affordance' along with cognitive and physical affordance.

The four types of affordance, Hartson believes, can guide, especially in the design of HCI artefacts. Nevertheless, he stresses the concept of affordance does not offer a complete prescriptive approach to interaction design but does suggest the value of considering all four affordance roles together in design of an interaction artefact by asking.

Hartson also points out the fact of false cognitive affordance that always misinforms and misleads the users. Therefore, it is very important for the designers to use cognitive affordance with caution. The users encounter errors when cognitive affordance falsely seen as physical affordances. Gibson use the term 'misinformation in affordances' whilst, Draper and Burton use the term 'affordance bugs' (Draper et. al., 1993).

Other work on affordance includes Form and Function by Tversky from the perspective of spatial language, which shows perceptual features allow inference to function, forming perceptual-function units or affordances (Tversky, 2002). Whilst Thimbleby proposes affordance and symmetry as concepts that could be fundamental in delivering successful interactive systems (Thimbleby, 2001, 2002a, 2002b). Graspable User Interfaces, meanwhile, collaborate the concept of affordances of physical artefacts to manipulate virtual objects (Fitzmaurice et al., 1995, Fitzmaurice, 1996).

2.1.2 Meaningful Interactions

Despite the many interpretations of affordance, what they all have in common is that an affordance invites the user to a particular action. An action leads to an interaction. Correct mappings, is believed to be the vital factor that makes an interaction successful. In Norman's The Design of Everyday Things book, he outlines the importance of natural mappings as he illustrates how the design of four controls of a stove should be. Natural mapping should be without any labels, diagrams or instructions, and it should reduce the need for information in human's memory (Norman, 2002).

Although Norman's natural mapping can be applied to anything in which spatial layout is meaningful, such as cooking rings, it is argued by Djajadiningrat et al. that this idea often fails in the electronic products and computers. This is due to the settings of these technologies being abstract and not having naturally spatial meaning (Djajadiningrat et al., 2002). They introduce the notion of creation of meaning in interaction design through *feedforward* and *inherent feedback*. They believe what is most important in an interaction is not in communicating the necessary action, instead, in communicating the purpose of the action (hence, feedforward). And this must work together with the feedback by strengthening the coupling between the action and feedback (hence, inherent feedback).

The work mentioned above – creation of meaning through interaction, is one of the steps to improve the usability aspect of tangible interaction. The shift from physical to tangible in the world of computing took place in 1997 when Ishii and Ullmer (1997) have introduced the notion of Tangible User Interfaces (TUI). This has become the most common known framework for tangible interaction, besides the Token-based framework which was later introduced in 1999 by Holmquist, Redström and Ljungstrand. Since that year, there have been many research efforts devoted to TUIs, which include another work by Ullmer and Ishii (2000) in their attempt to provide a narrower definition, whilst Fishkin (2004) presents a taxonomy which uses *metaphor* and *embodiment* as 2D space treats tangibility as a spectrum to show that the further from the origin, the more 'tangible' a system is. There are also efforts building on the previous frameworks by Calvillo-Games et al. (2003) and Koleva et al. (2003) – will see more in Chapter 7.

Meaningful interactions in the world of tangible computing has inspired Wensveen et al. (2004) to present a design framework, called Interaction Frogger, to analyse person-product interaction in terms of the couplings between the person's action and the product's function through a set of inherent and augmented information. The belief in transforming from the data-centred view to perceptual-motor-centred view in tangible interactions (Djajadiningrat et al., 2004) is also shared by Hummels et al. (2005) by emphasising on the movement-based interaction in the design of tangible interaction. A theoretical framework on the relationship between the three entities of action, meaning and value has been introduced by Feijs and Overbeeke (2003), which has in some ways change the way we see and understand products and how by embracing these new perspective could help in designing behavioural products.

In chapter 3, 5 and 7, we will be able to see how the literature review on affordances and interactions help us in dissecting our ideas in our quest to discover what is natural in interaction. Chapter 5 will look at interactions from the perspective of a user and user's action, whilst chapter 7 will discuss in what way TUI can be benefited from these understanding. In section 2.4, we will lay a theoretical framework based on these understanding to assist us in embarking our research work as presented in chapter 3.

2.2 Engaging Experience in Interactions

In contrast to physical interaction, which normally just limit the interaction between the user and input devices such as stylus, keyboard and pens, it is thought that now is the time to enrich the interactions with the full embodiment of the user. ‘Embodied interaction’ is described by Dourish in his book *Where the Action is. The Foundations of Embodied Interaction*, as “the creation, manipulation, and sharing of meaning through engaged interaction with artifacts” (Dourish, 2001, p.126) and as being central to tangible computing. Engaging experience, or experience in itself, is a separate topic, yet interrelated to interactions. There has been a large amount of work into describing how one can design for experience, and in particular, an engaging experience, which involves emotions and fun.

2.2.1 Products’ Physicality

The idea of creating an engaging experience is rooted back to our interaction with products. Overbeeke et al. (2003) claim that nowadays interaction with products has become less engaging, and believe that physicality should be reinstated. Most of today’s products, they say, reflect the maker’s training and often used user-centred design, yet this is seldom applied as they only considered cognitive skills. According to them, the designer should also consider the perceptual-motor skills and emotional skills that will allow the product to become ‘intelligent’. In order to make the interaction more engaging, they propose the designers to create a context for experience, in which the user enjoys with all his/her senses in search for challenging experience. The designer should bring together the context for experience and the aesthetics of interaction. It is important to note that aesthetics that is used is not something to do with making the products beautiful in appearance. It should shift from the beautiful appearance to beautiful interaction, and to engaging interaction.

Interestingly, according to them, fun is not the ultimate goal, yet it should be the results of a good experience of the products. They have come up with ten rules to augment fun and beauty, which in result have produced very unique and interesting products that we rarely see in our everyday lives, such as the rotating organiser. Products of this type are challenging, thus leading to more engaging experience.

2.2.2 Fun in Engaging Experience

Meanwhile, according to Brandtzæg et al. (2003), the element of fun can actually ensure engaging in experience. They believe experience that includes the element of fun is far more relevant in ensuring engaging experience, than easy-to-use in interactions between human and computers. They propose a model that consists of three elements, demands as fun, decision latitude and social support, in which the social opportunities is seen as a strong factor to facilitate enjoyable experience. Thus, the human design model should focus more on developing the design that provide more social opportunities.

The same view about the importance of fun in an experience is shared by Sengers (2003). As a computer scientist, she notices the focus has always been on increasing the efficiency of software or system execution when it comes to optimising an experience. To break down this phenomenon, the aspect of engineering experience must be shifted to inter-disciplinary approach. Fun should be part of experience in the hope that this kind of experience would exist in both work and non-work related tasks. According to it, fun should be less about efficiency, and should be more about quality of experience. By combining computer science and cultural analysis, Sengers proposes three generic heuristics that should be taken into consideration when designing experience, especially when designing one of Artificial Intelligence (AI) experience. The heuristics are; focusing more on shaping the ‘actual’, driving the ‘computational’ behaviour from human behaviour, and think about meaning, not information.

Whilst fun is believed to be an important element which ensures engaging experience, Blythe and Hassenzahl (2003) raise their concern about how we must not confused fun with pleasure. They point out that elements fun and pleasure, are both context-specific which by grasping what they really mean can be very useful in the design for experience. The following table shows the differences between fun and pleasure.

Fun:	Pleasure:
• being unexpected • distraction • a consequence of triviality, repetition, spectacle and regression	• focuses on activity • a deep feeling of absorption • a consequence of relevance, novelty, aesthetics and conformity

Table 2.2 Differences between Fun and Pleasure (adapted from Blythe and Hassenzahl, 2003)

2.2.3 Between Emotions, Enchantments and Challenges

Emotion too is to be thought of as an element which can create an engaging experience. Andersen et al. (2003) has carried out a project called FARAWAY project in which an engaging experience is created in a remote communication between people in affectionate relationship. It is suggested from this project that by conveying presence and emotions over distance of peoples' experiences and desires, it is not impossible to transform this kind of interaction and experience into viable products and/or services.

Enchantment is also thought to be an element which can engage people in an interaction or an experience. McCarthy and Wright (2003), in their work, believe the power of enchantment can turn an ordinary experience into an attentive experience. Fascinated by how films enchanted their audiences, they closely look at Jon Boorstin's (Boorstin, 1990), a famous writer and Hollywood producer, ways of seeing in making films. It is suggested that by adopting the same concepts, an experience is enchanted and can be engaging. The following are the three ways of seeing according to Boorstin:

- voyeuristic eye – the normal way we see things where we look to things closely and becoming bored as the newness of the thing has gone
- vicarious eye – experienced through imaginative participation in the experience of another
- visceral eye – bring into harmony the experience of thrill, joy, fear and abandonment

An engaging experience can be delivered through systems with fairly simple functionality, according to Hull and Reid (2003). They suggest a model which consists of three dimensions: challenge/satisfaction, social/interaction and drama/sensation that can be referred to, to improve the engagement of user experience. And it is not compulsory to adhere to the three dimensions just to improve an experience, as it is pointed out that it is sufficient to engage the user experience by having just one dimension of the three suggested dimensions.

2.2.4 Short Summary

Whilst all the above descriptions as a whole describe how experience is a factor that must not be left without in the design process of products, they are not quite close to the design framework of experience of tangible interaction. Hornecker's framework has looked at the social user experience of tangible interaction, which focuses on the role of physicality (user's body) and the physical world in four different themes. This framework gives an in-depth view of experiences differ in different settings, hence proposes approaches for research and design for these new hybrid environments (Hornecker, 2006).

Later in the thesis, we will see how we take on board what we have learnt so far about creating an engaging experience. Chapter 4 will describe how we create a user study that should be playful and enjoyable by using a novel input device. Meanwhile, chapter 7 will discuss and look closely at experiences of tangible devices and interactions. In trying to comprehend and grasp what makes an experience engaging, we have attempted to discover even further the element of fun. In appendix I, we explore the relationship between fun and engagement to see whether fun is a necessity in order to create an engagement experience, whilst in appendix II, we examine fun experiences between two cultures, with by a level of understanding can support diverse user communities.

2.3 The Way Humans Think and Do

In order to understand better the way humans think and do, we have reviewed a number of areas which we thought could help us in carrying out our own research work. How the following topics could be exploited in the later chapters in this thesis will be described at the end of this section.

2.3.1 Cognitive Perspective

In human information processing, according to psychologist, human memory consists of sensory memories, short-term memory (STM) and long-term memory (LTM). The expression of short-term memory is also known as working memory. The following are the brief descriptions of each type of memory (Dix et al., 2004, Preece et al., 1994):

- sensory memories – information is stored according to its sensory type: visual, auditory and tactile material (modality-specific). The sensory memories also act as buffers in which they hold information for a very brief period of time (a few tenths of a second),
- short-term, or working, memory – according to Norman (1988, p66), STM is invaluable in the performance of everyday tasks, as the information which is retained is automatically and retrieved without effort. Nonetheless, STM has a limited capacity for a short period of time (a few seconds),
- long-term memory – LTM has indefinite capacity which it can store information permanently. LTM, however, has a relatively slow access time and effort is required to fetch the information out. Unlike STM, LTM has a little decay.

A human processor model consists of three interacting systems: the perceptual system, the motor system and the cognitive system (Card et al., 1983). Figure 2.3 illustrates the processing stages involved when someone putting an input in response to seeing something on a screen.

Human Information Processing does not just divide memory into three classes of structure as described above, but also divide processing structure into conscious and sub-conscious operations (Miyata and Norman, 1986, Norman, 2002). According to Miyata and Norman (1986), conscious control, like STM, has limited resources and only one single task can be done under this condition at any one time. Sub-conscious, on the other hand, can perform several tasks which can be done simultaneously. It is added, however, only well-learned, routine tasks can be done subconsciously, as sub-conscious control does not appear to use STM.

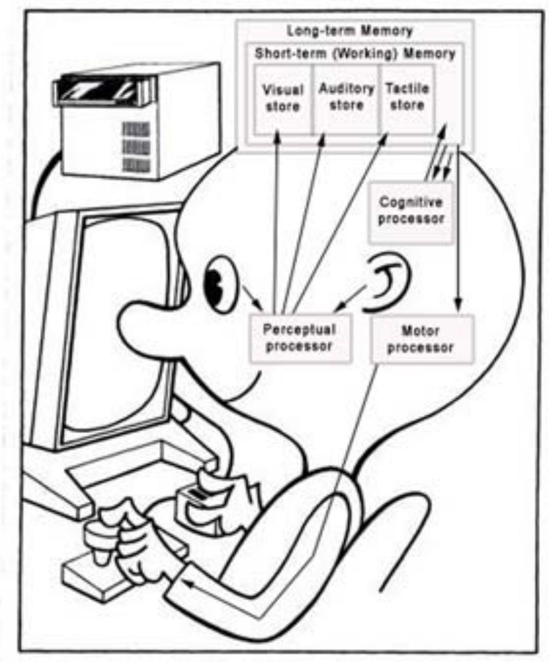

Figure 2.3 The human processor model (adapted from Card et al., 1983)

Following are four situations where conscious control is primarily used (Miyata and Norman, 1986, p267):

- when task to be performed is novel or ill-learned
- when the task is perceived to be especially critical, difficult, or dangerous
- when there is a need to override the automatic control
- when there is a need to resolve conflict among schemas or activities

2.3.2 Mental Models

In HCI, mental model is very important as it describes how a system works based on our understanding and knowledge which may have come from past experience, training, or instruction. In the simplest meaning, mental models are constructed by a conscious mental simulation which may be ‘run’ from which conclusions about the predicted state of affairs can be deduced (Preece et al., 1994, p132). Whilst wider aspects of users’ mental models ideas are discussed by Payne (2003), where he expands and elaborates the very ideas of users' mental models.

The type of mental model mentioned above is known as user's mental model, which is one of the three conceptual models, as outlined by Norman (Norman, 2002). The other two are: design model and system's image. Design model is the model conceptualised by the designers, whilst system's image is the interface of the system which users will interact with. As important as it is to distinguish these three aspects, it is also equally important to ensure the conceptual model is correct. In the example of a photocopy machine, the designer must ensure his design model is reflected in a correct representation on the system (system's image), for the user to translate what is being perceived to user's model so the user knows how to operate the machine correctly.

2.3.3 Learning and Tacit Knowledge

Some knowledge is acquired through the process of learning. Tasks which we never come across in the past will only become familiar to us gradually after a number of practices and trainings. Continuous and active process of learning can turn a novice user to become an experienced and a skilled user. An example of a learning knowledge is the operation of a DVD player.

On the other hand, there is the tacit knowledge. Although tacit knowledge also involves learning and skill like in learnt knowledge, tacit knowledge cannot be written down. The famous phrase which describes the essence of tacit knowledge is, "*we can know more than we can tell*" (Polanyi, 1967, p4). By this it means, there are kinds of knowledge which by only observing others, or through personal experimentation, can the knowledge be acquired. For instance, to learn how to swim or to ride a bike, although the rules and instructions can be articulated, they are of no use without personal experimentation.

Knowledge is also available in the world. According to Norman, information is readily available in the world that the need to learn it diminishes (Norman, 2002, p56). Knowledge can also be transferable from the past knowledge which resides in our mind, especially in the situations when we encounter with novel objects.

The theoretical stance of knowledge being in the world is also shared by distributed cognition (Hutchins, 1995, Perry, 2003). It is proposed by this philosophical view of cognition, that the information or knowledge is distributed around us by the acts of placing memories, facts or knowledge on the objects, individuals, and tools in our environment. The anthropology view of cognition, meanwhile, suggests that learning is situated – situated cognition. By situated it means, events or activities that take place in a specific context or in real situations (Brown et al., 1989).

2.3.4 Human Performance and Action

Referring to figure 2.3 - the human performance model, an act or response is carried out when the brain signals the appropriate muscles to respond. Some of the response may happen in a blink of an eye. No matter how fast it may seem, the responding process does take time. This process can be divided into two types: reaction time and movement time (Fitts and Posner, 1967).

How fast or quick a reaction time can be is depending on the sense through which the stimulus is received. Approximately 150 ms is the time taken for a person to react to an auditory signal, 200 ms to a visual signal, and 700 ms to pain (Dix et al., 2004). A faster and quicker reaction time can however be achieved when the person is skilled or trained, and the combination of signal will produce the fastest response. Fatigue and tiredness, however increases reaction time. Movement time, meanwhile, is dependent largely on the physical characteristics of the individuals.

The two important things when it comes to measure motor skill are speed and accuracy. Tasks and experiments that want to study and measure these two notions in any type of interactive systems, commonly, adhere to Fitts' Law (Fitts and Posner, 1967). This law considers the size of the target and the distance to hit the target to measure its movement time.

Moving on from the low level human performance to the holistic view of human action, there is theory on Activity Theory (AT) which formulates the structure of an activity within a social context. The essence of AT are down to three things: subject, tool, and object (Kuutti, 1996). Whilst Kuutti (1996) suggests that an object can be of a material thing or something that is less tangible, Verenikina (1998) suggests that tools can also be of social objects.

The importance of AT in HCI is stressed by Nardi (1996). She emphasises on the aspect of consciousness, which unifies phenomenon such as attention and memory, in which she highlights its existence in HCI's, among others, "direct manipulation", "intelligent agent" and "transparent".

Situated action, like AT, promotes the idea of, "every course of action depends in essential ways upon its material and social circumstances" (Suchman, 1987, p50). This differs somehow from AT, as it is more context-specific. Rather than abstracting and building theory of action away from and out of theory of plans, it aims is to closely look at how people use the circumstances and find evidence to perform an action.

What we have reviewed so far in this section will shed some light on the ways we elaborate and discuss the notions of interaction between user, physical and logical states. This is mentioned in the following chapter, Chapter 3, and is extensively analysed in Chapter 5, especially on topics such as mental model and learning and tacit knowledge. Subject on human performance, meanwhile, is a useful background material in our user study, Cruel Design, which is described in Chapter 6.

2.4 Theoretical Framework

In this section, we lay a theoretical framework based on the understanding, largely from section 2.1, to assist us in embarking our research work as presented in chapter 3. By focusing on our aim to understand the visceral qualities of mundane interaction, we also include and compare other related work.

Interfaces to consumer products are studied closely in an industrial design setting. Overbeeke et al. (2003), discuss 10 rules (guidelines) focusing particularly on making engaging products, for example “don’t think beauty in appearance, think beauty in interaction”. Whilst our aim has been more to understand the visceral qualities of mundane interaction, their more aesthetic and our more articulatory approaches have common features. For example, the quoted rule, which they relate to Dunne’s “aesthetics of use” (Dunne, 1999), concerns the naturalness of physical interaction. In addition, they take as a starting point the observation that modern devices often hide their functionality behind buttons and icons, and propose designs that expose functionality, echoing the issues of exposed state and compliant interaction which we will discuss in the following chapter.

Looking at the conventional interface literature, it is interesting to consider Shneiderman's direct manipulation principles: continuous representation, physical actions instead of syntax and rapid incremental and reversible operations (Shneiderman, 1988), and also other early work on understanding direct manipulation (Norman and Draper, 1986). These, and indeed the whole GUI endeavour, are effectively about trying to harness the naturalness of physical interactions in the digital domain.

We can see the connections between these related areas if we consider a simple 2x2 matrix looking at the controlling devices and the functionality controlled; both of which may be physical or virtual. Of course no device is completely virtual, some physical interaction with the user is always necessary, with the possible exception of direct brain sensing. By virtual, we mean devices such as on-screen buttons, which have no direct tangible properties.

In the real world we have physical devices with an immediate physical effect (the thing itself), in direct manipulation and graphical user interfaces we have logical devices and logical effects, and in our studies, tangible and some ubiquitous computing we have physical devices with logical effects. All exploit our innate abilities to live and act in the physical world.

		functionality (logical state)	
		physical	virtual
devices	physical	the real world, exposed mechanisms	tangibles, consumer devices, augmented reality
	virtual	industrial control, heads-up displays	GUI and direct manipulation

Table 2.3 Styles of physical–virtual interaction

In the bottom left corner of table 2.3 we have placed industrial 'glass' controllers[1] and similar kinds of controls such as heads-up controls in an aircraft cockpit. These are effectively some form of virtual control of a physical process (the operation of the factory, or movement of the plane).

In fact, industrial controllers remind us that the world is a little more complex than a simple diagram can show. The focus of the control is a remote physical process, but the control panel itself may include very physical knobs and dials. However, this is equally true of some of the devices we will analyse where the 'logical' system controlled is in fact an important physical process: cooking food in a microwave, washing clothes. As we noted, even a GUI is controlled by a physical device, the mouse, and often produces physical outputs on paper. In fact virtually all computer related interactions are at some level of the physical–virtual–physical kind, but do differ in terms of the focus, the directness of the relationship between control device and controlled process and the extent to which we receive feedback directly through the device or indirectly through the controlled process (more in Chapter 5).

When looking at a simple physical object, such as a cup, there is no separate logical state and simple affordances are about the physical manipulations that are possible and the level to which these are understood by the user: Norman's 'real' and perceived affordances (Norman, 1999). For a more complex, mediated interface the effect on the logical state becomes critical: the speaker dial affords turning but at another level affords

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[1] Industrial 'glass' controllers can be of operation machines which can be found in factories that require a highly detailed and/or involve dangerous substance in the operations. Operations are conducted behind a glass separation.

changing the volume. Hartson (2003) introduces a rich vocabulary of different kinds of affordances to deal with some of these mediated interactions.

Benford et al.'s SSD framework (2003) deals with this relationship between the physical device and logical state. It considers three aspects of the relationship:

- sensable – the aspects of the physical device can be sensed or monitored by the system,
- sensible – the actions that the user might reasonably do to the device,
- desirable – the attributes and functionality of the logical system that the user might need to control

These can be used to explore the design space and in particular mismatches between the sensible, sensable and desirable can be used to suggest directions for re-design. Note that what is sensible to do with a device depends partly on its perceived affordances and partly on the user's mental model of the relationship between the device and the logical state.

"The extent to which the physical structure and manipulation of the device naturally relate to the logical function it supports"

The concept of fluidity introduced in Dix et al. (2004a), as quoted above, and expanded in the next chapter is focused on the way in which this mapping is naturally related to the physical properties of the device. The examples provided in Dix et al. (2004a), such as the compact and complex design of a mini disc controller, and, an on and off power button, do not capture the naturalness of the design, but the relationship between the physical appearance and the underlying state they control. Whereas the SSD framework is primarily concerned with what it is *possible* to achieve, fluidity is focused on what is *natural* to achieve.

2.5 Conclusion

The foundation of this thesis is based upon our aim to understand the visceral qualities of mundane interaction to pursue the meaning of natural interaction. In our pursuit to understand what natural interaction is, we have reviewed selected literature to provide us underlying theoretical support. To begin with, there are always questions on what 'natural' supposed to mean, and its interpretation at this point is still quite unclear. Although there already is an attempt to shed light on what it supposed to mean or encompass (Valli, 2004), the presented notes are quite vague, but it manages to cover almost everything that is related to interaction.

We have learnt that Norman's definition of affordances has been a strong design theory and commonly used, in the design industry as well as in the human–computer interaction field, although it was first introduced by Gibson. Ambiguity still lies between their definitions of affordances, hence lay path for Gaver, McGrenere and Ho, and Hartson, among others, to clarify this ambiguity. As we learned more about the concept, and how meaning in interaction is equally important to affordances in the design, the concept of affordances is now moving away from Norman's and drawing closer to Gibson's ecology interpretation of affordances, which does not heavily adhere to perceived affordances. Rich interaction should allow more involvement of user's physical bodily movement and action to produce more meaningful interactions, especially in tangible interaction. The transition from perception to experience is now a new phase in the interaction designs research (Overbeeke & Wensveen, 2003).

Engaging in an interaction is interrelated to engaging experience with products or with any tangible artefacts. User experience, for once, can be engaging if the user can make sense of the products. Emotions, enchantment, and fun, are amongst the elements which can make an experience more engaging. Any product that is of new technology should be pleasurable, emotionally affective and have aesthetics values.

By reviewing the cognitive side of humans – the way humans think and do, has helped us to understand better the limitations, and potentials of a human being in general. We are particularly interested in the way the conscious and sub-conscious mind play its part in an interaction, and, how and to what extent can we consider something as a natural act when it comes to tacit and learning knowledge – as people get skilled over time.

As per outlined in section 2.4, we will try to discover our own interpretation of *natural* by looking at day-to-day things. In the following chapter, chapter 3, we will begin our study on everyday appliances to understand what makes our interaction with them natural and fluid.

Chapter 3

Underlying Mappings & Fluid Design Principles

In this chapter, we study real physical controls on really-used artefacts in order to understand the features of physical interaction and of the physical-logical mapping that make them comprehensible and natural. Our aim is to use rich knowledge implicit in the design of day-to-day artefacts to uncover principles that can be used in the design of novel tangible interfaces (more about this in Chapter 7).

Day-to-day devices, traditional graphical user interfaces (GUI), augmented reality and tangible interfaces all draw on innate human understanding of physical interaction, and so we will look at some of the properties of 'real world' interaction with physical objects in section 3.1. In section 3.2, we examine the relationship of the physical objects with their underlying logical state by producing a simple state transition network (STN). The section will then move on to the results of studying a range of consumer appliances and the ways in which they exploit natural physical interactions. This is used to produce a set of principles and issues of physical interaction, which will be exemplified by a table of interactions (section 3.3). This table enables us to see how certain appliances embody cross-sharing properties and how these properties interact with one another and other implicit properties. Finally in section 3.4, we will look at how these principles can be applied to a novel tangible interface device, the Cubicle. More in depth discussion about the properties will be covered in Chapter 5.

3.1 Understanding Physical Interaction

As we have previously seen in the previous chapter, direct manipulation, augmented reality and tangible interfaces all emulate or use interaction with real physical objects. The reason these different techniques work so well is that we have deep-seated mental and physical abilities attuned to the physical world. There is strong evidence that we reason differently with different kinds of experience, for example, physical vs. social situations (Barkow et al., 1993; Bownds, 1999; Donald, 1991). Whilst we can reason explicitly about most types of situation, this is both slower than more innately driven responses and it requires conscious attention. This is why the 'M' (mental processing) operator in Card, Moran and Newell's keystroke-level model was always so problematic (Card et al., 1980). Interfaces that break the natural properties of physical interaction may be difficult to learn, difficult to use or lead to various kinds of superstitious interpretative models (Dix et al. 2004b).

Furthermore, at the lowest level, motor activities involve neurological feedback loops within our bodies that do not involve conscious thought at all. These loops operate in time scales far faster than those that can be controlled using more cognitive processes and are hard to train, for example, learning new fingering patterns for a musical instrument, or physical actions during sports. Low-level hand-eye coordination, such as those used in Fitts' law (Fitts, 1954) tasks, are also largely subconscious. Where systems emulate aspects of the physical world, they can take advantage of existing low-level responses rather than requiring new ones.

3.1.1 Natural Interaction

It is often hard to distinguish those aspects of devices that work because of cultural norms developed due to exposure to technology, which can thus be expected to change (albeit slowly) over time, as opposed to more innate understandings of the physical world. Whilst it is not essential for many purposes to separate these, we can try to make this distinction based on the properties of natural physical objects such as stones. Whereas, Norman's DOET (Norman, 2002) discusses properties of everyday objects such as paper clips, watches and light fixtures, the properties which we are discussing focuses on the very basic level of properties of a natural object. In other words, whilst Norman's analysis would be concerned in a light switch because it controls the light, we are also interested in the properties of the light switch itself as a device, even when disconnected. The properties often violated by electronic, and even mechanical devices, include (Ghazali & Dix, 2005a):

- *directness of effect* – A small push makes a small movement, a large push makes a large movement; a push in one direction followed by an equal push in the opposite direction gets something approximately back where it started
- *locality of effect* – When you do something it has an effect here and now. If you push a stone you do not expect it to move 5 seconds later
- *visibility of state* – The fixed appearance, shape and other properties may be very rich, but the changeable ones are relatively simple (location, orientation, velocity) and immediately visible

If a physical object is constructed to violate these properties, for example, a beach ball part-filled with water, the behaviour appears 'magic' or 'alive' as the ball appears to move of its own volition. Part of the complexity of computer systems is that they violate these simple principles of physicality.

The above properties in some ways mimic what Shneiderman describes as direct manipulation (DM), and perceived affordances by Norman. Whilst the above properties strongly emphasised on the properties of a real object, including special constructed things (such as saw and hammer), the others' often reflect the properties in an application of a system, and in an operation of things.

3.2 Unleashing the Mundane Device Success

In order to understand how these natural interactions can be used effectively in design, we have studied a selection of day-to-day devices and consumer appliances including a washing machine and speaker volume control. We have sought to analyse and represent some of the rich physical interactions available on these mundane appliances.

The study is based on our personal experiences with devices and appliances, besides an informal discussion with users. We chose to undertake this approach rather than attempting a more formal study, as we believed personal experiences and casual approach can discover much more the way users encounter and understand today's devices and appliances.

In most of these, the explicit design of the physical object enables the user to understand how to manipulate the device as they exhibit strong affordances. However, we see that there are additional aspects of these devices that exploit the physical form of the device to inform the users' interaction with the logical function they control. In some cases we will see that this is not the case and then the devices employ various 'recovery' strategies to make the non-physical aspects more obvious.

The way we expanded the concept of fluidity (Dix et al., 2004a, section 2.4), is by closely looking at the physical and logical relationships. One of the techniques we have used is to represent separately the states of the device and of the underlying logical state (the left and right hand sides of figure 3.1). For each we have produced a simple state transition network and then examined the relationship between the two. However, we shall see that for certain types of physical interaction we find we need to extend normal state transition notation to deal with 'bounce-back' controls.

3.2.1 Exposed State

Some controls, such as simple on-off switches for lights, expose the underlying logical state of the system by their physical state. The interaction potential and feedback for the user is thus immediate as there is a direct mapping between the physical appearance and the logical state. Thus, the interaction appears to be natural, and the user can immediately apprehend how to control the device.

The directness of this mapping is obvious if we draw the state diagrams corresponding to the controlling device and the underlying system. Figure 3.1 shows the state of a kettle switch and also of the kettle itself. There is a one-to-one mapping between the states of the switch and kettle.

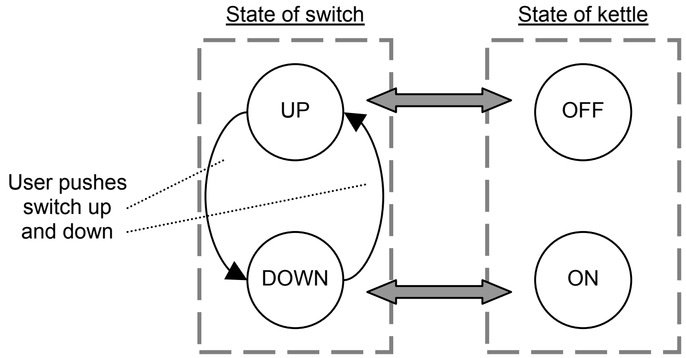

Figure 3.1 States for simple switch (UK conventions)

Of course, the ability to apprehend the state of the system from that of the device only holds so long as the user knows what aspect of the state is connected with the physical device and also the mapping.

Sometimes the corresponding state is obvious because of locality – the switch is on the kettle and there is only one thing to control. Where this is not the case naturalness breaks down, for example British people visiting the US often become confused when electrical outlets are not working – this is because the switches that control them may be wall–mounted a long way off.

The mapping is often more difficult. Conventions can help, but of course often differ between cultures (e.g. US vs. UK light switches – is up on or off?). However, for devices such as kettles both up=on and down=on may be found at which point additional decoration is often applied – for example a red colour that is only visible when the switch is on.

The washing machine dial is a more complex example of visible state (see figure 3.12). The dial shows the chosen program (indicated by written legends) and when a wash is in progress it also shows the current state of the wash cycle. This device displays the internal washer state as well as allowing the user to set it (we will discuss this dual role later under Compliant Interaction, 3.2.7). Obviously, the visible state of a control can only be used when there are a corresponding number of internal states. This is a simple but very powerful design heuristic.

3.2.2 Hidden State

In contrast to exposed state, there are controls where the physical appearance does not expose the logical state. An example is the twist control of the speaker in figure 3.2, which has no intrinsic on/off position given by its physical shape. The naturalness hardly exists for the user to know how exactly to manipulate the device. Therefore, this type of device requires additional features to provide further information. Sometimes this can be supplied by physical markings, for example a dot on the dial. In this case there are marks on the casing that indicate which direction to increase or reduce the volume. However there is no mark on the dial itself to see where the current volume setting is. To some extent this is unnecessary – you can hear the volume, but without an indicator of the current setting it is hard to see where in the range it is – can you make it twice as loud, ten times as loud?

Figure 3.2 Speaker control

Whilst in this case the lack of any decoration to clarify the state is probably an aesthetic rather than usability decision, there are times when it is essential. For example, if the dial could turn completely round several times to increase or reduce volume there would be no one-to-one relationship between location and volume. The best example for this would be the unbounded dials. And there are two types of unbounded dials; one which always return its logical state to minimum or zero as the power is turned on, and one which remembers the position or location of the physical dial whilst the power is off and maps the logical state to the current location when the power is turned off. The latter type, although at times can result to a full blast volume, it can be solved easily by leaving a mark of the minimum level on the dial. Also if the same control is used to manipulate different aspects of the logical state in different modes or there are large numbers of internal states, then it may be impossible to have a simple mapping.

Hidden state can be exposed in two ways, pre-use and while-using. Pre-use exposure is when additional features like text, signs, pictures, and lights that can be found around or close to physical controls give suggestions or instructions to the user of how to manipulate the device control. The marks are pre-use in the sense that before actually manipulating the device the user can begin to build a mental model of the hidden physical–logical mapping (c.f. Norman, 1988), and the information that assist the user before an action is performed is known to be as *feedforward* (c.f. Overbeeke et al., 2004). While-use exposure occurs when the act of manipulating the device makes the state or changes in the state perceived through haptic, aural or other feedback. We will return to this later when we discuss tangible transitions, 3.2.4.

In older devices the physical control was often connected directly to the internal mechanism. As controls have become electronic this connection is often lost and this becomes apparent in hidden state. Particularly problematic are 'touch' buttons. For example, an old tape recorder has buttons that stay depressed (see figure 3.4b), while the corresponding activity is occurring (play, record etc.), which shows a strong exposed state. In contrast, touch controls initiate the change of state but have no apparent state themselves. In the case of mechanical push buttons there is at least some intrinsic haptic feedback that the press has occurred whereas capacitative or low-travel buttons may have no physical feedback whatsoever. In such cases one sees the sure sign of poor exposed state – an additional on/off light or other soft visual display.

3.2.3 Controlled State

In most of the devices we studied, the control devices were under the complete control of the user: an on-off switch can be moved to both positions, the washing machine dial can be turned to any location. However, there are occasionally limitations. For example, whilst the washing machine dial can be turned clockwise to any position it cannot be turned anti-clockwise. If the dial is on 4 and you want programme 3 then you need to turn the machine off (to prevent it starting to do all sorts of things as you go past other programmes) and then turn it clockwise all the way around. The reason for this is probably mostly to do with the mechanical mechanism used, but may also be because clockwise is seen as 'advancing time'.

Sometimes the control is even more limited. For example, water taps in public places often have a push-on action. We push the top down and the water flows for a while and then stops. The intention is to prevent the tap being left on. Usually these types of tap cannot be explicitly turned off after use, no matter how hard we pull, the top only rises at its own rate. Electric toasters are often similar. We slide in the bread to be toasted into each slide, select a number and push the handle down. The handle will be pushed back up and pops out the toasted breads from the slides only after a period of time (with the exception of the ones which provides a little button to overcome this) – see figure 3.4a. Older tape recorders also behave in this way. You can press down the 'play' button, but not lift it up; instead you need to press down the 'stop' button and then the 'play' button pops back up (see figure 3.4b).

Different type of appliances or devices show different type of controlled state, but generally there are three types to how the physical control limit the user interaction:

i) the physical state return to its original position or state almost as soon after receiving an action from user, but over time, e.g. water fountain's tap (figure 3.3a),

ii) the physical control only return to its original position after *t* time, e.g. toaster (figure 3.3b),

iii) similar to (ii), but only return to its original position after completion of a cycle, i.e. does not allow inverse. In this particular scenario, although it is possible for the user to return the physical state to its original position by completing a cycle, the user cannot inverse the physical controller to the previous state, e.g. washing machine controller, heater/hot water timer controller (figure 3.3c)

The following diagrams illustrate the three types of controlled state as described above.

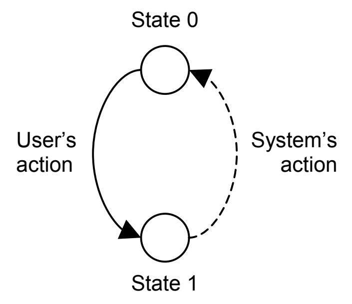

Figure 3.3a

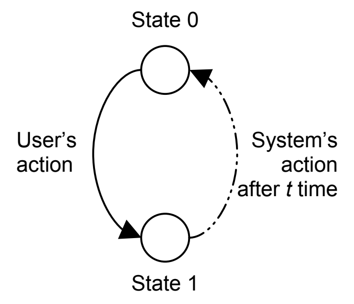

Figure 3.3b

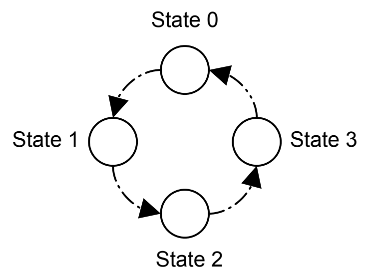

Figure 3.3c

Clearly simple physical objects tend to either be immobile in some way or allow full control. It is largely mechanical or electronic artefacts that have the strange semi-controlled behaviour like the toaster or water taps. Not surprisingly it is common to see users of these devices attempting to force the controls expecting that full manipulation should be possible.

Figure 3.4a Toaster

Figure 3.4b Old Tape Player/Recorder

3.2.4 Tangible Transitions

Some physical controls provide the naturalness of interaction by embedding a sense of feltness when manipulating the controls. The sense of feltness are emulated either in the real (mechanical) or animated (electronic, visual, audio) way. This may augment exposed state, or in the case of hidden state this provides while-use exposure. In the example of the speaker control, the physical control has a palpable bump so that the user can feel it go past the on/off position. This does not give the user knowledge of the current state before grasping the control, but whilst manipulating the device, the user is made aware of critical transitions.

The latter effect has been emulated in the iDrive haptic controller for the BMW series 7 (Immersion, 2003). The controller (see figure 3.5) itself is a small knob with no specific markings and is used to control a variety of functions though a menu interface. Electronic haptic feedback means that as the user twists the knob to move through menu options a small bump is felt for each menu transition. This can allow the user to perform frequent selections without needing to look continuously at the screen, which is very important whilst driving.

Figure 3.5 iDrive haptic dial

Under certain circumstances, tangible transitions can become critical transitions. For instance, a critical effect will be the result of the transition the user made, especially in situations where a user is dealing with crucial operating machines or systems in laboratories, factories and others that are similar to these. Emphasising the transition of the different states makes the user aware of the changes they are about to make. It would be even more critical if the user cannot reverse the action (transition) that they just made. Thus, in this case, tangible transition is most useful when the resistance is felt prior to transition.

3.2.5 Bounce Back

Some control devices return to their initial position soon after we release our fingers or hands from the knobs/buttons. For example, the on/off power button on many PCs – see figure 3.6, and on some models of washing machines. When we push the button in, the effect of this action starts up the system and the button returns to its initial position. This particular effect is what we call ‘bounce back’. Other examples that exploit bounce back include joysticks, mouse buttons, a mobile phone’s volume controller and MiniDisc controls.

Figure 3.6 On/Off control with bounce back – is it on or off now?

The bounce back control in figure 3.6 has aspects of both exposed and hidden states. It is exposed in that the user can immediately figure out how to manipulate the physical control, i.e. it exhibits strong affordances. Also the bounce-back on–off button has two clear states, one while the button is ‘out’ and one while the button is ‘in’. However, the ‘in’ state is a *transient state*, it only stays in the state while a finger is actually pressing it – our body becomes part of the interaction, which we refer this as embodiment. As soon as the pressure is released it bounces back to the ‘out’ state and so there is only a single stable exposed state. This lack of a meaningful stable exposed state means that bounce-back buttons typically rely on a screen display or some other sort of indication to show the present state the system is currently in after the physical manipulation has taken place.

Because of the transient state(s), bounce-back devices have effect either at their transitions or due to the length of time they are held in the transient state. Where these natural properties are exploited bounce-back devices can be powerful, where they are used inappropriately they are confusing, even though we are very used to them.

We will explore the features of bounce back by using state diagrams of three examples that illustrate the three conditions of unsymmetrical mapping between the physical and logical states of bounce-back interaction.

3.2.5.1 Simple bounce back

Figure 3.7 shows the state diagram of the PC on/off power button. The left-hand arrow shows how the button bounces back once the pushed-in button is released by the user. The ’in’ state is drawn as a dashed circle to emphasise that it is a transient state. Instead of directly mapping to one particular logical function during the transient state of ‘push in’, the physical transition maps to two logical functions. It could be either turning the system on when the button is being pushed in, or shutting down the system. The releasing action does not have any impact on the logical function of the system.

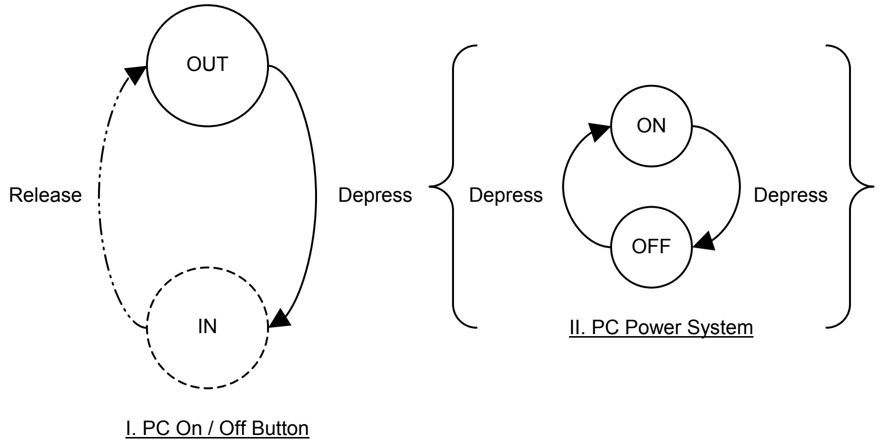

Figure 3.7 States of the bounce-back on/off button

Why this design is used instead of a more apparent on–off switch with exposed state? There could be good reasons. For example, some PCs allow you to turn on the machine using the power button, but only have a ‘soft’ or ‘gentle’ off invoked by software to ensure that data is properly saved. In this case the user would control the off-to-on transition, but the system would control the on-to-off transition.

In fact, the photographed system does not behave like this, as demonstrated in the state diagram. It appears to be an unnecessary case of hidden state with a characteristic power light near the button to expose the hidden state. The real reason for the bounce back seems to be aesthetic; a two state on–off switch would not look pretty on the front of the PC case.

3.2.5.2 Multiple states bounce back

The second example is a MiniDisc controller (as shown in figure 3.8). This has a number of bounce-back controls. There is a row of five tiny switches, each of which cycles through a different set of options. The small knob at the end is used to control the track and also volume. If the small buttons had been exposed state buttons there would not have been room for them all. Devices exploiting bounce back are often more compact and hence suitable for small devices.

Figure 3.8 MiniDisc controller

The track controller at the end is even more interesting as the number of tracks depends on what is recorded on the MiniDisc. Bounce back is often used where the physical control allows the user to access a variable number of logical functions. Figure 3.9 shows how the physical action of twisting the knob, can map to a variable number of functions, i.e. to various tracks for the different songs. By twisting the knob once, the system skips to the next song, i.e. from state 0 to state 1. When releasing the knob, the physical state is returned to its initial position, and the current state of the system remains there. The bounce-back effect, which does not affect the logical function, is understood by the user, and hence the user learns how to get to subsequent states – in this example, how to skip songs.

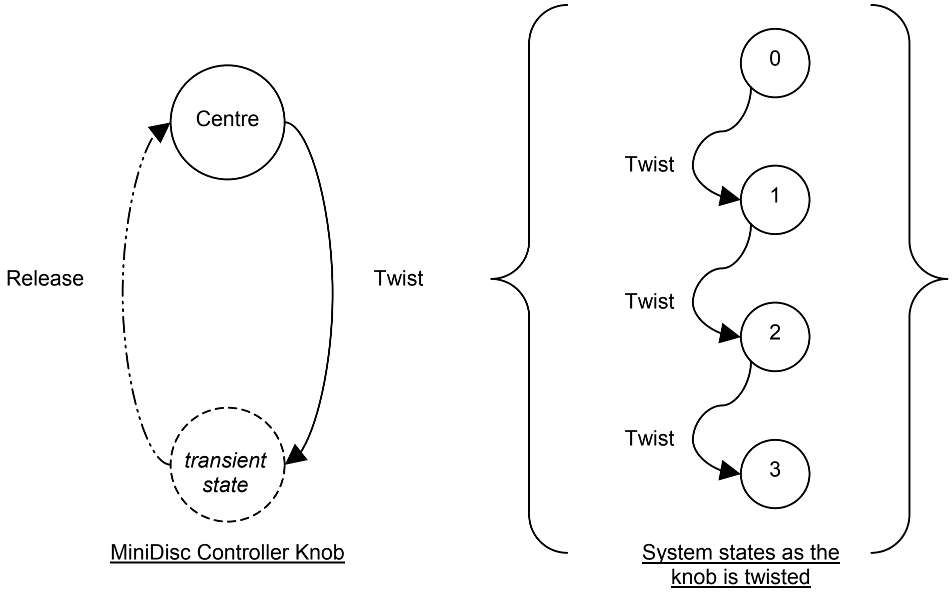

Figure 3.9 States of the MiniDisc track controller

3.2.5.3 Complex bounce back

The full picture, in fact, is a little more complex as the user can twist the knob anti-clockwise to step to previous tracks on the disk. Figure 3.10a shows the state diagram that corresponds to this behaviour: the knob can be turned right and left to skip to the next song(s) or to the previous song(s).

What makes this particular diagram significant is that the bounce back does not just map to a various number of states, but is also able to incorporate different functions by separating them according to the control's direction of movement. In addition to this, there is a strong coupling within the logical state of the system, i.e. the current state is 'remembered' despite the direction that the twisted knob may have taken. For example, when the knob is twisted to the right twice (0-1-2), and then is twisted to the left once, the current state at the end will be at 1 (2-1). Note that this is not a complete 'undo' if the playback is half way through a track; then turning the control right then left restarts the track rather then getting you back to where you are. We will return to this inverse action in the next section. The same effect also applies to the left twist. Figure 3.10a illustrates the physical movement of the controller.

Whilst a quick flick, which enables the controller to bounce back to the centre immediately, results to a change of track, the logical effect gives a different result when the logical state is kept in transient state for *t* seconds. The logical state is unchanged so long as the physical controller stays in this position. The period of *t* seconds in the transient state determines how much part of a track needs to be forwarded, when the controller is twisted to the right, or to be rewinded, when the controller is twisted to the left. Figure 3.10b shows the transient state which stays for *t* seconds before the controller is being released, while figure 3.10c gives the full illustration of the physical and logical change of states when a movement is being made to the mini disc controller.

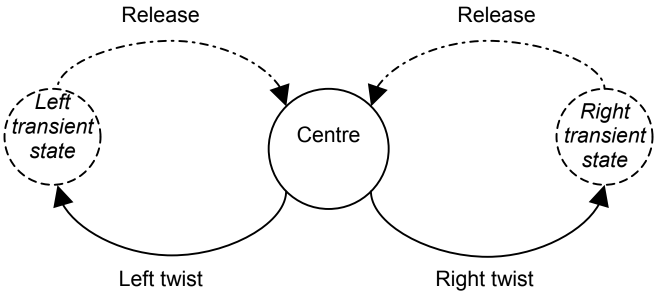

Figure 3.10a Change of states at the physical level of mini disc controller

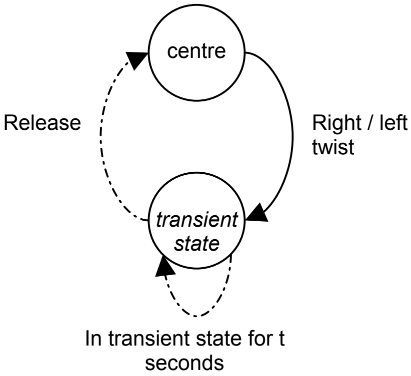

Figure 3.10b In the *transient state* for t seconds – track is either rewinded, or forwarded, with its logical state unchanged

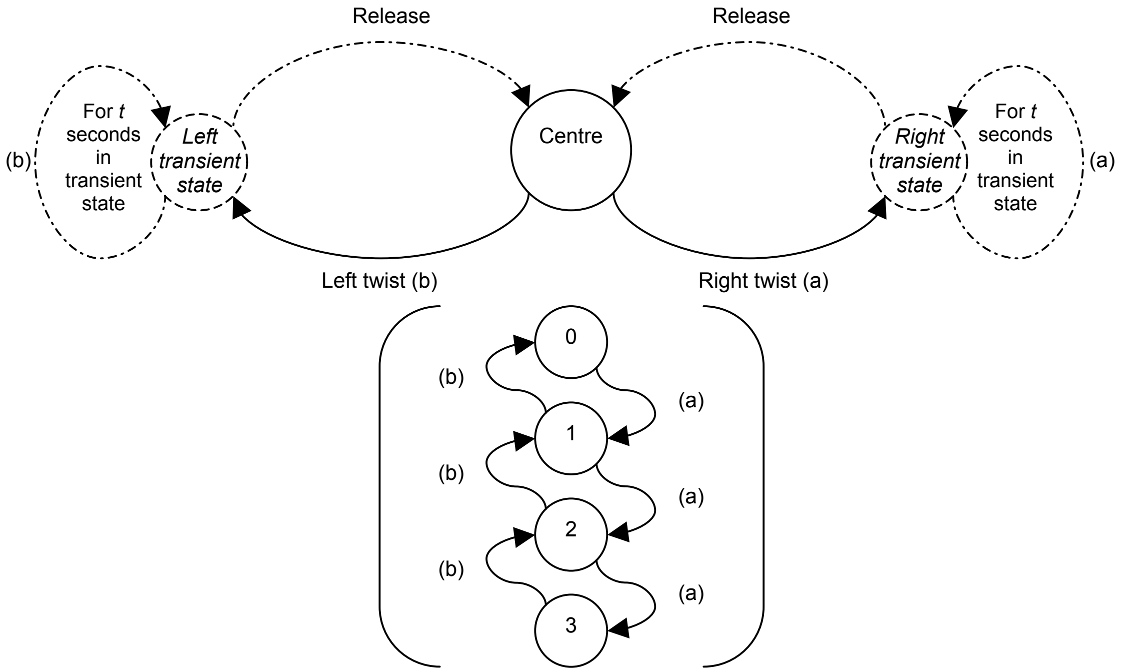

Figure 3.10c The full picture of the change of states of the physical and logical of a mini disc controller. Flick and rapid movement results to change of track, whilst staying in transient state results to the same track being rewinded or forwarded

This example shows how a bounce back's mapping of logical and physical can be varied in direction of movement and velocity. We can see the same in other controls such as a gaming joystick. In some cases (for example, video fast-forward), the longer the user holds the button/knob down, the slower or faster it changes the logical state (see figure 3.10b). Where a device is being used to control the direction or velocity of the logical states, it is important to know where the 'stationary' position is. Note how the bounce back to the neutral centre position does this. If you simply release the control, movement stops. The bounce back also means that movement only occurs when the user is applying a positive pressure on the device – the transient state is also a tension state of the user. This makes it difficult to cause movement or change by accident.

The analysis of the examples has led us to believe that bounce back is good in the following conditions:

i) where there are a large and variable number of logical states
ii) when the devices are small or compact
iii) when safety (as the case of PC shuts down) is critical

iv) when aesthetic becomes the focal point in the design

Where in the above conditions, bounce back could either be designed as a simple bounce back, multi-states bounce back or complex bounce back which incorporates directions and velocity.

3.2.6 Inverse Actions

We return now to the speaker volume dial (figure 3.2). As with most dials, turning the rotary knob clockwise increases volume, turning it anti-clockwise decreases volume. Similarly with the Mini Disc controller, twisting the knob right advances the track, twisting it left moves the track back (figure 3.8). These inverse effects, like the dial, exploit natural physical inverse actions – if you push a cup across the table you can also push it back in the opposite direction. Until it falls off the edge, opposite pressures have opposite effects.

Just as in GUI, the existence of inverse actions acts as an 'undo' and so reduces the risk of exploration (Dix et al., 1995). Rapid, reversible and incremental feedback in direct manipulation (Shneiderman, 1998: p229) allows user to make fewer errors and can be avoided more easily. However with physical devices it is not just that an inverse exists but that the inverse exploits a natural physical inverse such as push/pull, twist clockwise/anti-clockwise, or push up/down. In the best cases this is intrinsic to the device (as in the speaker's rotary knob), but may also be made apparent using visual or tactile decoration. Figure 3.11 gives an example of the latter where two buttons are clearly linked by being 'yoked' together.

Figure 3.11 Volume control – linked buttons

Inverse action is especially important if the user does not have a perfect knowledge of the physical–logical mapping. This allows the user to experiment with the physical control and find out the logical functions the control supports, by reducing the chances of getting the actions wrong.

A particular case of this is when a physical control may manipulate more than one logical function. The user can discover the different logical functions that lie under the physical appearance by inversing the actions. For example, some mobile phones have a small 'scroll' button that can be pressed up or downwards. This may control volume whilst in the middle of a call or scroll through lists when searching the address book. Although this sounds very confusing, it does not prove to be in practice. There is an immediate visual or audible feedback of the effect of the control and if the effect is not as desired, the natural inverse makes it easy to correct.

In some cases, inverse actions adopt the hidden state's additional features in order to provide additional information of the logical function that the physical form supports. The speaker control, which has been described earlier, has around it painted dots of different sizes that increase from one end to another, indicating to the user that the volume increases as he/she turns the knob clockwise, and reduces in the opposite direction. This additional feature with the volume of sound coming from the speaker provides some sense of coherence between the physical state and the logical function.

Inverse actions, in some other cases, work together with exposed state to deliver natural interaction, the tuning frequency of an old radio for example. Besides the manipulation of tuning the frequency by rotating the knob clockwise and anti-clockwise, it also exposes the position of the frequency that is pointed by a vertical line from a display as the user rotates the knob.

The naturalness of inverse actions' interaction may only be achieved when the user gets immediate feedback – for example, the sound of the speaker increasing and decreasing. Under certain circumstances, feedback may be delayed, for example in an electric cooker there is a lag due to the time it takes to heat the metal in the cooker's rings. As we discussed, temporal locality is one of the features of physical interaction and not surprisingly these delays are not dealt with naturally. For example, many people will adjust central heating beyond the desired temperature to 'heat the room more quickly'. So strong is this effect it even applies to those who understand the system well and know it will not have the desired effect.

3.2.7 Compliant Interaction

The rotary knob on the washing machine (see figure 3.12) is not just a good example of exposed state, but also exhibits symmetry of interaction. The user sets the program by turning the dial, but the system also turns the dial itself as the program advances.

Figure 3.12 Washing machine and its control

Exposed state and compliant interaction differ in that compliant interaction has some kind of mechanical movement that advances when the program advances in the same way as the user would interact. A simpler example is the on/off switch on some electric kettles. This can be moved up and down by hand, but when the kettle boils flicks to the off position. Old tape recorders also did this and the 'play' button would bounce back up when the tape reached the end.

Note how the kettle's on/off switch differs from a simple on/off switch such as a light switch. In the latter there is no control involved from the system, it solely depends on the user's interaction.

The state diagram in figure 3.13 shows a simplified version of the washing machine control. Because it has an exposed state the internal and visible states coincide, so these are not distinguished as they are in figure 3.1. The plain and dashed arrows show the user and system control of the device respectively. It is clear how these coincide except in that the system cannot turn the washing machine on from the stop state.

Compliant interaction means that the user can easily learn the relationship between the state of the control and the state of the device. The naturalness of compliant interaction enables expert users to use the device to exert fine control over the system's action. This is evident in expert washing machine users who can intervene in the washing program, such as skipping parts of the program, and start in unconventional places, as they learn how to fine-tune the device.

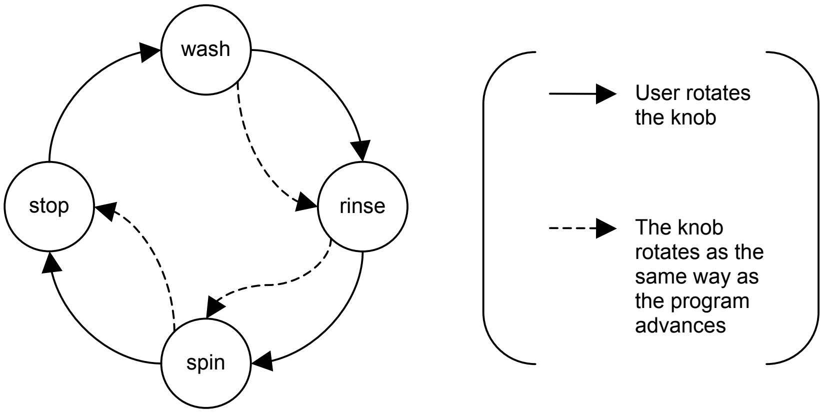

Figure 3.13 State diagram of washing machine

In principle this control could give rise to confusion as turning the dial does not complete the wash cycle that the system has been programmed to do. In practices this does not seem to occur with washing machine use or the electric kettle (switching it off is not assumed to have magically boiled the kettle). However, this does appear to be a potential danger for less well-understood applications.

Note that compliant interaction is named from compliant motion as used in robotics (Finlay and Dix, 1996). This refers to things like a tapered screw where the action of putting it into the hole is guided by the physical resistance of the screw. If the screw is placed slightly to one side there is a natural force pushing it into the right place. In contrast without the taper a slight miss means it just doesn't go in. The physical properties of the screw make automatic assembly easy.

3.3 The Table of Interactions

From the set of principles and issues of physical interaction we have seen above, we now have a table of interactions, which enable us to see how appliances embody cross sharing-properties and how these properties interact with one another and other implicit properties. This Table of Interactions (see table 3.1) can be used as a quick reference and guidance, especially when it comes to assisting in understanding how properties can work well with one another, by looking at the existing examples.

The following are the implicit properties and their descriptions which we have gathered from the previous section.

Intrinsic exposure control	Where the control is situated within or belonging solely to the physical device or appliances which it acts
Semantic feedback	Where feedback acts to confirm the intention of an action
Nowness, simultaneouity	The immediate result or effect of an action
Aesthetic/decorated control	Signage, icon, text, light that accompany a control to provide information and confirmation
Distance / spatial	Where the control is separated from the physical device or appliance it controls
Temporal locality	Feedback or result of an action either occurs within a period of time, or, after a short period of time. This feature is positive when the result meets the expectation, while it is negative when it is not
Transitory / transient state	Where a number of logical states keep changing while the physical state stays where it is
Embodiment	Where the human body is in the tension state, i.e. becomes part of the interaction
Emulation	The effect of the feedback, whether they are real, or animate

Principles ► **Implicit ▼**	**Exposed state**	**Hidden state**	**Controlled state**	**Tangible transition**	**Bounce back**	**Inverse action**	**Compliant interaction**
Intrinsic exposure / control	Kettle switch, table lamp switch						
Semantic feedback	Kettle switch & light, iron on-power light						Kettle switch, washing machine
Nowness, simultaneouity	Kettle switch & light, ceiling/wall light/fan switches, table lamp switch, blender speed level knob, vacuum cleaner, iron on/off dial	Speaker dial, light dim/bright knob dial, mobile phone scroll button, WC/coach doors 'button'	Buttons on cooker hoods, fans (in order to cancel off, '0' must be pressed),	BMW iDrive	Mini disc controller, coffee maker power button, Hand blender buttons	Speaker dial, kettle switch, blender/mixer speed level	
Aesthetic / decorated control	Kettle light	Speaker dial, shower temperature controller, iron temperature control light, WC/coach doors buttons' lights			On/off PC button, coffee maker power button,	Speaker dial	
Distance / spatial	Ceiling/wall light/fan switch			BMW iDrive (to what it controls)	On/off PC button	Light switch	
Temporal locality	Electric cooker, oven knobs	Shower temperature controller, iron/radiator temperature control dial - to map specifically to respective logical state level	Water fountain tap, toaster, old tape recorder, musical box winder, wind-up alarm clock	Cooker knob, thermostat in iron dial	coffee maker power button, hand blender button	Microwave, tumble dryer, dishwasher, slow cooker, steamer timer – also shares hidden,	
Transitory / transient state		Remote control buttons, mobile phone scroll menu, WC/coach doors button, cigarette lighter	Water cooler tap		On/off PC button, mini disc controller, hand blender button, coffee maker power button		
Embodiment		Remote control buttons, mouse (drag), cigarette lighter	Water cooler tap		On/off PC button, mini disc controller, water fountain tap, blender pulse button/knob,		
Real form emulation			Toaster, old tape recorder	Cooker, oven knob			Washing machine
Animate form emulation				BMW iDrive, mobile phone scroll	Mini disc controller (sound effect)		

Table 3.1 The Table of Interactions

Properties which we have seen earlier normally do not stand alone on its own within one appliance or device. Each appliance may exhibit a strong compliant interaction feature, but at the same time it also shares a similar property of the exposed state.

Many of today's appliances and devices actually exhibit more than one property. An electrical kettle for instance, which normally consists of a switch and a light, exhibits a clear exposed state about turning the kettle on and off – by informing when the switch is up=off, down=off (or vice versa). Due to this, the kettle has an *intrinsic exposure* which gives immediate information to users. In addition, the kettle also encompasses a *semantic feedback*, which is provided by the aesthetic light connected to it. The following shows a snippet from the Table of Interactions, which highlights the cross-sharing properties of a kettle.

	Exposed State					Inverse Action	
Intrinsic exposure control	**Kettle switch**						
Semantic feedback	**Kettle switch & light**						
Nowness, simultaneouity	**Kettle switch & light**					**Kettle switch**	
Aesthetic, decorated control	**Kettle light**						

Table 3.2 Kettle cross-sharing properties

Controllers such as blender pulse knob, water fountain tap, and cigarette lighter, although exhibit different design principles, these three controllers cross share the same implicit properties. The first implicit property is *embodiment*, where our body transforms to tension state to become part of the interaction and in order for the interaction to stay connected to the mapping with their logical states. In other words, for these controllers to work, we have to keep depress the controller for a few seconds. They are also strongly associated to transient states property due to this embodiment criterion (which was found in section 3.2.5). The three properties which are cross-shared can be seen from the following table.

		Hidden State	Controlled State		Bounce Back		
Transient State		**Cigarette lighter**	**Water cooler tap**		**Blender pulse knob**		
Embodiment		**Cigarette lighter**	**Water cooler tap**		**Blender pulse knob**		

Table 3.3 Three different controllers with similar implicit properties

Devices such as ceiling's fans and lights both have exposed states, but this type of devices have to deal with matters such as *spatial* or *distance* where the associations between the physical controls, e.g. switches, are not of the same location. Nonetheless, this is not an issue, as the characteristic of *nowness* or *simultenouity*, which exhibited by these appliances, instantly tell us what is associated or mapped to the switches.

	Exposed State						
Nowness / simultenouity	**Ceiling's fans & ceiling's lights**						
Distance / spatial	**Ceiling's fans & ceiling's lights**						

Table 3.4 *Nowness* and *distance* implicit properties on ceiling's fans and lights

The Table of Interactions, which was derived from today's appliances, has enabled us to see there are more to the physical characteristics than just the design principles. The implicit properties together with the physical characteristics, we believe, can be scaled up, i.e., can also be benefited in informing the design of tangible devices, particularly tangible controls (more in Chapter 7).

Figure 3.14 Few examples of today's appliances and devices' physical controls

3.4 Fluidity of Novel Interactions

We will now consider how these concepts of physical–digital interaction can be applied to a particular novel input device, the Cubicle. Note that whereas the previous discussion has been about analysing an existing device with a given physical–logical mapping, here we are considering a novel device and using the conceptual categories to suggest appropriate mappings.

3.4.1 Cubicles

Cubicles are cubes of various sizes that are instrumented with different kinds of sensors so that properties such as orientation, location etc. can be detected (Kortuem et al., 2003). These sensed attributes can then be used to control various devices.

Cubicles are being developed as part of the EQUATOR[1] project investigating the integration of digital and physical life and use Smart-Its technology to allow rapid prototyping of sensor-based systems (Smart-Its, 2003).

One example of a Cubicle is of a small cube with sides approximately 3 in (7.5 cm) that is used to control the feed into a large situated display in the seating area of the Lancaster Innovative Interactions Laboratory. Each of the sides is labelled with one of the possible feeds into the display: TV tuner, laptop cable, fixed computer, etc. The cube sits on the coffee table and is simply turned over to select a particular feed. Inside the cube is a standard Smart-Its main board with micro controller and wireless communications. A small Smart-Its plug-in module has accelerometers to detect orientation.

Other Cubicle designs have included much smaller or larger cubes and also cubes with different physical properties: soft ones that can be squeezed, furry ones that can be stroked. Separate work has investigated how these factors affect the way people choose to interact with Cubicles (Sheridan, 2003).

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[1] EQUATOR is an Interdisciplinary Research Collaboration (IRC) supported by EPSRC that focuses on the integration of physical and digital interaction (http://www.equator.ac.uk)

3.4.2 Visible State

The physicality of the Cubicle provides six visible states. But if the visibility of each side of the cube was to be manipulated and designed to become a screen-control, there would be a very clear one-to-one mapping between the visible state of the Cubicle (of each side) and the logical state of the situated display. However, like an on-off switch, this only allows the control of six-state applications. Also the unique labelling of the sides means that it is largely a single purpose device. It is interesting to note however how subtle changes in the decoration of the Cubicle change the number of visible states and the way they can be used in interaction. If a labelled Cubicle is placed on a flat surface and there is no preferred direction on the surface, then there are only 6 states corresponding to the uppermost face. In a situation like the communal coffee table this is exactly what we have.

If, however, there is a preferred direction, perhaps the direction of the display, then we can also distinguish the orientation of the cube. In principle, there are 360 degrees of orientation that could be detected, and if the Cubicle were a flat plate with an arrow inscribed on top, then these would all be potentially usable. In fact, the strong rectilinear visual affordance of the cube suggests that states with a face or possibly corner facing towards the screen are preferred, so, for illustrative purposes we will consider the cube as 'normally' in aligned face positions which means that strictly there are 24 states: six possibilities for the uppermost face and four further orientations.

In the case of the screen controller the fact that the faces were labelled with text (which suggests a single ‘correct’ orientation) and the lack of relation between the sides meant that this was effectively reduced to 6. An alternative decoration of the sides, for example, a squared-off globe would suggest treating the orientation as significant and hence allow all 24 states to be used. Both the text labels and globe decoration are very much single purpose. One of the goals of Cubicles is also to use them as generic controllers, so we also consider more open decorations.

One extreme is a fully labelled cube, for example with each side a different colour, or as in the case of a normal die, a number. Here all 24 states are in principle available, although in the case of the die there are strong cultural suggestions that one should consider it a 6 state device.

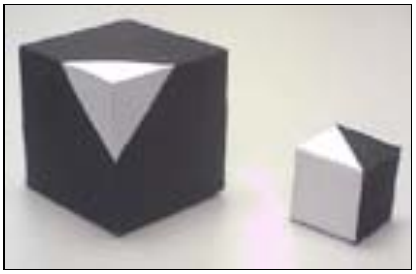

Figure 3.15a Coloured Cubicles (adapted from Sheridan et al., 2003)[2]

More minimal labelling includes painting one corner only or colouring one half of the cube so that one side becomes significant (see figure 3.15a). When the corner is painted there are 8 possible states (see figure 3.15b), although there is some suggestion that the corner could be used as a pointer, so possibly this may be used as a 360-degree controller When one half of the cube is coloured, there are 12 possible states. There are strong visual suggestions to regard the 3 different sides as 3 major states, with 4 orientation 'sub-states' when sideways (see figure 3.15c). Notice that some of the visible states of the Cubicle are given by its physical properties, but others depend on cultural or contextual factors.

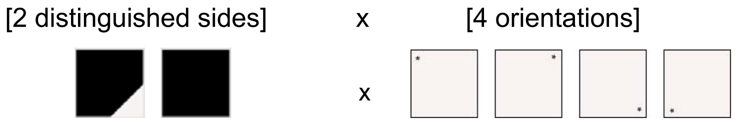

Figure 3.15b Cube with painted corner offers 8 possible states

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[2] In Sheridan et al. (2003), the picture is used as an example of patterned cubes. Various patterns of cube are one of the cube's unique set of characteristics besides size, texture, sound, shape and weight. Whilst they only explore the cube affordances, we look at the possibilities of number of states each patterned cube has.

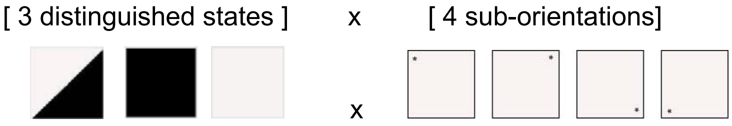

Figure 3.15c Cube with half side painted offers possibilities of 12 states

3.4.3 Inverse Action

The simplest decoration of all is an entirely unlabelled cube, which has no distinguishable states whatsoever. Although this sounds not very useful it means that it can be used in the same way as a mouse or joystick can, where the absolute location is not important: it is the relative movements (rotating, twisting) that are significant. For example, given a menu structure, tipping the cube from side-to-side can be used to cycle through options and tipping it forward can be used to select an option.

Depending on the sensors in the Cubicle, slowly tipping in a direction can be distinguished from a quick 'flick' in a direction or actually turning in the same direction. The desire to return to the 'natural' orientation of the cube with flat face up, suggests that the tipping action, rather like a sprung joystick, affords more continuous velocity effects, whereas a flick or turning of the face is a discrete action, more like cursor keys.

Whilst movements like this can be used to make a Cubicle into a universal controller, there are problems of registration. Which way is 'forwards'? For the users this would probably be tipping the cube away from them, but if the Cubicle does not have any absolute location or orientation sensors (which are more difficult than tilt sensors) then this may not agree with the Cubicle's 'own' idea of 'forward'. Also a new user coming to the Cubicle, perhaps finding it on a coffee table, would need to learn the interactions.

Just as in the appliances we have studied, these are exactly the situations where natural inverse actions can help. The use of opposing directions for moving in different directions through a menu list means that tipping the cube in one direction can be undone by the opposite movement. Similarly if tipping forward is selection of an alternative, tipping backward should be the 'go back' action. So long as this is the case a user picking up the Cubicle in the 'wrong' direction can learn up the effects and if desired then re-orientate the Cubicle. Where the inverse action breaks down, for example when selecting an option has an irreversible effect; then some sort of orientation independent action, such as a sharp tap of the Cubicle, will be necessary.

3.4.4 Compliant Action and Haptic Feedback

As we have seen compliant action is comparatively rare, but very powerful when used appropriately as in the washing machine dial, or on-off buttons on electric kettles.

Cubicles are predominantly passive and untethered input devices, so do not naturally suggest control back from the application. However, some potential designs have a small display on each side. This would allow interactions where the user could rotate a particular face upwards, but this could then change over time under the applications control. For example, if the Cubicle is used to control a menu system, then the system could gradually 'fall back' into a standard state after a period of inaction.

Haptic feedback is even more problematic although, in principle, a heavy gyroscope could be used to give controllable resistance to rotation or even used to autonomously flip the cube.

More practically a ball-bearing moving within a face-centred octahedral void within the Cubicle would enhance the 'joystick' effect – as one tipped the cube, even in mid air, it would be trying to get back to a face down state. Alternatively having a ball bearing roll within the cube itself would tend to suggest holding it with a corner pointing down and hence radically change its interaction affordances.

3.5 Discussion

In this chapter we have focused on the aspects of the physical controls that correspond to natural physical interactions in the world by looking at the design features of current day-to-day appliances. In our foray to have a complete coverage of physical interaction devices, we began with a collection of appliances and devices which we encountered in everyday life, things which we found elsewhere as we travelled and others which were mentioned by friends and colleagues. This was supplemented by a more systematic examination of appliances in shop catalogues. When no new patterns or similarities appeared in the growing collection of devices and appliances, we were confident that we had obtained a coverage of potential devices and interactions. The patterns of similarities of design characteristics were how we derived to the design principles, or, properties.

Studying these day-to-day devices has led to a number of principles and issues of physical interaction. This has enabled us to examine a particular novel interaction device, the Cubicle, and also to see how these principles correspond to generic categories of tangible interface object.

Table of Interactions illustrates further the results of the design principles by highlighting the cross sharing nature of properties exemplified by a range of appliances and devices. Together with the implicit properties emerged from our analysis has enabled us to see how these properties interact with one another, which results to a rather complex associations that exist within a design. Semantic feedback, which correlates with the nature of nowness and simultaneouity, exhibits strongly in appliances that have properties of exposed and hidden states. Whilst the transitory, or transient state, is a crucial implicit property of those appliances of hidden state and bounce back.

Although some of the principles are generally ‘good’ ones: exposed state, inverse action, compliant interaction; there are circumstances where they are and should be broken. For example, if there are many states or a variable mapping then exposed state is not possible.

The adequacy of interaction is normally seen in the light of a complete system; however, we have focused on the physical devices used for interaction with the system. Clearly rich interactions require high-level cognitive understanding, but, if the finer aspects of interaction recruit low-level abilities through the physicality of devices, then our higher-level abilities are freed to focus on the real purpose.

Our investigative approach has combined what can be thought of as an epidemiological study of devices that are extant, more psychological analysis of device use, common knowledge about good and bad design and detailed formal analysis. Most of the devices we have studied exhibit several 'good' and 'bad' properties and the effectiveness is a combination of designed and accidental properties of the device combined with skilled human behaviours arising from cultural, learnt and innate causes. To attempt to disentangle completely all these issues would not be productive for design purposes and our multi-paradigm approach has allowed a broad analysis. However, attempting to obtain some purchase on the complex interactions and trade-offs of physical design does lead not only to insight but also potential directions for more detailed experimental studies of individual effects.

3.6 Conclusion

We believe the act of exposing the underlying mappings is to be a wise step in understanding the relationship between physical and logical states. We have seen that a good corresponding between controllers and the functionality being controlled result to fluid interaction. Although this work may seem to be similar to Norman's understanding of natural mapping, in our set of work, we have looked in-depth into the interaction between the physical and the logical mappings and successfully identified a set of properties which we believe to be the key that make our interactions with today's appliances and devices natural. Furthermore, the Table of Interactions (table 3.1), have managed to provide us insights of other crucial implicit design characteristics that exist and cross-share within one appliance. We will return to this in Chapter 5 where we will be discussing this in further.

In short, this chapter can be concluded as follows:

- this work is different to Norman's in the way we focusing on the use of physical design and identification of physical design characteristics
- the identification of physical design characteristics was done by analysing the features, properties and relationships with their underlying logical functions and

presented using the STNs
- we know when to stop looking on today's appliances and devices when patterns started to appear
- the Table of Interactions is presented to show the richness of physical design by illustrating the cross-sharing properties between the seven listed design characteristics and the implicit properties
- the conceptual physical design properties is proven to be beneficial in informing and assisting in the design of the characteristics and functionality of tangible devices
- we believe the chapter has given us a very informative insight and a deeper meaning to the concept of fluidity, and furthermore, has proven that the conceptual design principles can be also adopted to the area of tangible interfaces

The next chapter, Chapter 4, presents the user study of the Cubicle, where we will be discussing the application of interaction design principles on the Cubicle as novel input device. The discussion includes overall performance and users' preferences, and also we will be looking at the applied design principles on the Cubicle in retrospect.

Chapter 4

User Study I: The Cubicle

This chapter reports an experiment on a Cubicle, a small cubic interaction device. These were used to control a virtual cube on a screen, and on each side of the cube represent a selection of movie trailers. This was designed to investigate whether users are able to understand 'soft', re-programmable mappings and also the playfulness of the Cubicle. Four designs were compared differing in the cognitive complexity of the mapping between physical cube and on-screen cube.

In the last part of the previous chapter we have considered the conceptual categories design properties to suggest appropriate mappings on the Cubicle. The existing Cubicle and application created an excellent opportunity used to apply the conceptual design principles and outline the possible design questions. A more exhaustive analysis of these design options is presented – appendix III, but in this chapter, not all principles are addressed by the study – just a subset, in particular, the exposed state and the hidden state, as these two could enhance better the underlying GUI of the Cubicle (section 4.5). The role of inverse action in the study, however, will be discussed in detail in the next chapter, chapter 5.

Section 4.1 describes the role of the cube as an input device by looking at other related work. In section 4.2, we will examine the technology of the Cubicle which includes the way it is designed and its functionality. The user study of the Cubicle is described in section 4.3, and followed by analysis results in section 4.4. We will analyse the comparison of the designs on the Cubicle with the interactions design principles in section 4.5.

4.1 The Cube as an Input Device

The cube is a simple and familiar shape and yet also affords a wide range of actions and interpretations. Earlier studies of cubes with different kinds of colourings, textures, etc. demonstrated the wide range of ways in which people would manipulate this apparently simple solid (Sheridan et al., 2003). Even on a solid unmarked cube the faces suggest 'stable' configurations where it can sit on a flat surface, and also natural direction to tumble or twist the shape. Decorations, differences between the sides etc., all influence these basic affordances.

A Cubicle is a wireless tangible cube that uses Smart-Its technology to allow rapid prototyping of sensor-based systems (Smart-Its, 2003). The Cubicle was first built for the purpose of basic navigation and input (van Laerhoven et al., 2003). The Cubicle has been studied in related work, such as cube affordances for wearable computing (Sheridan et al., 2003), and applications including an augmented die for playing games and a controller for a radio tuner[1].

There are also a number of related devices that exploit the physicality of a cube. These including the Cubical Mouse, a 6-DOF manipulation device (Froehlich et al., 2000), the ActiveCube used to construct and interact with three-dimensional (3D) environments (Sharlin et al., 2002, Watanabe et al., 2004), cube used in puzzle-solving tasks to compare collaboration performance in a real environment and in a virtual environment (Wideström et al., 2000) and a foldable 3D cube used as an interactive tangible interface for storytelling (Zhou et al., 2004). In the Chromarium, a pair of cube with coloured

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[1] Other information regarding the Cubicle is available from its website: http://ubicomp.lancs.ac.uk/cubicle/

faces is used to help children understand colour mixing in a mixed-reality experience (Rogers et al., 2002). In the purely digital world, an on-screen cube called the ‘Communication Cube’ has been used as navigation support for advisers in a customer-service center - part of the Motivational User Interface (Millard et al., 1999).

4.2 Experimental Device and Application

4.2.1 Accelerometer-based sensing

The Cubicle used in this experiment contains two 2d accelerometers allowing the vertical direction to be detected and also movements such as shaking. This means it is easy to detect which face is on top, but not the relative or compass direction of faces in the horizontal plane. So, for example, it is impossible to determine with confidence which face is pointing towards the user of the cube, or a television screen in the room.

Other variants of the cubicle incorporate a gyroscope, allowing compass directions to be determined, or other sorts of sensors allowing to detect squeezing etc. The advantage of pure accelerometer-based sensing is that accelerometers are comparatively cheap compared with, for example, gyroscopes or other forms of electronic compass, and do not require modifications to the environment as would, for example, ultrasonic or RF location systems.

Although it is not possible to determine the cube’s orientation given a single reading, the accelerometers do allow rotations around the non-vertical axis to be detected and thus, in many circumstances, maintain a model of which direction is which. If this model of ‘forward’ is determined in an initial calibration stage it drifts only slowly so long as the user only ‘tumbles’ the cube and does not twist it around the vertical axis (Z-axis) (see figure 4.1a)

4.2.2 The Cubicle as a TV Control

Some applications are possible just using purely the detection if the upper face. For example, the initial Cubicle application used the cube to select between AV modes for a large plasma screen. Each face had the name and icon for a mode on it and the upper face determined the mode (van Laerhoven et al., 2003). However, in this mode of use the cube has to be decorated differently for each application.

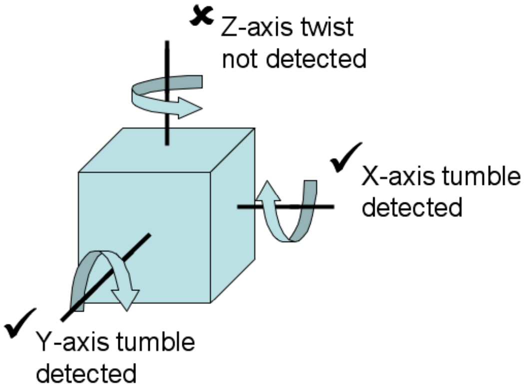


Figure 4.1a Detected rotations

Figure 4.1b Wooden Cubicle

In this study, we used a Cubicle application developed by Block et al., (Block et al., 2004) intended as an input device for playfully changing between different TV-channels. In particular, the Cubicle was used to select movie trailers for Alien, Die Another Day, Die Hard, Lord of the Rings: The Return of the Kings, Love Actually and The Matrix Reloaded, from a screen by manipulating the cube. Table 4.1 shows the ways in which a user could manipulate the cube to control the TV image.

The Cubicle itself constructed of wood with sides approximately 3 in (7.5 cm) – see figure 4.1b. As previously noted it was augmented with accelerometers hidden within the wooden case. The sides were numbered 1 to 6, but without any images of the movies or other indications of meaning. This meant that the mapping between the cubes movements and its digital effects could be ‘soft’ and reprogrammable. In order to help the user to understand the effects of the Cubicle, it also has an on-screen representation of itself. In this digital representation the sides each display a title image for the associated movie.

Whilst this indirect representation of the Cubicle means it can be used to manipulate arbitrary content, the effects of manipulations on the cube are far less obvious. The Cubicle is intended to be a fun device to pick up and use, so it is important to know whether users are able to successfully manipulate the virtual representation and hence digital effects of the device. In particular we expected that the user would have to be able to calibrate the cube so that rotations on the wooden Cubicle had well understood effects on the virtual cube.

Action	GUI output
Rotation	Display different movie trailers' images Full image of a movie trailer being displayed selects a movie trailer
No action (cube is placed on a table, or is held parallel to the ground)	Zoom out and play a movie trailer, provided that at that time the screen was showing just one side of the cube, which shows one full image of a movie trailer
Shake	Return to initial orientation (correct the calibration), or, zoom out the display if the application was playing a trailer (thus stop/pause the trailer)

Table 4.1 Cubicle actions and the associated GUI output

4.2.3 Applying Interaction Principles to Experimental Cubicle

In Chapter 3 – section 3.5, we have discussed how we can use the conceptual categories of the interaction principles to suggest appropriate mappings. In this section, however, we will assess the interaction principles by narrowing our scope on the experimental cube. Design questions on how we can incorporate every interaction principles to the Cubicle were made in the design stage (see Appendix III for details). The suggestions are as follows.

Exposed state. The Cubicle's six sides are labelled differently thus exposing the visibility of six states, while the physicality of the cube, i.e. its size and its weight, suggests the participant to hold the cube with two hands. Conversely, the virtual Cubicle can only expose three sides at a time (see figure 4.5).

Hidden state. The state of initial orientation of the Cubicle is unearthed only if we shook the Cubicle. Unlike the rest of devices with hidden state, this cube does not provide any indication of this reset state except via exploration. This is the same for the streaming capability (play), which only zooms out the trailer and plays when the Cubicle is placed on an even surface, or when it is held in a steady state parallel to the floor.

Controlled state. Whilst the Cubicle is under the complete control of the user, some limitations exist. Movement is limited to human's physical limitations: we can only move the Cubicle in a restricted range of our arms length, whether it is the furthest point of our right hand side or left hand side, or from the furthest point our hands can reach up or down, or from the furthest point our hands can reach to the front or stretch to the back. Although we can step forward or backward, or to the right or the left to overcome this limitation, we still cannot overcome the GUI interface limitation. In this situation, regardless how far we bring the Cubicle forward or backward, or to the sides, the GUI interface will only react to action that is occurring at one point in time due to its technical limitations, i.e. manipulations have no affect on the GUI screen when participants made gestural movement on the Cubicle (see figure 4.2).

Figure 4.2 Gestural movement along X-axis doesn't give effect in GUI

Inverse actions. Both the Cubicle's physical form and its GUI offer the opportunity for inverse action. If we physically rotate the cube forward, then we can rotate the cube backward. Likewise, if we physically rotate the cube in the physical world, then its virtual sister rotates in the virtual world. Virtual inverse actions mirror physical inverse actions. Most importantly cubes in both forms exhibit the exact inverse movement when the cube is reversed from its last position. For example, when the cube is tipped forward once, the inverse action of that action is the reverse of the former action.

Bounce back. Neither the physical state of the Cubicle, nor its GUI representation affords provide bounce back feature.

Tangible transition. In its current form, the Cubicle only presents a very slight tangible transition; the type of material and shape obviously provides some "feltness" and resistance. For example, whilst a user may rotate the Cubicle, rolling the cube is less easy to do. As well, because of the size of the cube, users are limited to rotating the cube with two hands or with one hand and a surface. The transition will work well with the ability to switch between media streams on the GUI interface.

Compliant interaction. In its physical form, the Cubicle cannot exhibit any compliant interaction since it is made up of one solid wooden part. The Cubicle does not change over time. The closest thing to compliant interaction criteria which we've seen previously is the GUI. It allows the participant to interrupt or intervene the 'play' selection, advances by the interface, by moving the cube.

Novel tangible devices, such as the Cubicle, are different to many of the existing appliances and devices, in which today's physical controllers make it easy for us to use the STN diagrams to illustrate the mappings to their underlying logical functionalities. Being an untethered input device, the Cubicle does not have obvious features like other physical controllers. Therefore, the design principles can only be adopted, not in the same way, but by applying the concepts of the design principles in the design study – as what we have done above. Nonetheless, a similar finite state diagram can still be used to describe the interaction. But this time by showing the possible states the Cubicle can have and map these states to the logical functionalities. Assuming that the cube's state 1 and 6 are at the opposite ends, the finite state diagram for the Cubicle would be like the following:

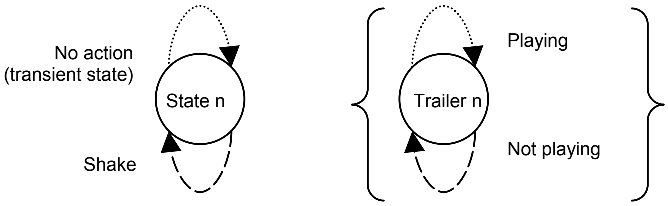
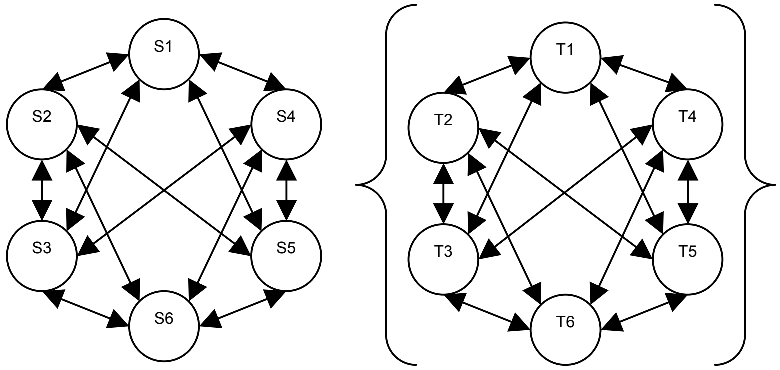


Figure 4.3a Finite state diagram for Cubicle's individual state



Six possible states during rotation

Six movie trailers in correspond to the six states during rotation

Figure 4.3b Finite state diagram for the Cubicle

4.2.4 Manipulating the Cubicle

In order to explore the users' ability to understand and control the digital representation of the Cubicle, four different mappings were designed for the experiment. Each condition independently manipulates a viewpoint (front-aligned vs. top-aligned) and a visual cue (numbered vs. unnumbered), giving a range of different calibration challenges for the user.

The front aligned view (figure 4.4a) is a condition where the virtual cube that faces the user represents the front side of the physical cube. The top aligned view (figure 4.4b) is a condition where the virtual cube that faces the user represents the top side of the physical cube. This is highly significant when a user is trying to calibrate the physical cube with the virtual cube on the screen. Because the sensor in the cube is an accelerometer, it can tell unambiguously which side is up.

When the virtual cube's sides are numbered, respectively from one to six, the condition is known as numbered. The unnumbered condition is when the virtual cube shows only the image of the movie trailers – no number being displayed. Displaying the numbers of one to six on the sides of the virtual cube (on top of the movie images) is expected to aid calibration, as the physical cube is also numbered (figure 4.1b).

Users can thus interact with the Cubicle by orienting the physical cube against the virtual cube on screen according to these four conditions:

(i) front aligned and numbered
(ii) front aligned and unnumbered
(iii) top aligned and numbered
(iv) top aligned and unnumbered

Whilst the difference between numbered and unnumbered conditions is obvious, that between the front aligned and top aligned is not visually apparent. To help reduce cross-over effects, different background colours (blue and red) were used for face and top aligned conditions (as shown below). Otherwise the interfaces were identical.

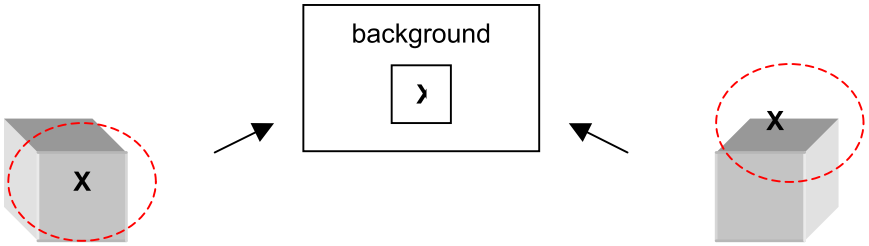


Figure 4.4a Front aligned
(blue background)

Figure 4.4b Top aligned
(red background)

4.3 The Study

The experiment was designed to study the Cubicle's performance as an input device in terms of ease of calibration and manipulations, and also users' experience and preference. Furthermore, a within subjects design was used in order to investigate to which type of mapping of control surface led to the best calibration and manipulation performance, and also to examine whether this type in any way influences the playful experience.

4.3.1 Methodology

We designed our user study as a semi-exploratory design study, hence the instructions given to the participants (table 4.2) included some prescriptive tasks, but also space for exploration.

1. Pick up the cube
2. Play around with the cube, until you feel comfortable
3. Then, manipulate the cube in your hand(s) so that any three sides of the cube visible on the screen
4. From 3, make one of its side (left or right) visible on the screen

   Please inform the instructor when this is accomplished
5. Select Matrix Reloaded trailer
6. Place the cube on the table
7. Watch the movie for a few seconds
8. Pick the cube up again
9. Select a different movie trailer
10. Then place the cube on the table, or make the cube parallel to the floor
11. Watch the trailer that you just selected for a few seconds
12. If you placed the cube on the table, pick the cube up again, or continue moving the cube
13. Now, resume the Matrix Reloaded trailer
14. Place the cube on the table once you select this
15. You can now browse to any other trailers available if you are interested

Table 4.2 List of instructions

Participants were first given time to familiarize themselves with the Cubicle interface. The following two steps were to give participants the idea of selecting a movie trailer by carefully rotating the Cubicle. The rest of the tasks were carefully designed to observe how participants manipulate the Cubicle, i.e. the calibration (if any), expressions, as they select the requested movie trailers. Nonetheless, because of the novel nature of the Cubicle and the limitations of the technology, we realized that these tasks were more likely to explore the limits of interaction rather than to provide solid quantitative task analysis data.

Participants were asked to complete four sets of test by using the same list of instructions. The four sets are as follows:

NF – Numbered cube with front-aligned view
UF – Unnumbered cube with front-aligned view
NT – Numbered cube with top-aligned view
UT – Unnumbered cube with top-aligned view

The order of these four sets was varied and partially balanced in order to measure and compensate for order effects. However, to avoid confusion the two face aligned and two top aligned variants were always together. That is the possible orders were:

NF–UF–NT–UT NF–UF–UT–NT UF–NF–NT–UT UF–NF–UT–NT
NT–UT–NF–UF NT–UT–UF–NF UT–NT–NF–UF UT–NT–UF–NF

From our questionnaires and observations, we expected to make sense of the Cubicle performance as input device according to calibration, manipulations, experience and user preference by referring to our observations and time measurements results. Furthermore, our ultimate goal is to discover what type of orientation of control surface the calibration is performed best, and to seek whether this type in any way enhance the playful experience, thus enabling us to improve the design of the Cubicle.

4.3.2 Participants

We solicited volunteers from within our department and posted a call for participation on a university-wide mailing list. We required that our study to include anyone above the age of 17. The majority of our participants were postgraduate students, most of them were from the Computing Department (8), and others from Psychology (3 participants) and Accounting and Finance (1 participant) departments. Two participants were in their A-Levels. More than half of our participants were men (9 male, 5 female). Five participants have used alternative input devices, such as haptic gloves, and two of them have used the Cubicle interface before the test. Volunteers were informed prior to the test that they were participating in a user study that will assist in determining guidelines for tangible device design.

Three (3) out of eight (8) from the Computing Department were Ubicomp researchers and thus have a vested interest in ubicomp technologies. Because of this reason, there is cautiousness when it comes to viewing the produced results. Nonetheless, although these participants were more critical than others in anticipating the ‘perfect’ condition from the

Cubicle, the way they interact with the Cubicle in terms of manipulating the cube itself were not as different as the rest of the participants.

4.3.3 Measures

To record our data, we use a combination of recording to allow post-test qualitative and quantitative analysis and also collected qualitative data during the experiment including observations and questionnaires. All tests were recorded with a video camera and log files were used to record the data about the cube's orientation. These two results were then synchronized with a small purpose built tool to allow the video of the participants physical movements to be reviewed alongside the on-screen representation. Volunteers were asked to fill out a background questionnaire prior to the study and they were informed before beginning the test that they were going to be videotaped. Investigators recorded, via pen and papers, participants' non-verbal manipulation. At the end of the design study, users completed a short post-questionnaire. Using multiple forms of observation and data collection allowed for detailed evaluation and analysis of user behavior.

4.3.4 Procedure

Our design study took place over one week in our department. Each participant interacted with two investigators before and after the test. The primary investigator was responsible for greeting and debriefing the volunteers and collecting questionnaires. A second investigator was responsible for videotaping. Both investigators were responsible for note taking during the study and for analysing data and questionnaires after the study.

The Cubicle was evaluated in four separate stages. First, participants filled out a pre-test questionnaire individually, which allowed us to gather background data about each participant. Next, we observed how participants interacted with the cube. On each testing day participants were given a list of instructions in which they conducted via the Cubicle. During each test, participants followed the instructions listed in table 4.2 for each of the four sets. Investigators directly observed participants and collected data concerning these observed activities. As well as investigators directly observing participants, investigators used video camera to record (audio and visual) user activity, whilst the log data recorded the Cubicle movements. Thirdly, volunteers completed a post-test questionnaire individually which included both independent and dependant ratings of the Cubicle. They were asked to comment on the procedures, tasks, cube attributes and overall study. Lastly, the collected data were analysed.

4.3.5 Data Collections

Individual responses were collected via the pre and post-test questionnaires and indirectly collected via video and log files. Both the independent and dependent ratings from the post-test questionnaires results were converted into charts in order for investigators to discern the overall performance of the Cubicle. When analysing the video data, investigators collected information on how each user handled the Cubicle, for example, rotating or flipping the cube, using one or both hands. As well, investigators measured how long participants took to complete a task. When analysing the log data, investigators matched the mapping of movements of the physical cube to the mapping of the virtual cube. We then matched these results to the comments participants made via the questionnaires and observations taken during the tests.

4.4 Analysis Results

The results from the observed manipulations of the Cubicle are presented into two categories: observations results, and, overall performance results.

4.4.1 Observations Results

Observations results illustrate the whole experience of manipulating the Cubicle performed by the participants, which include descriptions that are elaborated in accordance to the list of instruction (see table 4.2), remarks when the cube was front aligned and top aligned, and annotations when the cube was numbered and unnumbered.

Steps 1-4 In almost all tests, participants picked up the cube that was placed on a table next to the screen with one hand. One participant who was cautious and careful used both hands. The cube was then brought up to the centre against the screen. At this point, the cube was handled with two hands. Out of 13 participants, only one participant continued to hold the cube single-handedly.

We observed that during the first few minutes of the first set of instructions, the participants tried to manipulate the cube in all directions to try and discover the Cubicle's range of movement. Some of the participants swung the cube from left to right, and right to left, and even in a circular motion.

Due to accelerometer's limitation (see 4.2.1), the rotation along the Z-axis was not as smooth as the rest of the movements. The majority of the participants failed to make the virtual cube rotate on the screen. Only those who had used the Cubicle before the test knew how to properly rotate the cube, i.e. by rotating the cube abruptly, or with a little speed (as mentioned earlier in 4.2.1).

Figure 4.5 A user exploring the cube interface by interacting with a large screen

All participants successfully made any three sides of the cube visible on the screen and made one of its side visible on the screen. It is worth pointing out that miscalibration, however, occurred before and during the completion of these two tasks. Some participants seemed to be struggling in order to get the mapping right. In most cases participants were not aware of the cube referent they were manipulating at that time, and this resulted to miscalibration. For example, a participant who handled the cube by making the top view (NT, UT) as referent had some difficulties to get the mapping right.

As this happened, the screen was actually showing the front view (NF, UF) of the cube. This happened in both conditions: with numbers on the virtual cube, and without.

As participants had to go through the same instructions for all four sets, they often skipped steps (tasks) 2, 3 and 4.

Steps 5-6 Due to the fact that we did not give them any extra information apart from the instruction sheet, the participants often at the beginning were not sure how to select and did not know what to expect after displaying the Matrix image on the screen, i.e. the term used, ‘select’ was not so clear to the participants. Yet, they eventually discovered that the movie trailer would begin as long as the movie’s image was displayed on the screen.

The delay between selection and play caused participants some confusion. They weren’t sure if the delay was a result of a mistake that they made or if there was a technical problem. This caused them to begin manipulating the cube before the intended action (play) commenced and so the trailer never get played.[2]

In situations where the participants were patient enough to wait whilst holding the cube steadily and evenly in their hands, the zoom effect was activated. If then the participant decided to place the cube on the table, the zoom effect got deactivated (zoom out) and started to zoom in again once the cube was securely placed on the table. As this scenario happened on many occasions, the investigators gathered that the instructions in steps 5, 6 and 9, 10 were not accurate enough, which due to this reason, most of the participants did not know how exactly to select a trailer.

Miscalibration between the two movements - physical and virtual, happened quite frequently at this stage. Apart from the reason stated in the previous steps, miscalibration also occurred when participants wanted to rotate the cube along the Z-axis. The virtual cube did not act as the same way as the physical cube, i.e. either the virtual cube rotated

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[2] The delay is an example of a negative temporal locality – from implicit properties, page 53.

slowly or did not rotate at all. This sometimes led to displaying a different image hence showing a different movie trailer. This unintended result caused frustrations to some of participants as we could tell from their expressions.

Step 7 Participants watched the movie trailer for a few seconds as expected.

Steps 8-10 As these steps were similar to steps 5 and 6, the experiences and issues arose were the same, i.e. problem in selecting, delays and miscalibration. At this stage, the participants were informed about the alternative method to selecting, as stated in the instruction sheet. However, we observed that most participants continued comfortably with placing the cube on the table rather than hold it still in their hands.

Another occurrence that led participants to disappointment was when the selected movie image did not give any result, i.e. the picture did not zoom in hence the trailer did not play. For instance, when a participant chose to watch the Love Actually trailer after making the respective image displays on the screen, the picture did not zoom in. As this happened, we advised participants to continue with the test. We suspected the reason to this occurrence is due to the cube being tilted when it was placed on the table (see figure 4.6).

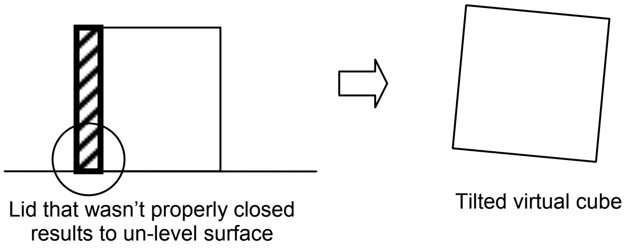


Figure 4.6 Un-level physical cube

Step 11 Participants watched the movie trailer for a few seconds as expected.

Steps 12-14 As these steps were similar to steps 5 and 6, the experiences and issues arose were the same, i.e. problem in selecting, delays and miscalibration. In the occasion where participants had watched the Matrix trailer till the end in step 7, they were advised to continue with the test, as the screen only displays a blank screen when the image was zoomed in.

Step 15 Very few participants viewed other trailers available.

Results from log files, when compared with the recorded videos, show that at some point during the test, the virtual cube didn't move as the same way as the physical cube. The virtual cube movement from log files show that the cube sometimes jerked and sometimes delayed for few seconds although the physical cube was moving during the delay. Again, we suspected that is due to the limitation of the accelerometer, especially when the cube is rotated at Z-axis.

4.4.1.1 Front aligned and top aligned cube

From the observation alone, it was quite difficult to conclude as to whether the participants prefer the front aligned, or the top aligned, which was represented by blue and red background screens respectively. We are, however, fascinated by the fact that participants hardly looked at the cube in their hands when they carried out the tasks, and focused on the screen instead.

In the case where the calibration was correct, there are also a number of interesting methods used to confirm their selection of a movie image. One was by tapping the cube hard on the table. Second, was by placing the cube very slowly on the table when a glimpse of the image of the selected movie was about to appear fully on the screen. The cube was then rotated until the full image of the movie is shown.

Furthermore, we also observed the performance of each participant, relatively, gets better and faster as they carried out all four sets, despite what type of alignment goes first. For example, the order of background screens, i.e. what condition is being shown first, had no effect on participants' performance. The following charts show the average time (of numbered and unnumbered) taken to complete the tasks.

Figure 4.7 illustrates performance where cube's referent (numbers) was first set to front aligned (NF, UF), which is showed in blue line, and was followed by top aligned (NT, UT), in red line, whilst figure 4.8 shows conditions where cube's referent (numbers) was first set to top aligned (NT, UT), in red line, and was followed by front aligned (NT, UT), in blue line. Average time of numbered and unnumbered for every condition was plotted against participants.

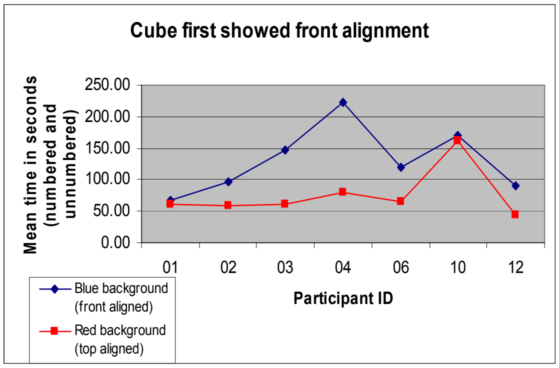


Figure 4.7 Participants performance when the cube's referent was first set to front alignment

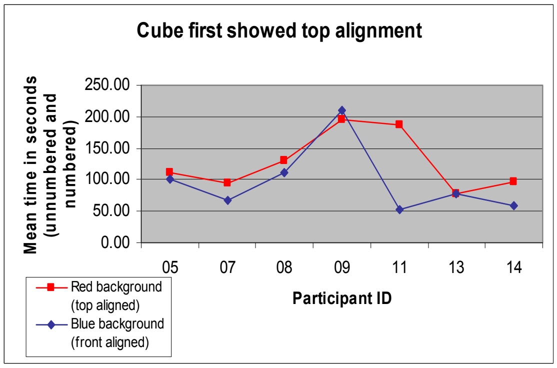


Figure 4.8 Participants' performance when the cube's referent was first set to top alignment

From both charts illustrated above, we see that in most cases, participants spent less time in the second alignment, despite which alignment was set first. Although there was no significant difference between both charts, the gap between the time taken between the first and second test in the first chart (figure 4.7) dropped quite noticeably.

Participants who first undergo the top aligned (NT, UT) referent did slightly faster than the front aligned referent – except for participant #09, who admitted, "*I had problem with the screen cube facing me…*".Whilst, participant #11, who thought that there wasn't any difference between the red and blue background did significantly quicker when referent was front aligned (NF, UF).

Despite proving which alignment is more significant, the results inform us that performances get better and faster as participants became familiar with the application. We observed from the videos and written checklists that participants spent more time in the first condition to overcome miscalibration. They became less concerned with calibration in the second condition, even when the condition was different, as their attentions were more attended to the virtual cube in the screen.

4.4.1.2 Numbered and unnumbered cube

What would be ideal in making the Cubicle as an input device is a fast and precise performance, i.e. the tasks get completed quickly and accurately. But with ratio 8:6 between the numbered cube (NF, NT) and unnumbered cube (UT, UF), the type of conditions seem to be insignificant. The following figure 4.9 shows the results.

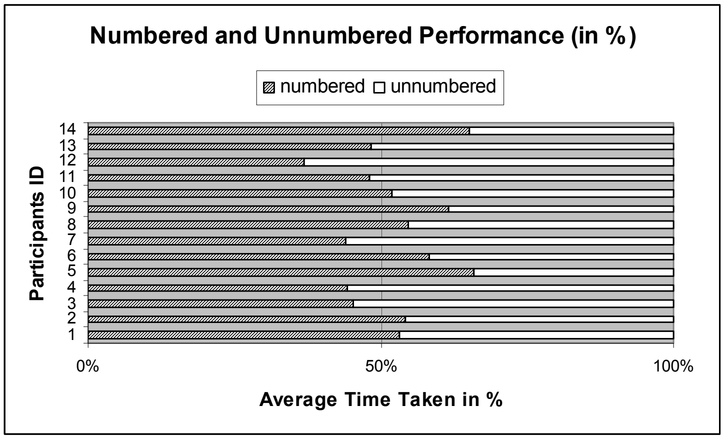


Figure 4.9 Participants' performances on numbered and unnumbered conditions

Even though we cannot conclude which is the best condition based on the results, we however find it interesting to see how participants who do not have a strong computing background and participants who do, performed in these two conditions. Eight participants who do not have a strong computing background spent quite some time on numbered cube in order to match the numbers with the one on the screen. We observed they only looked and concentrated on the virtual cube when manipulating the unnumbered cube, thus result to faster performance.

The time spent by the remaining six participants (with computing background) on the numbered cube, on the contrary, was less than the unnumbered cube. More time was spent on the unnumbered cube as they tried to understand the movement of the virtual cube and how the movement mapped to the physical cube in their hands. For these participants, the numbered cube assisted them rather easily in calibrating both of the physical and virtual cubes.

Although these observations may not able to clam whether one condition more significant than the other, they do signify the characteristic of participants with different background, particularly those whom with computing background.

4.4.2 Overall Performance Results

All participants were (eventually) able to manipulate the cube to achieve the fixed goals of the test procedure. Thus there are no error rates to compare. However participants did vary in the time spent to perform the central (non-exploratory) stages of the experiment. These measurements were obtained by using the video and log records.

Data were analysed using a multi-way ANOVA of log data. Log data was used as we expect timing data to have multiplicative effects (e.g. one participant may be 50% slower than another on all tasks). The ANOVA fitted for participant effect, the presentation order and the main effect of cube mapping. Whilst initial by eye analysis of graphs seemed to suggest an order effect, in fact none of the effects were statistically significant at 5%.

	Sum Sq.	F	d.f.	Sig. Level
Presentation order	0.042	0.797	3	n.s.
Main Effect (mapping)	0.008	0.149	3	n.s.
Residual	0.630	–	36	–

Table 4.3 Analysis of performance data

Given the number of participants we would not have been able to detect small differences between mappings and order. However, given the apparently large differences in ease of use between the different mappings, we were expecting to perhaps see substantial differences between, say, the numbered top facing mapping (NT) where once participants realised that the face they could see was always the top face they could simply use it rather like the fixed image cube. A larger number of participants, or, longer experiments might resolve fine differences between the conditions, but we can be confident from these results that there are no substantial effects.

We also rated the overall performance based on the feedbacks received from the participants as they filled in the dependent and independent rating scales.

4.4.2.1 Dependent rating scale

The dependent rating scale was supposed to provide us with information about the four conditions, by rating the later three sets against the first set. Meaning, after the first set was rated, participants need to rate the latter three sets by rating them more negative or more positive against the first set. Table 4.4 gives an overview of the attributes and the items that were intended to test.

The insignificance effects of the four conditions as mentioned above is reiterated in the post-test Dependent rating scale results. The scales of four sets were rated almost identical to one another (see figure 4.10). Participants did not distinguish in these assessments between the front and top alignment, or the numbered and unnumbered cube. Thus, from this particular result, we could not tell in which condition the attributes performed best.

We suspect that participants could not remember every little detail for comparison after having completed all four sets in one attempt. The post-questionnaire answers, however, tell us that there were many of the participants prefer blue to red, as blue is much calmer than red. This preference is solely based on colours, and nothing to do with alignments.

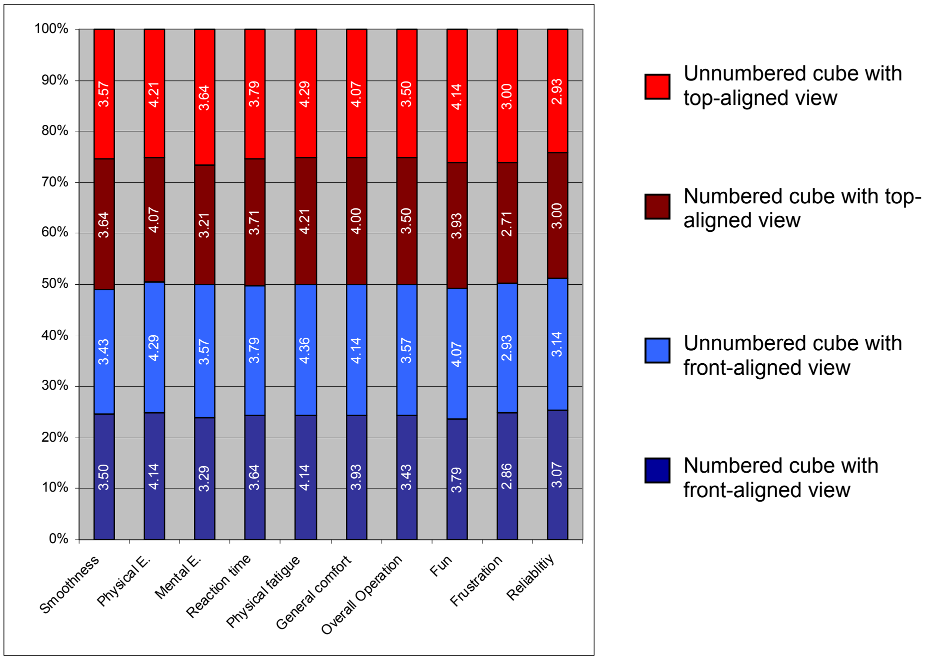


Figure 4.10 Dependent Rating, attributes against four sets

4.4.2.2 Independent rating scale

The independent rating scale was designed to provide us general information about users' acceptance towards the Cubicle application as an input device. For this reason, we came up with ten attributes that we wished the participants to evaluate on a scale 1 to 7, with 1 being poor and 7 being good. The following table (table 4.4) gives an overview of the attributes and the items that were intended to test.

Whilst they made no distinction between the conditions the participants did give substantially different ratings to each attribute. Figure 4.11 summarises the average rating for each attribute. "Smoothness" and "Reaction time" have the average of 3.98 and 4.00 respectively. We suspected this was due to the reliable wireless link and the matrix smoothening algorithm that results to a smooth 3D rendering.

The scores for both "Physical effort" and "Physical fatigue" which are 2.07 and 1.36 respectively, and the high score of 4.93 for general comfort tell us that the application was quite comfortable that requires low physical effort and results less fatigue. Nevertheless, it was found that participants required quite high "Mental effort", with average of 3.36, in relative to "Physical effort". The "Reliability" of the application was thought to be not as good as it scores less than the average: 3.29. With "Frustration" scale rating describes 1 as the least and 7 as the most, the average score of 3.57 clearly shows some of the participants' disappointment when encountered with the application.

Smoothness	Wireless transmitting
	Speed of driver processing
	3D rendering
Physical effort	Weight and measures of the Cubicle
Mental effort	Application usage
	Miscalibration
Reaction time	Wireless transmitting
	Speed of driver processing
	Usability of full screen toggling
Physical fatigue	Design of full screen toggling
	Weight and measure of cubicle
General comfort	Checking overall impression of the handling (comfort wise)
Overall operation	Checking overall impression of the handling (technology wise)
Fun	Playfulness of interaction
Frustration	Application design

Table 4.4 Attributes and their descriptions

The "Overall operation" was rated 3.71 as its average which marks a positive performance. Most interesting though was that the rating for "Fun" was the highest of all. This would of course be largely connected to novelty, but given the many frustrating and difficult aspects of several of the conditions this was perhaps surprising and shows the potential for Cubicles for playful interactions reinforcing previous anecdotal work (Block et al., 2004).

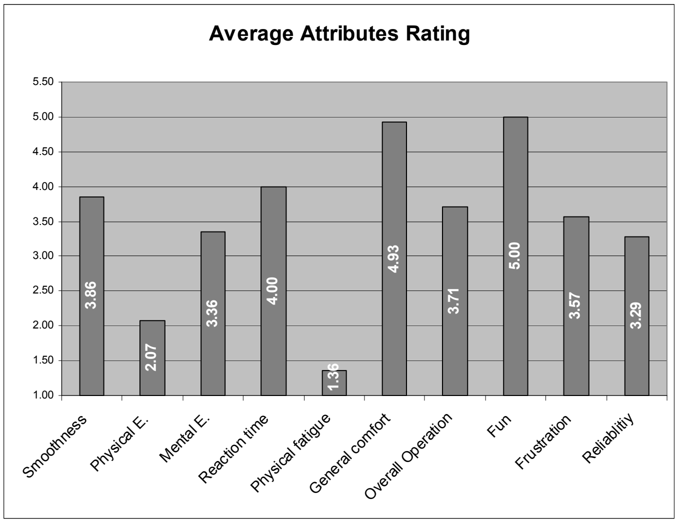


Figure 4.11 Average property rating

4.5 Comparison with Interaction Principles

In this section, the results from the observations and recorded data are compared with our interaction principles, and against the suggested mappings that we described earlier in section 4.2.3.

The visibility of each side of the cube, which exposed the six states of the Cubicle, directly informs the participants that the cube has six different states – this is emphasised with the labels of numbers from 1 to 6 on the sides. This also led the participants to play around with the cube by bringing one side to the front, sides, back, top, or bottom to reveal a different number (or three the most) at one time.

Hidden states were closely correlated to the exposed states in the way that the hidden states revealed themselves depending on the movement of the physical cube. Moreover, hidden states proved to be an important feature that we could use in order to integrate more and different variety of functionality.

The suggested mappings of controlled state, inverse actions, and tangible transitions proved to be an excellent ways to integrate other kinds of functionality onto a tangible device. These, no doubt, enrich the way the participants interact with the cube.

4.6 Discussion

The physicality of the device, i.e. the Cubicle itself, and its weight, is vital matters *per se*. The study has determined that the size of the cube led the participants to hold the cube with two hands instead of using just one (only one participant, who is expert in juggling, held the cube with one hand). By holding the Cubicle with two hands, the choices of manipulations are more in variety, i.e. the participants can rotate, flip, twist, and turn. There were few participants who started off with one hand, but changed to two hands shortly afterwards, as manipulation with one-hand could only allow them to rotate the cube along y-axis. The only participant, who manipulated the cube single-handedly with his right hand, used his left hand to rotate the cube along x-axis.

From the results, participants could not distinguish the difference between the front aligned (NF, UF - red background screen) and the top aligned (NT, UT - blue background screen). The results, however, showed that in average, participants performed faster when they were in top aligned (NT, UT) condition. The participants, surprisingly, hardly looked at the physical cube as they manipulating the Cubicle. Calibration barely occurred. The order of which alignment goes first didn't give any significant effects on the results (see ANOVA result – 4.4.2).

We observed that those who tried very hard to calibrate the mappings between the physical cube and the virtual cube normally resulted to frustration. This scenario often took place when participants handled the numbered cube. Added with the fact that they didn't get the orientation correct, whether it was front aligned or top aligned, worsen the scenario. Thus, when dealt with unnumbered cube, participants were more freely to rotate and orientate the physical cube. Unnumbered cube has successfully brought smiles to their faces, especially after they failed to calibrate in with the numbered cube.

It is very interesting indeed to discover that what we thought about correct physical-logical mapping (calibration) plays extremely important role when it comes to tangible devices, especially when one deals with the Cubicle as a medium to control media applications, was not exactly true. Although all participants initially attempted to calibrate the cube with the one on the screen, it just seemed to be an impossible thing to do. We will see more about this in the next chapter.

Other findings, from the comments received, highlighted the facts that aesthetic is such a salient feature in the design of a tangible device, for instance the texture of the cube, sounds, weight and lights, and how important it is to make it fun to use. In addition to this, it is fascinating to see how participants thought of the blue and red screens. The different background colours that were supposed to distinguish how the cube is controlled (by referring to its front or top views) have been misinterpreted. Instead of discovering the different ways to control the Cubicle, participants commented on their preferences on colours, i.e. which environment is more comfortable. In addition, it was suggested that the cube to be covered with different textures on the sides, incorporate sounds and has flashing lights. Textures and sounds would be highly significance for visually impaired. And to overcome the 'select' problem, they suggested some buttons on the cube to select once preference is made.

4.7 Conclusion

The exploratory design study on the Cubicle has, among other things, given us the opportunity to apply the conceptual design questions on the application of the Cubicle. Although the ultimate aim of the Cubicle was to find which form of interface suits users better and whether this encourages playful experience, the study has enabled us to witness the interesting nature of calibration between the physical and logical mapping. Because of the nature of the Cubicle being untethered, the characteristics of the suggested designs are not exactly similar to what we have seen with today's appliances and devices. Nonetheless, we will see how one particular design characteristic plays its role in assisting user with the Cubicle interaction in the following chapter. In which, we will return to the nature of calibration that occurred in the Cubicle user study in the light of cognitive and physical mappings.

In short, this chapter can be concluded as follows:

- the experiment has given us the opportunity to apply the concepts of the physical design characteristics in the design development of the Cubicle
- although it is possible for us to use the same techniques which we carried out on today's devices and appliances, i.e. the STNs, on finding the possibilities of the tangible's functionality, the nature of the tangible devices, such as being an unthethered and a passive input device, it is strongly recommended and advised to adopt and use the conceptual design principles in the design of tangible devices
- despite the constant breakdowns when manipulating the Cubicle, participants thought it was fun and enjoyable, and they successfully completed the tasks

Chapter 5

Interaction in Focus

Previously in Chapter 3, we have studied closely the physical–logical mapping relationship of everyday appliances and devices, in order to understand what makes them comprehensible. To complete our understanding of interaction between the physical–logical relationships, we now include the third entity in the existing interaction: the user. The user entity is never absent in an interaction, but so far in this thesis, its presence has only been implicitly described. By bringing in and highlighting the user entity, we will be able to discuss the relationships between the user and the physical states, and between the user and the logical states.

This chapter begins by introducing a triangle that depicts the nature of interactions that exist between the three entities: user, physical and logical (section 5.1). As we already discussed in detail the physical–logical relationship in previous chapters, we will now focus on the two relationships: user–physical and user–logical.

Each relationship will be elaborated and described from these two aspects: cognitive and feedback. The cognitive aspect will describe each property with regard to the level of mental effort one has to put in, which is categorised into: low-level cognitive and sub-conscious. We will see this in section 5.2. In the same section, we will also introduce a spectrum of levels of cognitive understanding which incorporates the design principles and the implicit design properties found from Table of Interactions from Chapter 3. The spectrum will assist us in understanding both physical-user and logical-user relationships.

In section 5.3, the two relationships will be discussed from their feedback aspect. In this section we are able to identify whether the results of feedback come from user's action or from the change of state alone, or both, and we do this by using status/event timeline diagrams.

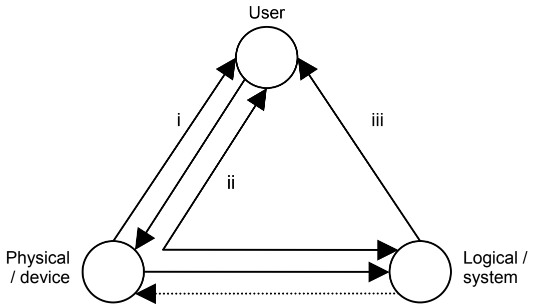
Section 5.1 to 5.3 discuss heavily on interactions that emphasise on the coherency of mappings between physical and logical. Whilst this is vital in ensuring an interaction is comprehensible, thus, making it a success, incoherency, on the other hand is not a failure. In section 5.4 we will be looking at the mis-calibration between the physical and logical mappings. We will recapitulate the conspicuous scenarios from the previous user study; the Cubicle from Chapter 4, to discuss in detail about the incoherency that occurred. Finally, we will introduce the term *visceral interaction* which emerges from the Cubicle study that plays such a significant role in assisting the users in manipulating the cube.

5.1 Physical, Logical and User

In previous chapters, the interaction has been emphasised on the relationship between the physical and the logical states. The user entity is never absent in an interaction, but its presence has only been implicitly described. By highlighting the user entity in this section, we will be able to discuss the relationships between the user and the physical states, and between the user and the logical states. Figure 5.1 diagram illustrates a triangle that depicts the nature of interactions that exist between the three entities: user, physical and logical.

As users, the way we usually perceive a physical device is we never or hardly think of physical and logical states as two separate states. This unity way of perceiving and understanding is part of a process which is described by Norman as bridging the gulf of evaluation and execution (Norman, 1986). Bridging these two gulfs is the psychological interpretation of user's goal and physical system, in which the physical system is the unity of physical and logical states. Although this is ideal, as it makes it simpler to understand, there are times when understanding of states independently becomes convenient. For example, when a kettle which we use everyday doesn't work as it should be, we can 'guess' what is wrong by separating the states.

In order to enable us to examine how interaction works, we separated the three states: user, physical and logical, independently (as presented in the triangle, figure 5.1). Whilst Norman's two gulfs unite the physical state and the logical state, here we have the logical state separated from the physical state.



i. User–physical two-way interaction relationship
ii. User–logical, via physical, two-way interaction relationship
iii. Logical–user one-way interaction relationship

Figure 5.1 Physical–logical–user relationship triangle

As shown in (i) in figure 5.1 above, the user entity has a two-way interaction with the physical/device entity. In this relationship, the physical entity is referring to its physicality alone, hence, this refers to how user would perceive the features of appliances and devices to build their understanding of the device. In figure 5.2 below, we are able to see how user's perception of a physical device leads to building of understanding, hence leads to action, which follows with feedback.

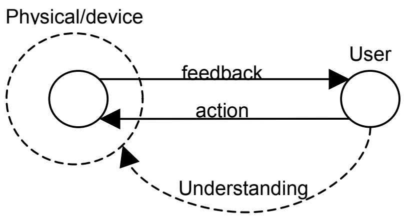


Figure 5.2 A two-way direction of interaction

The relationship with the logical/system entity, on the other hand, is rather peculiar. It has a two-way interaction between the user and the logical/system via the physical/device entity, as shown in (ii), and a one way interaction, in which the user receives signals/results from the logical/system entity (iii). The two-way relationship via physical is best described as a relationship which the physical entity is only used as a medium to realising a logical functionality that also sometimes can exist in a rather more abstract form. For example, a mouse is used to move a cursor on a screen. We will see more of this in 5.2.3 and 5.3.2. The one-way interaction, meanwhile, only involves feedback which a user receives from the logical state. Although this seems as if there is absolutely no physical device involved, it is not entirely true. The logical feedback is still physical, but just not directly related to the physical device. For instance, the logical feedback to toasting a slice of bread using a toaster would be the bread being toasted. More about this relationship will be mentioned in 5.2.4 and 5.3.3.

The following sections, 5.2 and 5.3 are our attempt to describe what entails between the user–physical and user–logical relationships from these two perspectives: cognition and feedback, respectively, by incorporating the design principles and implicit design properties (from chapter 3).

5.2 Cognitive Aspect

Cognition is part of human information processing system, and is suggested by Kantowitz (1989), that cognitive stage is a central processing or thought stage where the new information is compared with current goals and memories, transform the information, make inferences, solve problems, and consider responses. In our discussion which is concerned with our approach to understand physical functionality, we describe cognition as an aspect which is involved in the interaction according to its 'complexity' with regard to mental effort that one has to put in.

By referring to section 2.3.1, clearly there are two types of information processing: conscious and sub-conscious. In addition, there are also two types of knowledge: learning and tacit knowledge. This understanding, together with our attempt in elaborating the relationships with regard to the design principles, we categorised cognition into two categories: low-level cognition and sub-conscious.

We consider *low-level cognition* as a process that occurs when the user has to think deeply in order to maintain the interaction. Knowledge around the user or anything visceral about the system is limited to help the user performing an action. Low-level cognition requires a little more of mental effort from the user's part, either the knowledge has to come from his memory, or, it has to be developed over time.

Sub-conscious category is what we described as something that is close to Norman's knowledge in the world (Norman, 2002) and distributed cognition. When the knowledge is in the world, the less effort is required for a user to think or to remember how to work things out. A structural arrangement, for hobs and controls on the kitchen stove for instance, results to natural mapping which actually assist us in performing an interaction; right means right, left means left. And when there is hardly any mental requirement required, the design principle(s) is said to be close to a natural thing.

We also see visceral aspect of interaction, which is all about the notion of momentary-ness, i.e. the understanding about the interaction exists in such a fluid moment to moment connection to be belonged in the sub-conscious category. For instance, when someone is reversing a car, the only moment the driver is able to reverse the car correctly is when the driver's attention is not on the mapping, but on the visceral. When the driver is 'aware' of what he is doing, he can no longer get the car reversed (or he will take slightly longer time than he usually does). We will see more about visceral in section 5.3.

To help us in our discussion in elaborating further the relationships from the cognitive point of view, we will be using the following diagram (table 5.1) as a guide. The following diagram illustrates the design principles against the two cognition categories and the spectrum of mental requirements and cultural influences.

- mental requirement - the level of mental effort one must put in,
- cultural influence - how our experience with physical devices and appliances shaped our understanding in interaction, which among others include our familiarisation of artefacts from past experience, and different age group.

The position of each of the design property across the table is decided upon our description and understanding to assist us in our analysis, hence due to their fuzzy boundaries, and from other point of view, the properties may be positioned differently.

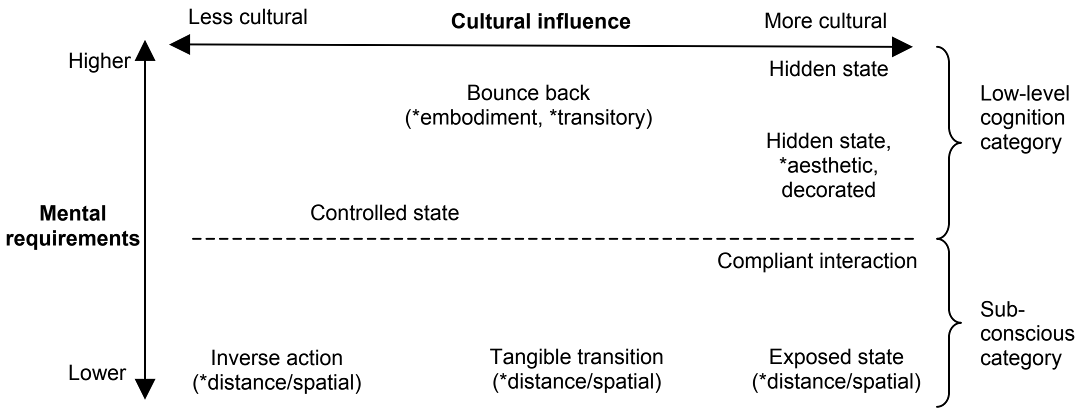


Table 5.1 Design principles according to mental requirements and cultural influence

5.2.1 User–Physical: Low-level cognition

In this category, we will discuss how the hidden state, bounce back and controlled state properties, are being positioned across the table, from the ***low level cognitive*** understanding.

When a user encounters with such physical device, the user normally identifies or comes to recognise how to use and interact by trying to remember from memory of any other features which resemble the physical device (Dourish, 2001, Norman, 2002). The user will try to relate and associate what one sees with their familiarisation of other objects (c.f. Norman's 7 steps). If by recalling method does not work, the user just simply has to learn the way to interact with the physical device.

5.2.1.1 Hidden state

Physical controllers that lack of exposed state often embody hidden characteristic design to make their associated functionalities associated more visible. It can be difficult at times for users to instantly know what the physical controller actually controls, as there no visible or clear indications of what aspect of logical state is connected to the object or the device, nor there is any clear mapping that shows the relationship. This is the precise description of the hidden state from table 5.1, which is positioned at the top right hand corner, with high mental effort. But this level of thinking requirements is compensated by our familiarisation of other physical things that we have encountered before. This familiarisation is what we considered as cultural influence. But some physical devices which are rather abstract or ambiguous will require a lot more mental effort as it requires learning.

5.2.1.2 Aesthetic, decorated

Nonetheless, this type of physical controls can now be found to be decorated to enhance the associated logical meaning. The two common alternatives that these devices and appliances normally adopt are the provision of additional details, for example, the dotted lines which increase in size and marker (pre-use information), and the allowance of exploratory and discovery while using the objects, for instance the changes or increment of volume or light as the knob is being turned (whilst-using information) The latter is often described as semantic feedback, which is also close to type (iii) in figure 5.1 triangle. This information, which can also come in the form of visual or audio, to an extent help to lower the user mental effort. Examples of appliances that fall into this category include menu buttons on mobile phone, and volume controller on radio. A rather ambiguous physical device with lack of information is considered to belong to low-level cognitive as learning is required.

5.2.1.3 Bounce back

Bounce back's unsymmetrical mapping between its physical state of its control and the logical state it controls often creates confusion for the first time users. Owing to this phenomenon, it often requires an amount of user's mental effort to recognise and familiarise with the mapping relationship, especially when the bounce back affects the physical control to return to its original position whilst the functionality logical state remains unchanged. And as the feature of bounce back almost become the silver bullet when it comes to designing compact yet powerful control devices like the mini disc controller, users have become used to this design and since then had developed their understanding of the way bounce back feature works. The two implicit features - *transitory* and *embodiment*, although closely correlated to bounce back, are inconspicuous to users. We see that once the understanding is attained, users normally become 'unconscious' in the what-I-do-next loop. Figure 5.3 shows how one understanding grows as he/she involves in the interaction.

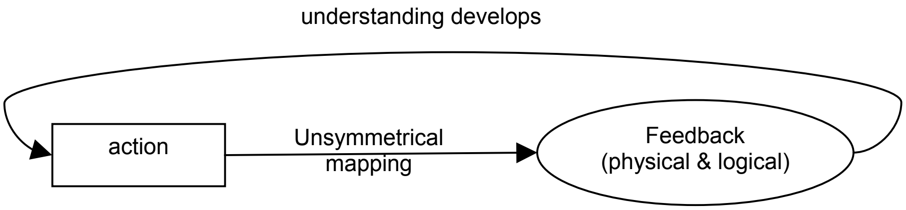


Figure 5.3 The bounce back effects – physical and logical, inform the existence of unsymmetrical mapping due to the transient state. An understanding of the system is then, however, established

5.2.1.4 Controlled state

Semi-controlled artefacts, such as the toaster, have limitations to what users can do. We consider this characteristic to require a higher mental effort than the sub-conscious category's design features due to the fact that the limitations have to be learned by users in order to understand the interaction of the physical controls. Despite having similarities to exposed and hidden state, by learning that the semi-controlled artefacts have limitations to what users can do, then only the users can understand how the physical devices work.

Unlike the rest of the design characteristics that reside in the low-level cognition category, the controlled-state design feature is not as much as applied in the appliances. Hence, we see the controlled-state characteristic to have less cultural influence. The mechanical design form encourages exploration for people who have limited experience with semi-controlled artefacts.

5.2.2 User–Physical: Sub-conscious category

Sub-conscious category is when the mental effort that one has to put in is low. The following describes this category by looking at each design principles and some of the implicit design features.

5.2.2.1 Exposed state

In the simplest form of exposed state, it offers a direct one-to-one mapping to user, to instantly tell the user of what it is and what can be done to it. A switch, which we normally find on the wall, would be the best example to exemplify this. The switch has two physical positions – up and down, to control, in the logical term, two functionalities, which by norm means on and off. These two movements alone, which bring the physical (controller) to two different positions, distinctly show the two physical states, even without them being associated to any logical meaning or functionality. For instance, a light switch on its own, i.e. not wired on the wall, clearly suggests to us its two physical states. Thus, lower mental effort is required for user to apprehend how to manipulate this type of physical form. In addition, switches among others, have come known to us for longer than us all can remember, and thus become the most cultural part in our lives. We encounter with these physical controls everyday that we become sub-conscious when we interact with them.

5.2.2.2 Compliant interaction

The washing machine dial, which exhibits compliant interaction design characteristic, is an example of a complex exposed state. The dial shows the chosen program and when a wash is in progress it also shows the current state of the wash cycle. When compared to the simple physical controls, the complex exposed state physical controls require a slightly higher mental effort from the user part. But as complex as these devices can be, they still are no strangers to us. Due to strong cultural understanding we already have such type of devices assist us in recognising how to use and interact with them.

5.2.2.3 Tangible transition

Certain physicality of controllers embed a characteristic of tangible transition, which emphasises the critical transition as the controller is being manipulated, for example, the iDrive dial knob. As this feature is ultimately about *feltness* that is experienced by users as they interact with the devices, we consider the act to be sub-conscious because the user, technically, has nothing to think about. The devices which have tangible transition feature use their physicality to make users aware of the transition between one logical state to another. Because the fact that tangible transition are not widely embedded in most of appliances today, if compared to simple exposed state, we consider it to have less cultural influence.

5.2.2.4 Inverse action

Inverse action, which situated at the other end of the cultural influence spectrum (less cultural) shows that this feature comes naturally to user when compared to the previous characteristics. Inverse action is simply the reverse manipulation, or act, of the first action. Inverse action, we believe, is very innate to human nature. Due to this, unlike exposed state characteristic, if we observed humans who lived thousands of years ago, inverse action would be the response movement when something goes wrong. As this action, at most of the time correlates to the reflect results, thinking hardly exists in the process, thus lower mental effort from the user part.

As we humans are very used to the concept of ‘opposite’, we usually expect our action or performance to be able to, in some way, reversed – e.g. push-pull, in-out and left-right. The inverse action property reflects this natural behaviour, which describes the intuitive nature of human being. As this becomes naturally to users, learning is not required, and it is especially important if the user does not have a perfect knowledge of the physical-logical mapping, hence reduce the risk of getting the ‘wrong’ action. We will see how inverse action assisted users in coping with incoherent physical-logical mapping in section 5.4.

5.2.2.5 Distance / spatial characteristic

Despite the differential of the cultural influence, the common implicit feature we have found across the sub-conscious category is the distance/spatial characteristic. Some of the examples of the physical controls of the exposed state, for instance, ceiling light, and iDrive dial knob for tangible transition, shows that although the association between their physical state and the logical state can be quite a distance, but due to our strong cultural influence, we can still understand and manipulate these physical control, which do not require a lot of mental effort. And for inverse action, as it is more about the natural ability to undo an action, the matter of distance that exist to its logical state, does not affect the level of mental effort, which is minimum.

5.2.3 User–Logical Relationship via Physical

Interactions of most appliances and devices we found today are heavily emphasised on their physicality which are closely connected to their underlying logical functionality. The user–logical relationship via physical, in the contrary, is best described as a relationship in which the physical entity is only used as a medium to realising a logical functionality in a rather more abstract form. One example which can exemplify this relationship is dragging a cursor via a computer mouse.

If we refer to table 3.1 from Chapter 3, using a PC mouse to drag something has the characteristics of both hidden state and embodiment. From the cognitive point of view from table 5.1, dragging a mouse in order to move a cursor on a screen is supposed to be requiring an amount of mental effort, due to its abstract nature of mapping between the mouse in our hand and the cursor on the screen. Theoretically, this may sound correct, but as we have become so familiar to the application of a PC mouse, our way of perceiving this particular application has changed. Our understanding of this application and the cultural influence result to lower mental effort from our part.

5.2.4 User–Logical Relationship

As mentioned earlier in 5.1, this one-way interaction, which only involves feedback from the logical state, is still physical – but not directly related to the physical device. The examples of toasting a slice of bread, and turning up a volume speaker, describe the logical state of bread being toasted and sound (volume) being increased. Both do not directly related to toaster, and speaker. This type of relationship does not require higher mental requirements as the feedback of the logical state is conspicuous and easy to comprehend, thus it belongs to sub-conscious category.

5.3 Feedback aspect

There are many things that can result to feedback. The feedback may be the results of users' actions, or it may be the result of the change of state(s) alone. In this section, we will be able to see, by using status/event timeline diagrams (Dix et al., 2004), the iteration of feedback of each property, hence identify the cause of feedback. In 5.3.1 we will see how feedback is caused in the user–physical relationship by looking at every design principles. Section 5.3.2 describes the user–logical via physical relationship, while section 5.3.3 describes the relationship of user and logical.

5.3.1 User–physical relationship

By nature, the three relationships: user–physical, user–logical via physical and user–logical, are not that separate. In the following status/event timeline diagrams, you will be able to see this, as we will denote each type of the relationship by inserting (i), (ii) and (iii) from figure 5.1.

Exposed state

When there is an exposed state, the feedback of an action normally comes in two forms:

a) the change of the physical state,

When an action is performed on a physical device (controller), devices with exposed state, usually, and consequently, shows a distinct and a clear position of the corresponding physical states. An exposed state has the advantage of providing a freedom to users as per manipulating the physicality due to the clear direct mapping between a performed action and the physical state.

b) the change of the logical state

> The change of the logical state refers to the change of the underlying functionality. The feedback, at most of the time corresponds and meets user's expectation, and sometimes it may not, as this depends on cultural influence. For instance, the on/off switch in the UK and in the US didn't meet the British user's expectation while he/she is in the States.

We will be able to see the changes of both states, represented in thick lines, in the following figure 5.4 status/event timeline for switching on a ceiling light.

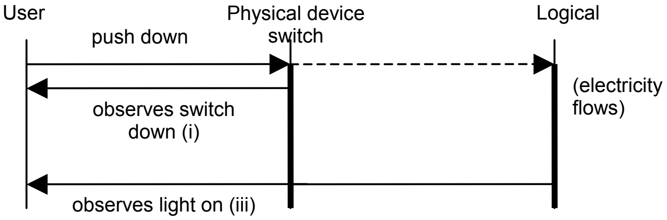


Figure 5.4 Exposed state – ceiling light switch

Hidden state

In contrast to exposed state, depending on how user understands the pre-use information to exert action on the physical control, or explore the physical control to discover the whilst-using information, the action performed by the users triggers the instantaneous feedback to inform users of the missing details, such as the logical state of the device. For certain type of appliances, it also informs users of the current physical state, although this current state does not specifically represent the actual logical state. If we take a volume controller of a speaker for instance, the dotted lines (pre-use) which increases in size from one end to another, inform us that the 'effect' (which we presume this would be the volume) will increase.

The feedback immediately informs us the effect of rotating the knob would adjust the volume of the speaker. This type of feedback, which in a way guides us in manipulating the controller further, is similar to what Wensveen et al's (2004) described as *feedforward*. The result of an action for the hidden state, comes in two forms: the change of the logical state, and the physical state. The latter state, however, is not conspicuous, i.e. there is no direct mapping that ties the physical appearance to the logical state. This is shown by the descending arrow in figure 5.5 below.

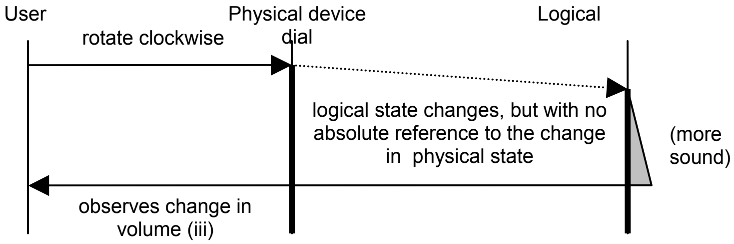


Figure 5.5 Hidden state – speaker

Controlled state

There are two parts to feedback of controlled state as the result of user's action. The first part consists of feedback that is caused by user's action in which caused the change of both the physical and the logical state. And due to the controlled state feature, the second part of the feedback is not caused by user's action but by the controlled state itself which results to the change of both physical and logical states. The following figure 5.6 is an example of the status/analysis timeline of a toaster.

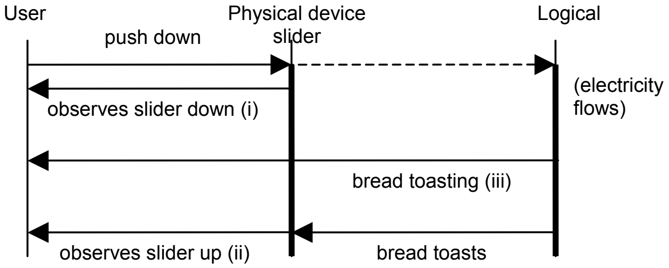


Figure 5.6 Controlled state – toaster

Bounce back

Transient state and unsymmetrical mapping are the two notions which explicate bounce back feature. We have learned that although through this feature the logical states can be clearly distinguished, these states are yet incoherent to physical states. For physical controller which exhibits exposed state, for example the on/off power button of a PC machine, the button bounces back to the 'out' state as soon as the pressure is released, hence there is only a single stable exposed state. In this situation it normally relies on a screen display to show the present state of the system. Things are more exploratory for the physical controllers of hidden states, which can be obviously confusing but rapidly learned by users from the effect of manipulations, which can either be as soon after the pressure is released or during the transient state itself. For instance, the velocity of a minidisk controller determines the changes of track or the speed of a track.

We can never discover the transient state, or the effect of bounce back, until we manipulate the physical control. The process seems to be interrelated, but not the same, and related, but separated. The feedback of bounce back is resulted from the user's action which changes, temporarily, the physical state that triggers the change of the logical state. The physical state was said to be temporarily changed (shown by the short thick line in figure 5.7), as once the user's finger is lifted, the physical state bounces back to its original position. The momentary act of pressing down the button causes the change in the logical state.

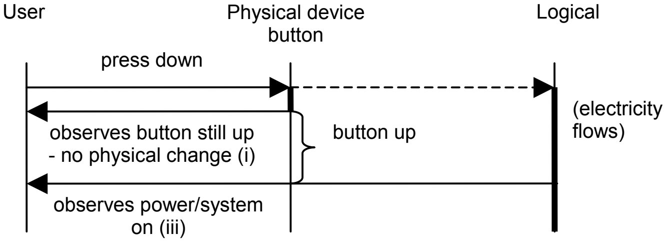


Figure 5.7 Bounce back – PC on/off button

Inverse action

Inverse action is about exploiting the natural physical inverse action. User may instantly see and understand the relationship between the physical and logical mapping from the artefact that exhibits exposed state, but a user must first perform a semi-exploratory action on those artefacts which normally feature additional signage or label of the logical function that the physical form supports. The instantaneous feedback feed into our understanding of the existence of the reverse effect of inverse action. And we see the status/events analysis for inverse action as the combination of two status/analysis of the exposed state when the control exhibits this feature, or the combination of two hidden state when the control has a hidden state. By performing an action on the physical controller which allows user to perform the opposite direction of action – rotate clockwise/anti-clockwise, slide left/right, push up/down, gives users the inverse effects of the underlying logical function, as shown below in figure 5.8 and 5.9. Different colours denote changes in physical and logical states.

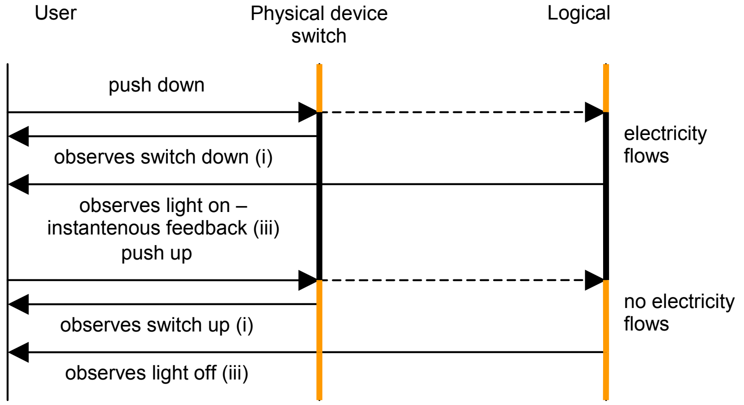


Figure 5.8 Inverse action for exposed state – ceiling light switch

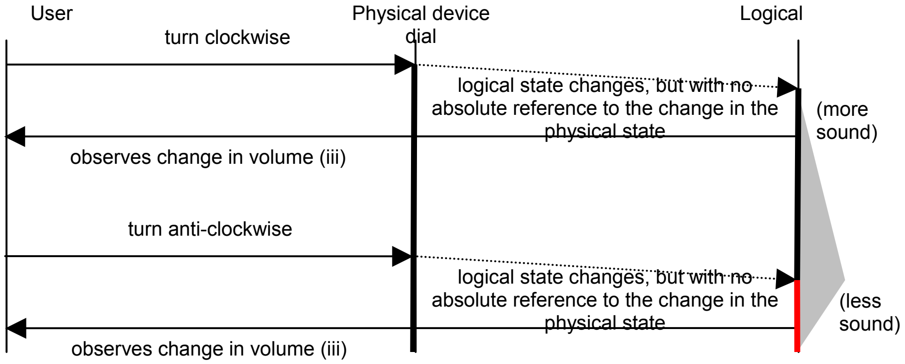


Figure 5.9 Inverse action for hidden state

Compliant interaction

The symmetrical interaction that exists between the user and the system makes it easy for the user to learn the relationship between the state of the control and the state of the device, as the control advances when the program advances in the same way the user would interact. As the compliant interaction is the complex phenomenon of an exposed state, the feedback process is not much different, except with the additional entity of an agent. The following figure 5.10 describes the status/event analysis for a washing machine. When the dial is being rotated, the user observes the change of the physical state. As the logical also undergoes a change, the user also observes program being advanced. And when the agent rotates the dial, the user now observes the changes in both physical and logical states. Different line colours denote changes in physical and logical states.

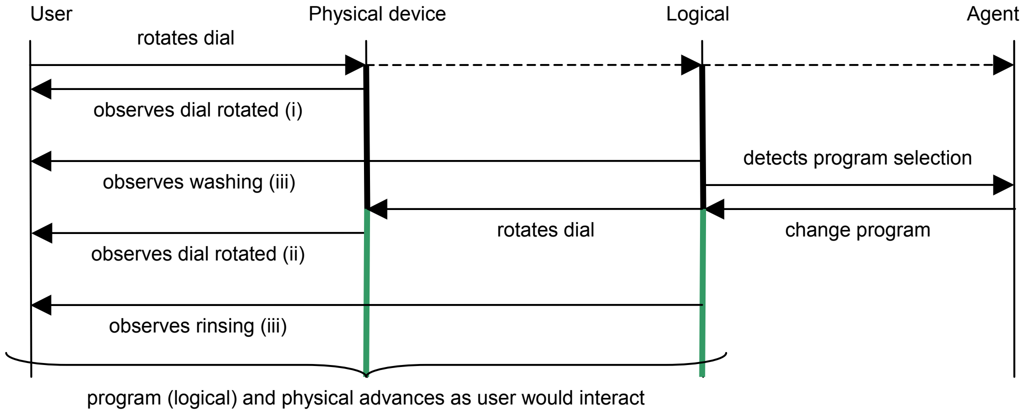


Figure 5.10 Compliant interaction – washing machine

The clear relationship enables the expert user to exert fine control over the system's action, as illustrated in figure 5.11.

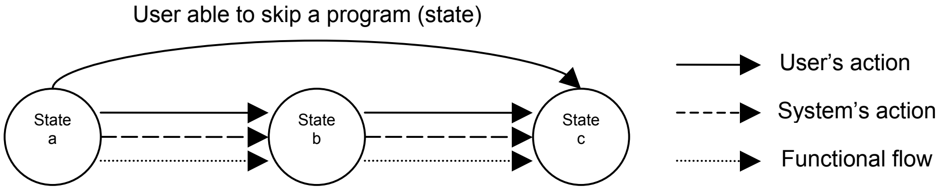


Figure 5.11 An illustration to an example of skipping action performs by a user

5.3.2 User–logical relationship via physical

The following figure 5.12 illustrates the status/event analysis for dragging a mouse PC, from section 5.2.3. A user observes the cursor movement as a result of the movement of the mouse. Here, the mouse is used as a medium to realising the logical functionality in a rather more abstract form. Other examples include those which have been marked as '(ii)' from section 5.3.1.

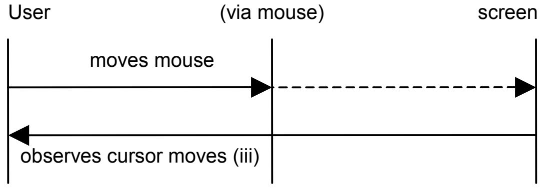


Figure 5.12 status/event timeline for dragging a mouse

5.3.3 User–logical relationship

The second form of interaction between the user and the logical entity is the one-way interaction from the logical/system entity to user, hence it only involves feedback. The logical feedback can also be of physical feedback. With physical, it does not refer to everything in the physical world. For example, a user feels a haptic feedback as he moves the mouse. Other examples include those which have been marked as (iii) in status/event timeline diagrams in section 5.3.1.

This nature of relationship can also be seen as a separation that exists after an action has been performed on the physical/device. The situations that best described this one-way interaction are when the artefacts exhibit implicit features of temporal locality (delay) and distance/spatial. The sense of separation between the action which has just been performed and the result, is best described in artefacts such as electric cooker, for temporal locality, and outdoor ceiling light switch, for distance/spatial. Figure 5.6 (toaster) in section 5.3.1 above illustrates the status/event of feedback which occurs over/after a period of *t* time – temporal locality.

5.4 Incoherency in Mappings

The relationships we have covered so far shows how vital it is to have, or to create, an understanding of the interaction between a physical control (artefact) and logical functionality. We have also witnessed the importance, to some extent, the coherent in interaction between the mapping relationship and feedback. But in some occasion, these are not necessarily valid. In the following section, we will discover the mis-calibration in interaction and how our cognitive mind works and cope in situation like this.

5.4.1 (Mis)calibration

The previous user study; the Cubicle, revealed that tasks completion did not 100% rely on correct calibration between the physical cube and virtual cube. The more effort they put in to correct the miscalibration, the more frustrated they became. Without worrying about the mapping (calibration) resulted to more playful, fun experience, as it was more about intuitiveness rather than effectiveness of a device.

To recapitulate, the participants all followed the same general pattern during the experiment. They commenced the first few steps of each condition with an attempt to establish a correct mapping between the physical movement and its effect on the screen. But this exploration did not last long. We could see the participants struggled trying to match their movement with the movement of the virtual cube on the screen, and consistently failed, even when there were numberings on the sides of the on-screen representation that were intended to help. On a few occasions they were able to briefly establish calibration, but they were not able to maintain this. The participants were clearly quite frustrated. Eventually the participants abandoned their attempts to calibrate and understand the cube mappings and then proceeded to successfully accomplish further steps. Over subsequent trials, independent of the order of conditions, each participant's attempts to calibrate became progressively shorter before abandoning the attempt. However, despite all this, they still managed to successfully complete tasks, and enjoyed it at the same time.

We anticipated the act of calibration between the Cubicle in their hands with the virtual cube on the screen from the participants – but this was hardly occurred. Instead, what we observed was a similar pattern of manipulation act toward the Cubicle – participants heavily relied on *visceral interaction*. They more focused on the screen rather than on the physical device and responded appropriately to feedback.

5.4.2 Visceral Interaction

Let's consider this scenario, if you have ever driven a car in reverse using mirrors you may have experienced something like the following:

(a) you look in the mirrors and try to turn the wheel in the 'right' direction but you keep getting it wrong – it is the opposite way round to what you are expecting
(b) you then stop and perhaps work out which way the wheels will go as you turn the steering wheel
(c) you then very fitfully move the car, small turn by small turn, in the right direction
(d) suddenly you find yourself just driving effortlessly backwards

(e) then something goes wrong, you over steer slightly, go too fast, an odd angle in the road, and it collapses – you are back to stage (a)

Our interactions with the physical world operate at many different levels from explicit concrete reasoning “if I put a long stick under the rock I will be able to move it” to instinctive motor feedback: hand jumps back from sharp point. Between these we have tacit knowledge, for example, if a cup begins to fall we move our hands beneath it to catch it because of gravity, but without thinking explicitly about it.

Note how the stages in the above car reversing task are operating at these different levels. Steps (b) and (c) are at an explicit reasoning level. In order to do this the car has to reveal enough of its operations for you to be able to infer the mapping between actions and their effects on the car. Your ability to do this with the car, and with a device in general, depends on your own mechanical understanding and also on the extent to which the device reveals its mapping to you; that is its affordances (Norman, 2002), or in the case where information may be deliberately exposed to augment this is called *feedforward* by Wensveen et al. (2004).

Step (a) is addressing something a little ‘lower level’ in our mental functioning. If you were an experienced truck driver or used to reversing using mirrors something about the situation of sitting, looking in the mirrors would trigger learnt reactions and you would simply drive backwards without thinking about it. This happens in all types of motor learning: when a user chooses to use a mouse upside down, in the classic experiments where people wore left–right reversing glasses, or when you practice a finger sequence on a guitar or a move in martial arts. Our human ability to achieve this for technologically enhanced interactions, such as mouse–screen, is amazing and it has been suggested this has its origins in the skills needed for very early tool use (Dix, 2002).

So what is happening at stage (d)? Clearly, this is more complex than a pain–withdrawal response as it involves hand–eye feedback. However, neither is it a sign that the ‘driving backwards’ action has become learnt as the breakdown in stage (e) tends to be pretty much back to the beginning. At this point a more generic behaviour seems to be in play: "if you do something and the response is 'the wrong way', just do the opposite". Even though when reversing using mirrors the action–effect mapping is the opposite to driving looking over your shoulder, still it preserves a crucial property: opposite actions have opposite effects. We have previously called this property the *natural inverse* (chapter 3, 3.2.6 inverse action) and have identified it as one of the ways in which our natural responses to the physical world can be exploited in 'fluid' interaction design.

Note that during the tight loop of hand–eye interaction in stage (d) in some way you 'know' the directional mapping. However, this is a momentary knowledge and embedded within the flow of interaction. As soon as the interaction breaks down the 'knowledge' is lost.

In addition, the term visceral we introduced here is different to Norman's visceral (Norman, 2004). Both concern the deep unconscious feel of the device, however, whilst we emphasise on the visceral aspect within an interaction, Norman's visceral, i.e. visceral design, revolves around product's appearance, touch and feel – the initial impact of a product.

5.4.3 Cubicle Experiment

Here, we will recapitulate the Cubicle experiment, as per outlined in Chapter 4, in the light of what we have understood about mappings so far. In section 4.4.2.2, a post-experiment questionnaire of ten criteria using 7 point Likert scales six of the criteria (smoothness, mental effort, reaction time, overall operation, frustration and reliability) obtained average ratings between 3 and 4 giving a baseline. The two ratings for physical effort and fatigue were much lower (2.07 & 1.36), reflecting the fact that the fact the cube had to be held in the air during much of the experiment. However, the ratings for general comfort and, importantly, fun were substantially higher (4.97 & 5.00), demonstrating an overall appreciation of the device, despite its frustrating aspects! In addition to the questionnaire answers, we observed participants enjoying their interaction with the Cubicle and this resulted in a playful, fun experience. Several of the participants commented on this: “good fun :-)”, “great device, enjoyable experience (would like to use again!)”. These participants also spent a longer time watching the trailers.

Why is it that despite failure to establish a mapping the participants were able to successfully and enjoyably manipulate the Cubicle? As previously mentioned, we believe this is due to *visceral interaction*, the physical aspect of device which recruits our natural human abilities. In particular, the Cubicle had *natural inverses*. At any moment the participants did not know how a physical rotation of the Cubicle would translate into rotations of the virtual cube. In fact, not only did they not explicitly know, but because of the lack of calibration there was no stable mapping. However, it was always true that the reverse of a particular rotation moved the cube in the opposite screen direction – a *natural inverse*. This means that without explicit conscious deliberation ‘errors’ would be corrected in a sort of constant exploration of the *momentary mapping*. This is exactly like the car reversing during stage (d) and likewise recruits our natural abilities for physical object manipulations.

From our observations, participants preferred not to dwell on understanding the mapping, especially when their attempts never seem to make any differences. They, rather remarkably, found it easier to manipulate the Cubicle by just paying attention to the visceral interaction. By doing so, the participants didn’t need to plan their action; all they had to do was respond to feedback in a very direct perceptual–motor cycle with apparently little explicit cognitive understanding. Even though the mapping established was strange and ever changing, it was impressive to see how the mind and body works unconsciously in comprehending the physical and virtual movements in order to complete the tasks. This ‘carefree’ and intuitive act seemed to shape their attitudes towards the Cubicle.

5.5 Conclusion

The relationships of user with physical and logical entities, although may seem similar, pose different type of interactions. Whilst the user–physical relationship reflects the trivial two-way interaction, the logical–user relationship has, (i) an instantaneous two-way interaction via physical/device entity, and (ii) one-way interaction from logical/system entity to user.

There is more to just an appearance, or an understanding that one must has before one can begin with the manipulation of a device or an appliance. In the user–physical relationship, we have seen how the design principles which are found from Chapter 3, are categorised into two categories: low-level cognitive and sub-conscious. The categories signifies the amount of mental effort required in order to understand or apprehend before one can start performing an action on the artefacts; higher mental effort for low-level cognitive, and lower mental effort for sub-conscious category. The design principles were positioned according to the amount of mental effort one has to put in, and, how much the cultural reasons have effects on each principle. For instance, at the end of higher mental effort scale in low-level category, we have hidden state design principle, which was positioned at the right hand of the cultural influence scale.

Whilst cognitive understanding discusses the mental effort requirement, among others, the feedback aspect looks at the cause of feedback for each design principle in user–physical relationship, and the characteristics of feedback in user–logical relationship.

The notions that lie in between the user–physical–logical entities convince us how important it is to create and to develop such an understanding for interaction(s) to occur. Whilst this is true in most situations, there are in certain occasions where the coherency between these three entities doesn’t exist in interaction. The momentary mapping situations from the Cubicle study were discussed to exemplify this exceptional situation. Visceral interaction proves how natural inverse comes naturally to users to help them in situations where there isn’t calibration going on between the physicality one is controlling and to what is being controlled.

In conclusion, this chapter can be concluded as follows:

- We believe we can have a better understanding of an interaction by including the third entity – the user, in the physical–logical relationships. By doing so, we were able to discuss the position of cognition, which takes into account mental requirements and cultural influences, in the way we understood each of the design principles

- The status-event timelines is used in the illustrations of the behaviour of each of the examples from the physical appliances and devices. Nonetheless, for our particular study, the timelines are modified to suit the design principles' behaviours, to assist us in finding the causes of feedback for each interaction. This can be clearly seen in the speaker volume example (showed by the triangle shape to depict the increase and decrease in volume)
- When we recapitulated the scenes from the Cubicle user study (chapter 4), despite the breakdowns in the users' ability to create explicit mappings, users still could complete tasks, and found the whole experience enjoyable, we identified the *inverse action* enabled users to construct *momentary mappings* to help them to overcome breakdowns. We call the momentary knowledge that embeds within the flow of interaction as *visceral interaction* – liken to the momentary knowledge that we experience as we try to reversing a car

In the next chapter, we will be looking at the second user study: the Cruel Design, which was designed, ultimately, to observe inverse actions, and to evaluate cognitive and physical performance when mappings of four conditions are being swapped.

Chapter 6

User Study II: The Cruel Design

Interaction works very well when there is coherency in mappings, which leads to an understanding of the concept of mappings between the physical and the logical states. Nonetheless, there are situations where incoherency occurs in mappings. The Cubicle study, which led to the discovery of *visceral interaction*, has shown how natural inverse, which is one of the keys of physical features, assisted in situations like this. Now, we are trying to further observe the cognitive and physical performance in conditions where the mappings of the controller are swapped from its original (designed) mapping. And this is what Cruel Design is all about.

In this chapter, we will report on the Cruel Design user study. The task is to use two joystick controllers to move a cursor from the start box, by following a flashing arrow, and hit the cursor in the target box. The objective of this user study is two-fold: i) to find what plays more dominant role in an interaction – cognition or physical, and ii) to observe whether inverse action is the most common, or natural, act when a mistake takes place. To fulfil both, the Cruel Design program considers four different conditions to enable us to seek what plays strongly in the performance: physical or cognition. The descriptions of the four conditions are stated in section 6.2. The program is also designed in such a way that it would encourage the cursor to be overshot the target box, thus the control movement was not as simple as it was expected to be. This enables us to observe how participants perform when they overshoot the target box. The same procedure is repeated throughout the four conditions.

In the following section, section 6.1, we will present a set of related work which in some ways provides us a broader perspective of input devices. The type of experimental device and how we come to a set of design decision are presented in section 6.2. Section 6.3 consists of details with regard to the experiment, such as procedures, subjects and data measurements. In the next section, section 6.4, we will be discussing the results which have been gathered from the experiment. The results are presented in three main categories: learning effects in both horizontal reaction time and horizontal movement time, statistical analysis on the four types of conditions, and observations on overshoots in different conditions. This section will be followed by a discussion and a conclusion.

6.1 Related Work

The idea behind the Cruel Design is to seek the properties that make things work well by making them difficult and annoying to use (Dix et al., 2005). As far as we are concerned, there is hardly any user study or experiment available for reference, which is purposely designed to be hard, difficult, or annoying to users. Nonetheless, if this particular experiment was to be treated like any other experiment which its ultimate aim is to achieve robustness and effectiveness of a system of two-handed input, Leganchuk et al. (1999) would be the most suitable reference. The study reveals the bimanual techniques resulted in significantly faster performance than the one-handed technique. In addition, this study also shows bimanual performance is far better and faster as cognitive difficulty of the task increases. Among the first experiments which study two-handed input was carried out by Buxton and Myers (1986). Two-handed technique outperformed one-handed technique due to inefficiency of hand motion.

Joystick is the most popular input device in the world of virtual games. Its flexibility of 360 degree rotation and movement, with its precision and reliable performance, give users a sense of in control in the simulation environment. Joystick controller is normally recommended to be used to play PC games such as Flight Simulator 2002, Warbirds 2006, and Heavy Gear for piloting planes and as gun control. In the arcades, joysticks are attached together with the machine to give a more real experience. Games such as After Burner and Gundam are among the most popular games which can be found in the arcades, whilst Star Wars Arcade by Sega uses a joystick not only for piloting planes but as a gun control and lightsaber. Steel Battalion is an example of an XBOX game which comes with its own 'cockpit' like with joysticks attached on it.

6.2 Experimental Device and Application

In our experiment, we have chosen to use two Microsoft SideWinder Joysticks (as shown in figures 6.1-6.4), as they are proved to be easy and friendly to use, and have very subtle force effect that helps in controlling a movement. Although there was an idea in the beginning to use keyboard arrow keys, joystick seemed to be the better physical control as it has stronger physicality characteristic. In our experiment in particular, although the joystick's flexibility to rotate still remains, we limit the mapping of both controllers along the Y axis. This means, the cursor in the program only moves when the joysticks are moved up or down.

The design of the Cruel Design program was motivated by our pursuit in comparing the cognitive and physical performance in both 'good' and 'bad' context. Hence, four combinations between good and poor physical and cognition were designed to create four different conditions in the program interaction. What we mean by, and how, we design every condition are described in the following sub-sections.

i. Good physical and good cognition
ii. Poor physical and good cognition
iii. Good physical and poor cognition
iv. Poor physical and poor cognition

6.2.1 Good Physical and Good Cognition (GPGC)

A tutorial is to be given to participants to allow them to know, and learn, the (initial) mappings of the joysticks along the Y axis. The revelation of the correct mappings, which is visually displayed before the program begins and the provision of mapping diagram on the table, should assist participants in their cognitive aspect. While keeping each pair together along one axis should give a good sense of physical mapping (see figure 6.1).

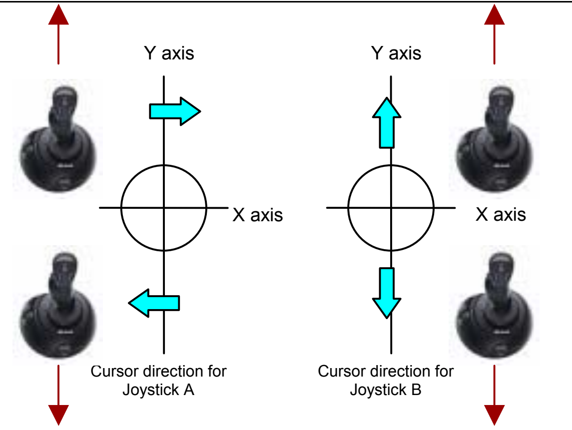


Figure 6.1 GPGC Joysticks Mappings

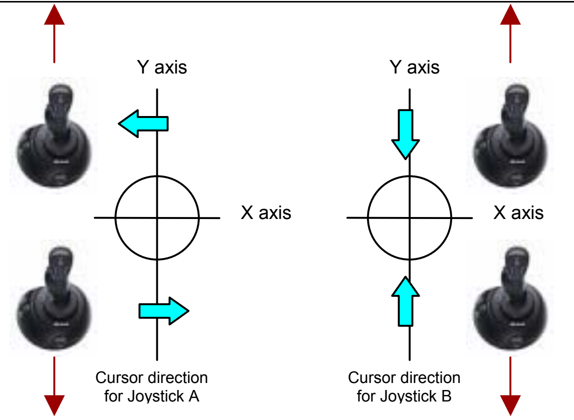


Figure 6.2 GPPC Joysticks Mappings

6.2.2 Good Physical and Poor Cognition (GPPC)

In order to maintain the idea of good physical, the joysticks mappings have been swapped by 180 degree from the first condition; hence allowing both joysticks to retain the sense of good inverse, i.e. up vs. down, and right vs. left. For the condition to be having poor cognition, there will be no tutorial provided to inform participants of the changes in mappings of the joysticks. Participants must explore and discover the new mappings themselves. Figure 6.2 illustrates this.

6.2.3 Poor Physical and Good Cognition (PPGC)

For the third condition, we break the physicality rules, which participants have attained from the previous two blocks, by swapping the directions across the two controllers. The pairs, i.e. up, down and left, right, are no longer positioned on the same axis. In order to ensure the new condition is cognitively good, a short tutorial is given on the screen for a few seconds just before the program of this respective condition begins. In addition to this, a tutorial sheet is provided on the table for user reference. Figure 6.3 shows the new directions of mapping for both joystick controllers.

6.2.4 Poor Physical and Poor Cognition

Neither a tutorial nor physical-cognition rules which have been designed in the three previous conditions are applied in this final condition. Participants are expected to explore the new mapping themselves. Mapping is shown in figure 6.4.

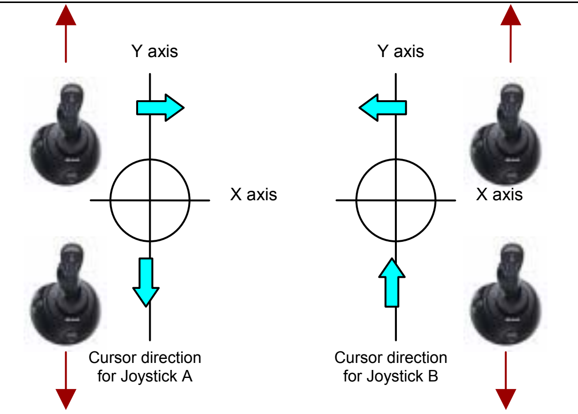


Figure 6.3 PPGC Joysticks Mappings

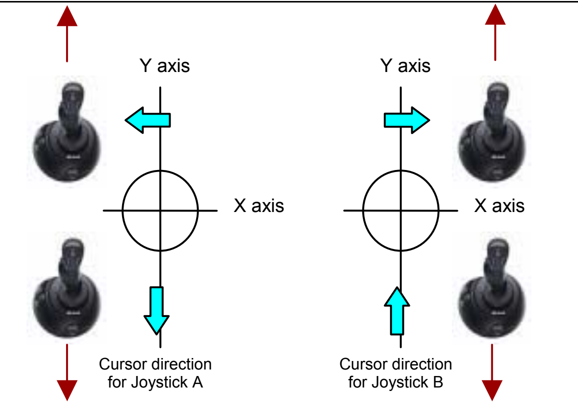


Figure 6.4 PPPC Joysticks Mappings

This experiment is a collaboration work between the author and her colleague, Mr. Kiel M Gilleade. The author was responsible in the creation of what makes good and poor condition for both physical and cognitive, and the possible ways to achieve overshoot effects. The author worked closely with Mr. Gilleade who was responsible of the implementation of a cruel game (see section 6.3).

Before we came to arrive to the decision of the implementation of the Cruel Game, as described in section 6.3, there were two design prototypes. The first one is aimed to destroy a target area by including a timer, and points are awarded based on accuracy and reaction action. But as we felt the first prototype lacks of the usage of joystick controller, i.e. lack of physical manipulation, we thought about translating the same idea onto a grid. The grid game should provide a variety type of cursor movements, hence is able to make full use of the joystick controller. Nonetheless, we found it difficult to control the type (variation) of movement on the grid. Finally we limited the 'grid' to appear as 6 boxes, hence made it easier in the development of the Cruel Design game.

6.2.5 Ordered, not Randomised

The order line for these four conditions in the user study is the same for all participants, i.e. not randomised, as per described above. It is ordered in such a way to create a sense of moving from a good condition to 'less good', then to 'less poor' and lastly to poor condition. The first condition with both good physical and cognition should set a good sense of mapping, hence act like a benchmark for the rest of the conditions. We save the worst condition last, to observe how participants cope and to see whether any of the previous mappings are any help to them. We retain just the good physical mapping in the second condition, as we thought this condition is more suitable to create 'less good' condition than to 'less poor'.

6.3 The Study

In this study, we are manipulating the coherency of physical-logical mappings of two joystick controllers of a simple program (as per explained in previous section 6.2). There are two main objectives of this user study. Besides enabling us to observe the effect of cruel design on the cognitive and physical performance in the four conditions, we are interested in seeing how participants react to overshoots. We believe, in the situations where overshoots happen, natural inverse occurs in the same way as Visceral Interaction assisted users in the Cubicle study from Chapter 5.

In this experiment, the two joystick controllers are used to move a cursor across a screen. In particular, the cursor must follow a flashing blue arrow, which acts as a guide, out from the start box to the target box (see figure 6.6). Cursor movements include both horizontal and vertical movements. In order to encourage overshoots to take place, the velocity of the cursor is enhanced to a bigger value depending on the speed of the joystick movement, which means, if the joystick is pushed forward quite rapidly, the cursor is likely to leap 2 or 3 times greater to an unanticipated position.

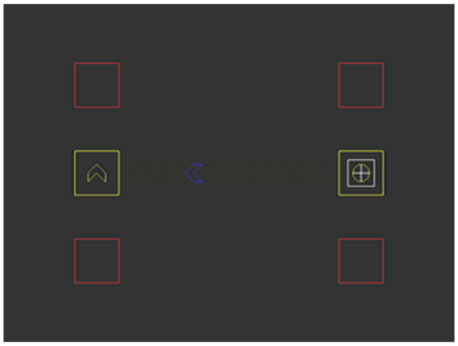


Figure 6.5 Program's screenshot

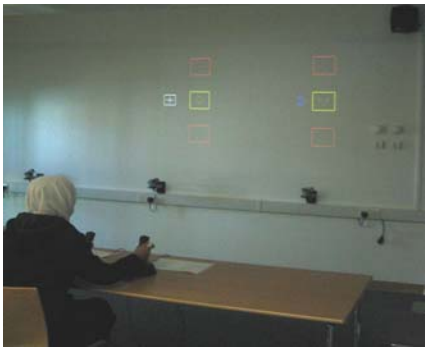


Figure 6.6 Program in operation – the program is projected onto a wall

6.3.1 Methodology

Participants were first briefed on how the program works. We informed them on what they need to do: to move a cursor from the start box to the target box by using the joysticks. Once reached the target box, a trigger must be performed for confirmation, before proceeding to the next task. A flashing blue arrow will guide them on which path to follow (see figure 6.5).

Participants underwent four sets of tests, which were displayed as Block1/4, Block 2/4, Block 3/4 and Block 4/4 consecutively. The order line for these four conditions in the user study is the same for all participants – as per described in 6.2.5. Following is what each block represents:

Block 1/4 – Good Physical and Good Cognition (GPGC)
Block 2/4 – Good Physical and Poor Cognition (GPPC)
Block 3/4 – Poor Physical and Good Cognition (PPGC)
Block 4/4 – Poor Physical and Poor Cognition (PPPC)

Participants were informed about the different mapping for each block. We provide participants with a 2-set of one-page guide which illustrate a simple set of diagrams of mappings of Block 1/4 and Block 3/4 for their reference. The same set of diagram is also being displayed for a few seconds just before Block 1/4 and Block 3/4 programs begin.

Each set, or block, consists of 15 attempts, which each attempt comprises horizontal movement alone, or horizontal and followed by a vertical movement. The order and type of attempt is random. Below are the nine types of attempts we have in this program:

i) Horizontal, left to right of bottom boxes
ii) Horizontal, right to left of middle boxes
iii) Horizontal, left to right of top boxes
iv) Horizontal, left to right of middle boxes, followed by vertical, 1 box down
v) Horizontal, right to left of top boxes, followed by vertical, 1 box down
vi) Horizontal, left to right of top boxes, followed by vertical, 2 boxes down
vii) Horizontal, right to left of middle boxes, followed by vertical, 1 box up
viii) Horizontal, left to right of bottom boxes, followed by vertical, 1 box up
ix) Horizontal, right to left of bottom boxes, followed by vertical, 2 boxes up

6.3.2 Participants

We solicited volunteers from within our department and posted a call for participation on a university-wide mailing list. Our participants were a mixture of undergraduate and postgraduate students that makes up the total of 21 participants, with 6 male and 15 female. 18 out of 21 participants have never, and have limited use of joystick, but all of them are exposed to other input devices such as mouse and wireless mouse. Out of 21 participants, 4 participants play simulation games that use joysticks and steering wheel regularly, while few others play PC games that require inputs from keyboard and mouse. Only 1 participant involved in the pilot study before the actual test took place. Volunteers were informed prior to (and after) the test that they were participating in a user study that will assist in understanding cognitive and physical performance with different input mappings.

6.3.3 Measures

To record our data, we use a combination of recording to allow post-test qualitative and quantitative analysis and also collected qualitative data during the experiment including observations and questionnaires. All tests were recorded by using two video cameras, and log files were used to record the data about the joysticks movement. The results of the log files which should be able to present the accurate data movements of joysticks were first analysed before taking them into synchronization with the two recorded videos which recorded participants' physical movements and on-screen presentation. Volunteers were asked to fill out a background questionnaire prior to the study and they were informed before beginning the test that they were going to be videotaped. Investigators recorded participants' non-verbal manipulation, via pen and papers. Using multiple forms of observation and data collection from log files allowed for detailed evaluation and analysis of user behavior.

6.3.4 Procedure

Our study took place within two days in our department. Each participant interacted with two investigators before and after the test. The primary investigator was responsible for greeting and debriefing the volunteers and collecting background questionnaires. A second investigator was responsible for videotaping. Both investigators were responsible for note taking during the study and for analyse.

The study was evaluated in three separate stages. First, participants filled out a background questionnaire individually, which allowed us to gather background data about each participant. Prior to each test, we briefed the participant of the simple instructions. We then observed participant's performance as each of them manipulating the joysticks in the four mapping conditions. Investigators directly observed participants and collected data concerning these observed activities. As well as investigators directly observing participants, investigators used video camera I to record user activity (audio and visual), video camera II to record on-screen presentation, whilst the log data recorded the joystick movements. Lastly, the collected data were analysed.

6.3.5 Data Collections

Individual responses were collected indirectly via videos and log files. The results of log files were first converted into graphs. The data themselves are able to tell us the general patterns of participants' performances, for instance, the time taken to complete each block. The converted data into graphs allow us to see in detail the movement of the joysticks as per controlled by participants, such as overshoots and deliberations of the next moves. When analysing the video data, investigators collected information on how each participant cope with the understanding of mappings and their actions, for example, how they try to memorise the tutorial before the program begun, and the effects of incorrect physical joystick movements.

6.4 Analysis Results

What follows is an analysis of the results from our study. We group the results into three categories:

i. Learning effect - here, we will be able to find out whether there is any learning effect picked up by participants as they go along from attempt 01 to attempt 15
ii. Statistical analysis - we will see whether the different conditions have effects on the performance from the statistical point of view.
iii. Observations – we observe participants' usage of joysticks under the different conditions and their reactions towards overshoots.

Results of Participant 1 and 2 had to be eliminated due to misjudgement in our part. The program was initialised with 5 attempts in each block instead of 15. Thus, inadequacy of data from both participants had to be ruled out.

Despite the fact that both horizontal and vertical performances data were being logged, we only consider the horizontal performance results in our analysis. As the vertical movements are of many kinds (see 6.3.1 - iv-ix), the results were proved to be inconsistent throughout the 15 tests for each block. For instance, a block may run 1 (i), 1(ii), 2(iii), 2(iv), 2(v), 2(vi), 2(vii), 2(viii) and 1 (ix). The only consistent movement that occurred throughout all 15 tests were the horizontal movements, as for each vertical movement was preceded by a horizontal movement.

6.4.1 Learning Effect

Each condition consists of fifteen attempts. We use the log data to tell us whether there is any effect on learning as participants went through all fifteen attempts for every condition. We will be looking at both horizontal reaction time (RT) and movement time

(MT) to find out whether there is any learning effect taking place.

6.4.1.1 Reaction Time (RT)

Reaction time is the number of milliseconds (ms) elapsed between the start of attempt and when the joystick controller is moved out of its deadzone[1]. Reaction time can also be considered to be as thinking time, as it is a phase before participants proceed with a decisive movement. By calculating the average, or mean time in milliseconds spent in every attempt of each condition, we have been able to generate a graph which illustrates the overall performance of reaction time (RT) for horizontal movements for every condition (see figure 6.7 below).

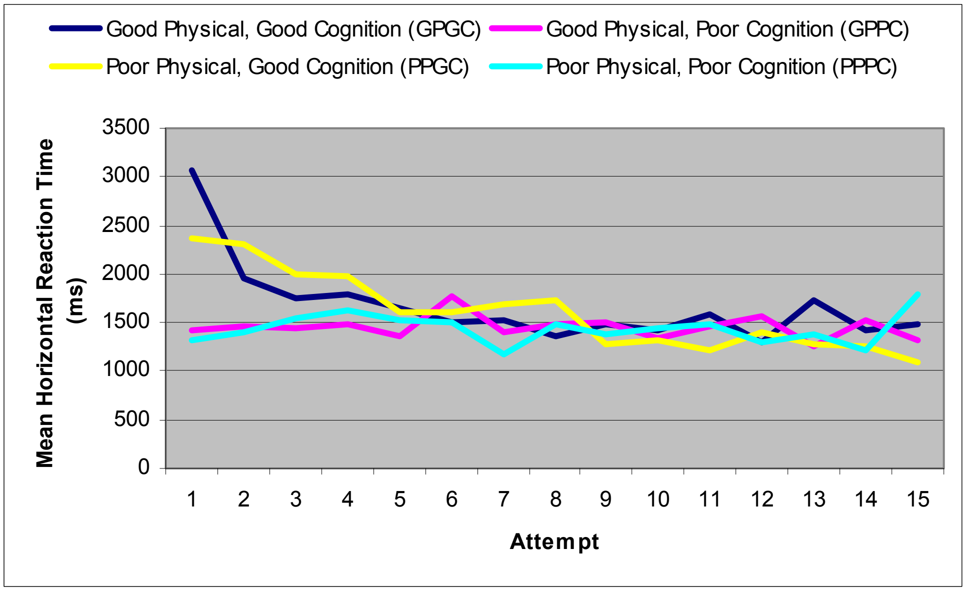


Figure 6.7 Mean horizontal reaction time (RT) for every conditions

All reaction time is well above 200 milliseconds (refer page 25), which corresponds to the reaction time in other studies (Card et al., 1978). The conditions with good cognition (GC) seem to begin with a short pause, with about 3000 milliseconds for GPGC attempt 01 and about 2400 milliseconds for PPGC attempt 01. We suspect this is due to introductory to the new sets of reference mapping tutorial sheets which are provided on the table. Having provided the sheets for these two conditions tempted participants to

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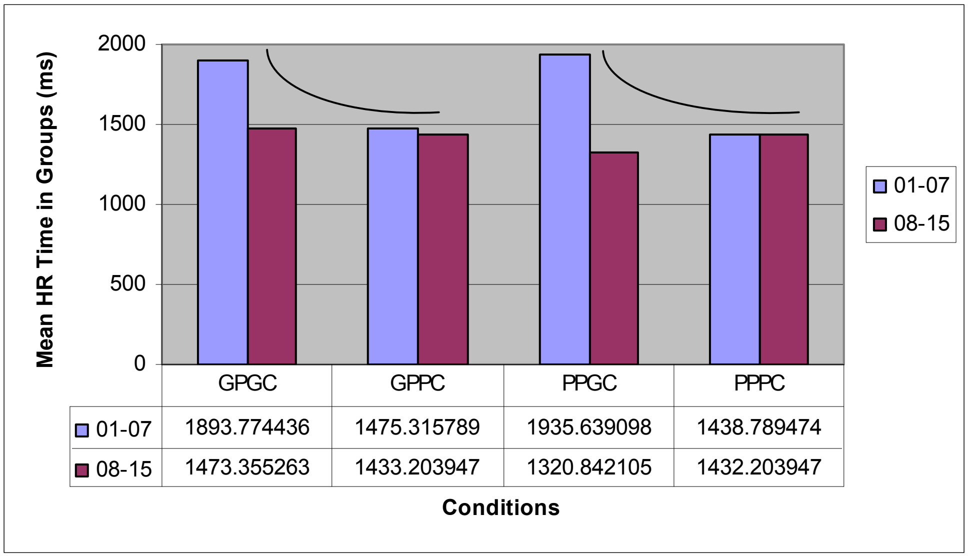
[1] Deadzone is a zone which is purposely designed to extend the rest-point around the centre point of a joystick. A deadzone is required as the joystick's auto-centre was never perfect.

spend longer time to first to familiarise with the new set of mapping before proceeding with a movement. Without any mapping tutorial sheets, both GPPC and PPPC conditions had a shorter (in the context of milliseconds) reaction mean time, of about 1400 milliseconds. Throughout all fifteen attempts for every condition, the reaction mean time drops quite significantly from their first few attempts to the remaining of the attempts GPGC and PPGC conditions, whilst PPGC and PPPC conditions tend to have a consistent reaction mean time, which is about on the same level throughout all fifteen attempts.

We divide the fifteen attempts into two by grouping the first 7 attempts together to form 01-07 group, and 08-15 group by grouping the last eight attempts. We see the 01-07 group to be the phase where participants learn about mapping interaction, and 08-15 group as the participants' actual performance having gone through seven trials beforehand. Henceforth, we will call the groups as *learning session* and *actual session*, respectively. We do the division to enable us to see whether there is any learning effect in the reaction phase itself. See figure 6.8 below.



	GPGC	GPPC	PPGC	PPPC
🟦 01-07	1893.774436	1475.315789	1935.639098	1438.789474
🟥 08-15	1473.355263	1433.203947	1320.842105	1432.203947

Figure 6.8 Mean horizontal reaction time (RT) between sessions 01-07 & 08-15

Learning effects seem to take place from condition GPGC to GPPC and from PPGC to PPPC (as shown by curve lines). Looking closely at GPGC and PPGC, the learning sessions, respectively, are about 420 milliseconds and 615 milliseconds higher than their actual sessions. We suspect, the reason being would be similar to what we have described above – reference to tutorial sheets. Ruling this reason out, there is no substantial learning effect as shown by both GPPC and PPPC conditions.

6.4.1.2 Movement Time (MT)

Movement time is the number of milliseconds (ms) elapsed between the time the controller is moved out of its deadzone and when the user correctly acquires the target and fires. The time spent for each movement may affected by the speed of the controller, as per mentioned in section 6.3.

Our approach in manipulating the movement time log data would be similar to our approach in RT. By finding the average (mean) horizontal movement time (MT) for each attempt in every condition, we are able to see the generic overall performance, as per shown below.

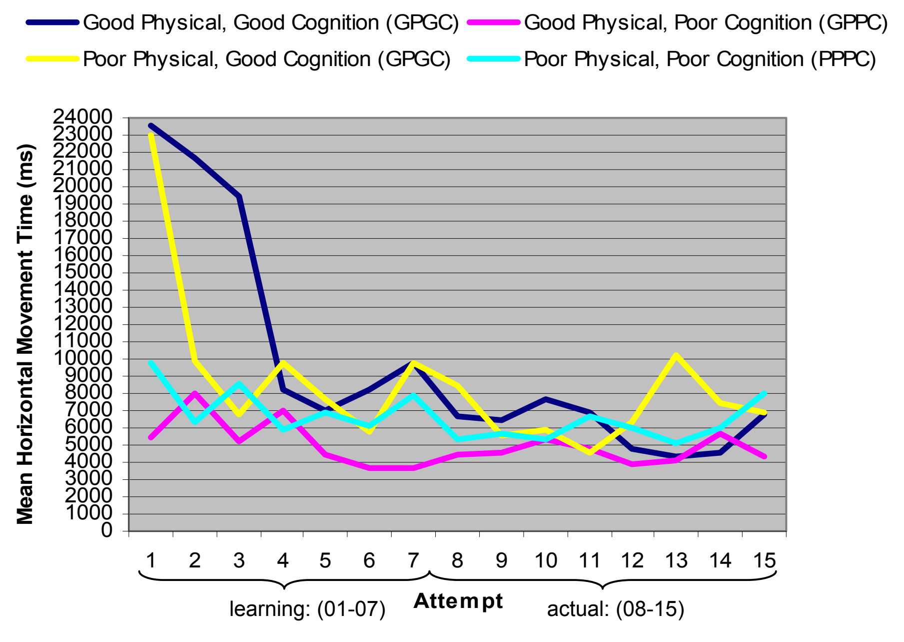
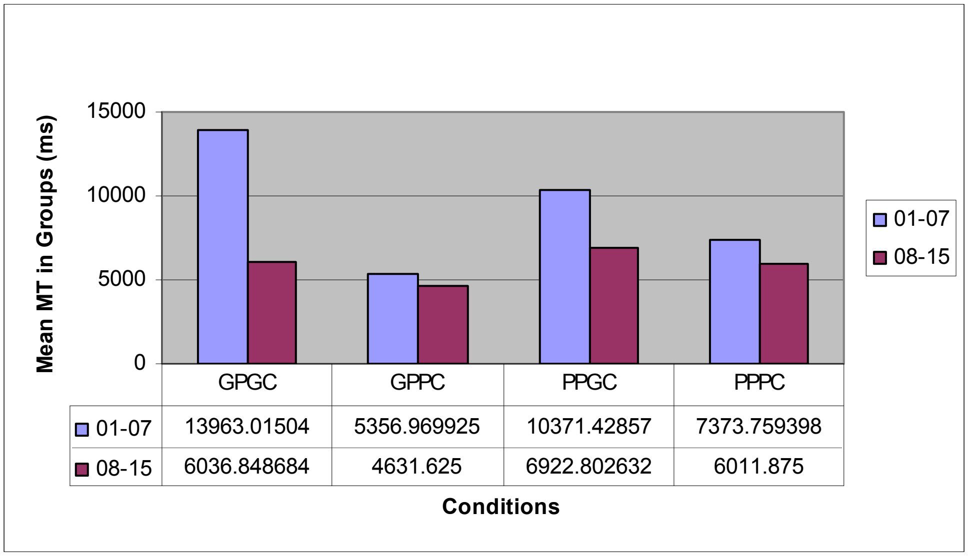


Figure 6.9 Mean horizontal movement time (MT) for every conditions

Both GPGC and PPGC conditions have high mean horizontal movement time, with GPGC recorded high from its first to fourth attempts, and only in the first attempt for condition PPGC. The significance difference of about 17000 milliseconds for these two conditions before they both levelled at the range of 6000-9000 milliseconds is suspected due to way participants attempted to refer to and tried to follow what is presented on the tutorial sheets provided and to steer the controller at the same time.

The fluctuation we see for all conditions is due to the unexpected augmentation effects caused by the speed participants performed on the joystick controller, which at most times created confusion especially when participants encountered with a new mapping condition. For example, when the cursor was supposed to go up, it bounced against the top of the screen and resulted in the opposite direction. But due to the high speed, this confused the participants especially when they had already understood the current mapping. Out of all four conditions, GPPC mean horizontal MT ranges the lowest. Conditions with poor cognitive (PC) seem to keep the horizontal movement time lower than when the conditions are said to be cognitively good.

Similar to what we did previously in RT, by grouping the attempts into two groups: 01-07 as training session, 08-15 as actual session we will be able to see if there are any learning effects between the transitions. Figure 6.10 shows comparison between these two groups in all conditions, whilst the following four diagrams (10.1 – 10.4) illustrate all four conditions individually.

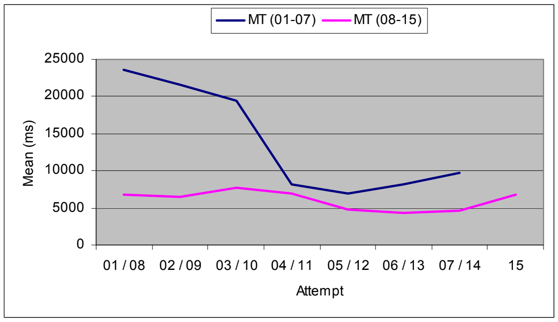


	GPGC	GPPC	PPGC	PPPC
🟪 01-07	13963.01504	5356.969925	10371.42857	7373.759398
🟥 08-15	6036.848684	4631.625	6922.802632	6011.875

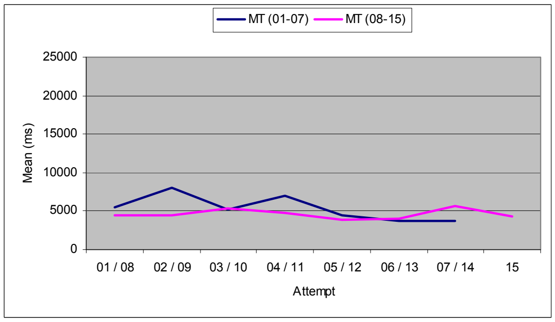
Figure 6.10 Mean horizontal movements time (MT) between sessions 01-07 & 08-15

Figure 6.10 shows that for all four conditions, the mean for every attempt in actual phase is lower than the mean for every attempt in training phase, with about 7900 milliseconds, 700 milliseconds, 3400 milliseconds and 1300 milliseconds difference respectively. From this scenario, we believe there are learning effects took place during the transitions between the two phases. The obvious difference as we can see in condition GPGC is suspected due to the fact that GPGC being the first condition participants had to encounter with (see also figure 6.11a). They had to learn the usage of joystick, familiarised with the environment and the program, and in addition, to overcome the surprise caused by the augmentation effects due to the speed of the joystick movement. Furthermore, in the first few attempts, participants still tend to look and refer to the tutorial sheet. And this is the similar factor that contributed to the significance difference of mean 3400 milliseconds showed in the PPGC condition (see also figure 6.11c)

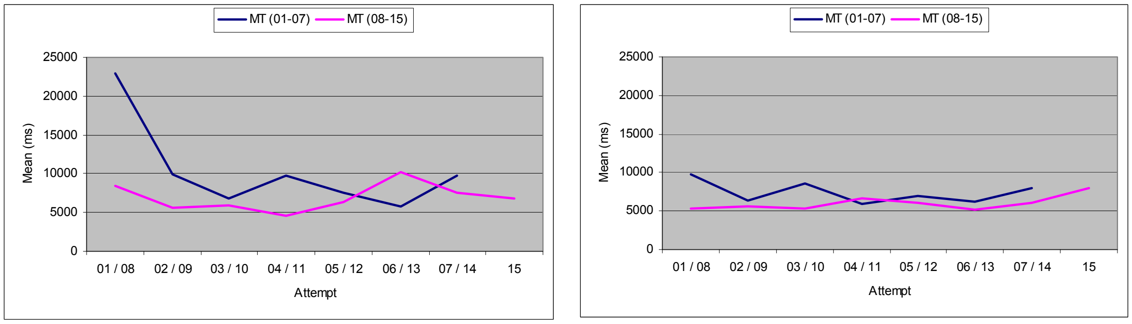
When we look closely at the individual conditions of GPPC (figure 6.11b) and PPPC (figure 6.11d), the learning and actual performance both have small range of mean difference between the two. Without the mapping tutorial sheet, it lessens the transition effect and closer the range of difference between the learning and actual phases. Furthermore, conditions with poor cognition (PC), seem to allow the participants to perform faster and rather well compared to other conditions.



(a) GPGC



(b) GPPC



(c) PPGC (d) PPPC

Figure 6.11 Training vs. actual performances

6.4.2 Statistical Significance

Data were further analysed to test the significance of differences of the four conditions using SPSS[2] program to run analysis of variance (ANOVA). The ANOVA fitted for participant effect, main effect of the condition (GPGC, GPPC, PPGC and PPPC), and learning and actual sessions effect.

As per seen in 6.4.1, initial by eye analysis of graphs seem to suggest effects caused by different type of conditions, which in fact is statistically significant at 5%, with $F_{(3,\ 54)} = 4.748$; $P < 0.05$ (as shown in the first line of the table).

Source	Sum of Squares	Df	Mean Square	F	Sig.
CONDITION	28188783277.862	3	9396261092.621	4.748	0.005
Error(CONDITION)	106867766586.264	54	1979032714.561		
SESSION	11848253132.376	1.000	11848253132.376	8.069	0.011
Error(SESSION)	26430860916.001	18.000	1468381162.000		
CONDITION * SESSION	14314571717.126	1.551	9230309062.325	3.628	0.05
Error(CONDITION*SESSION)	71019626132.001	27.915	2544156137.006		

Table 6.1 ANOVA summary table for the within subjects factors and their interaction

The type of condition does affect participants' performance. In addition to this, by referring to the above table and in the columns highlighted, the conclusion we can reach is that there is also a main effect for session (P = 0.011, significant at 5%), and interaction

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[2] SPSS is a computer program which is among the most widely used programs for statistical analysis in social sciences.

effect between the two factors (P = 0.05, significant at 10%). Thus, it did matter if one was in GPGC, GPPC, PPGC or PPPC condition, and it did matter if one was in the training or actual session. Furthermore, the type of condition does have an impact differentially on the type of session's performance.

Having said this, for this particular analysis, we only selected horizontal movements log data and left out other type of vertical movements log data, which consist of moving upwards by one box and two boxes, and moving downwards by one box and two boxes, as all attempts began with horizontal movement. We are not certain if this in any way affected participants' performance and consequently draw different significance effects. Longer experiments, which consist of larger number of attempts, or, eliminating the vertical movement altogether might result in different performance, but we can be confident from these results that the type of conditions used has a substantial effect.

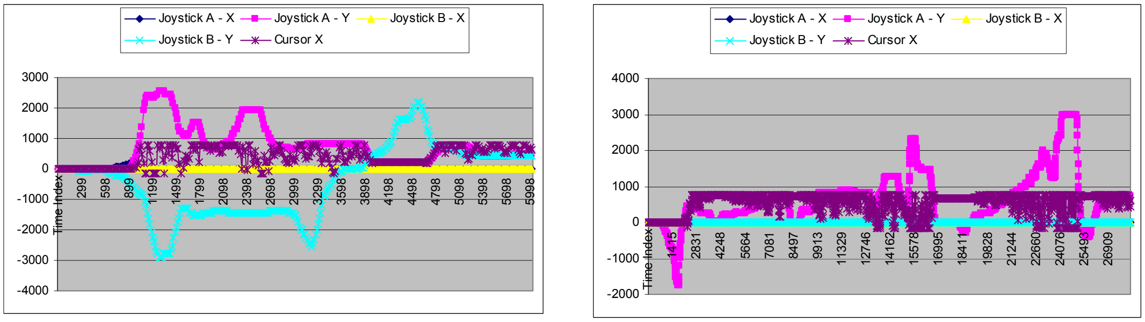
6.4.3 Observations

Our observation analysis is presented in two parts. The first part is about our observations on participants' usage of joysticks under different conditions in general, whilst, the second part focuses on reactions to overshoots.

6.4.3.1 Usage of Joysticks

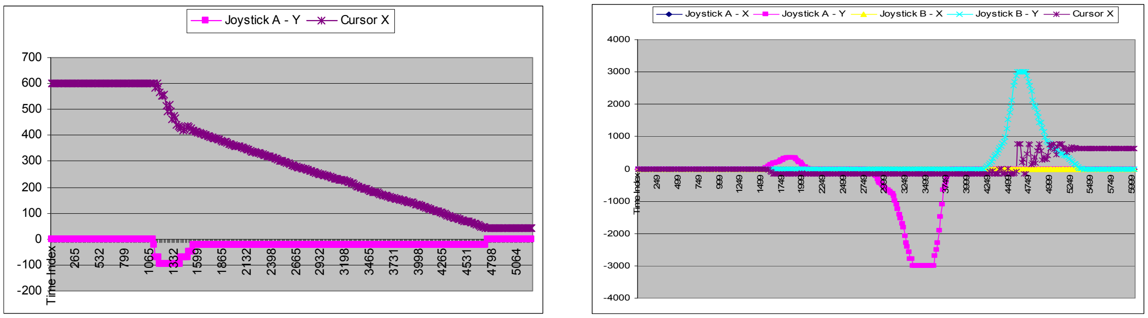
Every individual participant had their method or style when they performed the experiment. From our observation, there were some who really conscious about their actions by referring to the tutorial sheet for GPGC and PPGC conditions almost in every attempt, and in the conditions without the tutorial sheet (GPPC and PPPC), these participants explored every single direction of the both joysticks to discover the mappings. In both situations, they whether continued referring or exploring towards the end of the attempts, or tried to recall what they remembered from the previous attempts of the condition they were in at that time. There was also a few who did not bother either to look at the tutorial sheet, or explore in a more structured way, i.e. by moving both controllers up and down at the same time (see figure 6.12a).

It is also interesting to discover the way a few participants handled the joystick controllers. They began by using just one hand and swapping this hand from one controller to another throughout the first two conditions: GPGC and GPPC. We suspect what encouraged them to do so, is the good physical sense that exist in both conditions, i.e. the *pairing* between up and down on one joystick, and right and left on the other joystick. As they moved on to the third condition, they seemed to struggle a little in the beginning. These participants were so used with the idea of *pairing* from the previous two conditions that in the third condition, they persisted on using the same joystick to inverse an action (see figure 6.12b). In few occasions, participants discovered accidentally that overshoots can be avoided by moving the joystick controllers at a slow speed constantly. As these occurred, no inverse action or effects were taking place (see figure 6.12c).



(a) A participant uses both joysticks without referring to tutorial sheet in the first attempt in the GPGC condition

(b) A participant just uses one joystick without considering the other joystick in the third condition, PPGC



(c) A participant discovers the way to control the movement of the cursor by maintaining the speed of the joystick

(d) Explores the joysticks' mappings by moving in every single direction in the first attempt in the PPPC condition

Figure 6.12 Observations on the usage of joysticks

Out of all participants, there were 4 participants who frequently play simulation games, such as flight simulator, with joysticks. Based on our observations, these participants' attitude was very positive. In comparison with the rest of the participants, these so called gamers participants were more positive than others from the way they performed. They always keep their mind open and explore every single direction, i.e. up, down, left and right, for each joystick to unearth the new set of mappings, especially when there were no tutorial sheets provided (see figure 6.12d).

6.4.3.2 Overshoots

As briefly described previously in section 6.3, the cursor in the program was designed in such a way that it would encourage overshoot. Overshot occurs when the participant triggers the cursor beyond the target box. This was done by augmenting the distance of the cursor, which increases proportionally to the joystick's velocity. Thus, in occasions where the joystick was moved rather quickly, the cursor was overshot, despite the anticipation a user had in taking the cursor to the target area. Overshoots also occur quite unexpectedly due to the augmentation effect. Overshoots can also be avoided, by controlling the speed of the controller.

In this section, we will be closely looking at some examples performed by a number of participants on different type of movements in different conditions. Before we do this, we present an overall overshoots performance that occurred in the horizontal movements.

		no. of overshoots	*average time taken (ms)*	no. of inverse (same joystick)	*average time taken (ms)*	no. of inverse (different joystick)	*average time taken (ms)*	other direction	*average time taken (ms)*
GPGC	01-07	296	*677*	228 (77%)	*627*	n/a	*n/a*	68 (23%)	*846*
	08-15	233	*647*	199 (85%) ⓐ	*640*	n/a	*n/a*	34 (15%) ⓑ	*658*
GPPC	01-07	231	*680*	193 (84%)	*637*	n/a	*n/a*	38 (16%)	*901*
	08-15	215	*679*	195 (91%)	*718*	n/a	*n/a*	20 (9%)	*390*
PPGC	01-07	266	*647*	84 (32%)	*459*	105 (39%) ⓓ	*882*	77 (29%) ⓔ	*531*
	08-15	208	*695*	30 (14%) ⓒ	*568*	126 (61%)	*825*	52 (25%)	*453*
PPPC	01-07	241	*578*	56 (23%)	*527*	66 (27%) ⓕ	*656*	119 (49%) ⓖ	*560*
	08-15	189	*545*	37 (20%)	*453*	39 (21%)	*603*	113 (60%)	*556*

ⓐ	Inversing the same joystick is the correct recovery movement for overshoots in GPGC and GPPC conditions (see figure 6.1 & 6.2 Joystick A)
ⓑ	Other directions include left and right movements which were thought to be the correct recovery movement for overshoots
ⓒ	Inversing the same joystick controller was thought to be the correct recovery movement for overshoots
ⓓ	Inversing an action on the second joystick is the correct recovery movement for overshoots in PPGC (see figure 6.3)
ⓔ	Other directions include left and right movements, and, repetition of the movement that causes the overshoots
ⓕ	Inversing an action on the second joystick was thought to be the correct recovery movement for overshoots
ⓖ	The correct recovery movements for overshoots in PPPC condition is not by performing an inverse action on either joystick (see figure 6.4)

Table 6.2 Overall Overshoots in Horizontal Movements

A number of points about the overshoots performance can be drawn from the table:

- The number of overshoots decreases from the first training session to actual session in every condition

- When the correct recovery to overshoot is retained on the same joystick controller which causes the overshoot, the percentage of getting it right is high with 84%, as per shown in condition GPPC

- The average time taken to perform an inverse of the same joystick which causes the overshoot is relatively lower in the conditions with poor physical condition (PPGC and PPPC) – (c) < (a). In spite of this, both GPGC and GPPC average time taken for inverse action is still relatively lower than the average time taken for other directions action (a) < (b)

- The number of inverse actions on different joystick is highest for PPGC as the actions correspond to the correct mappings, as per shown in the tutorial sheet. In the training session (01-07), 39% of the overshoots receive correct recoveries, 32% sees inverse action of the joystick controller which causes the overshoot, and 29% in the other directions. The percentage of getting the correct recovery for the overshoots shoots up to 61% in the actual session (08-15) by reducing the inverse action of the joystick which causes the overshoot to 14%, and the other directions to 25%. Based on our observations, the smaller percentage of inverse actions when compared to other directions is due to the fact that the participants are now aware that the correct recovery cannot be found from the same joystick

- There was no tutorial sheet provided for the final condition, PPPC to make the condition worst. Exploration in the first session of the attempts to find the correct mapping movements gives 23% for inverse of the same joystick controller which causes the overshoot, 27% for inverse of the second joystick, and 49% for the other directions, which consist of the correct recovery for the overshoots. After discovering the correct mappings, the percentage of correct recoveries increases to 60%, which leaves 20% and 21% for the inverse actions on the same joystick and the second joystick

- Participants' differences – although the table may reflect the overall overshoots performance for all participants, it is however not the case. There were 2 participants who only encountered overshot in their first attempts, but overcome the potential overshoots in the remaining attempts by maintaining the controller's speed movement. Hence, the overshoots pattern showed in the table is atypical behaviour for all participants. The table, however, illustrates the typical behaviour for participants who actually encountered overshoots (although the number of overshoots varied from one participant to another)

In the following, we will look at a few examples from the typical behaviour performed as overshoots occur.

Condition I: Good Physical, Good Cognition (GPGC)

Overshoots in good physical and good cognition (GPGC) condition were mostly caused by the high speed of joystick's movement. Participants in this condition, who had been informed about the joysticks' mappings before the program begun, already had a clear understanding in terms of controlling the joysticks. Figure 6.13 shows the unanticipated augmentation effects that resulted in overshoots. Because of these, the movements look almost like they are random (up and down) until it hits target. But at the very end (as shown in circle), the speed of joystick is more constant, hence cursor's movement could be controlled till it hits the target.

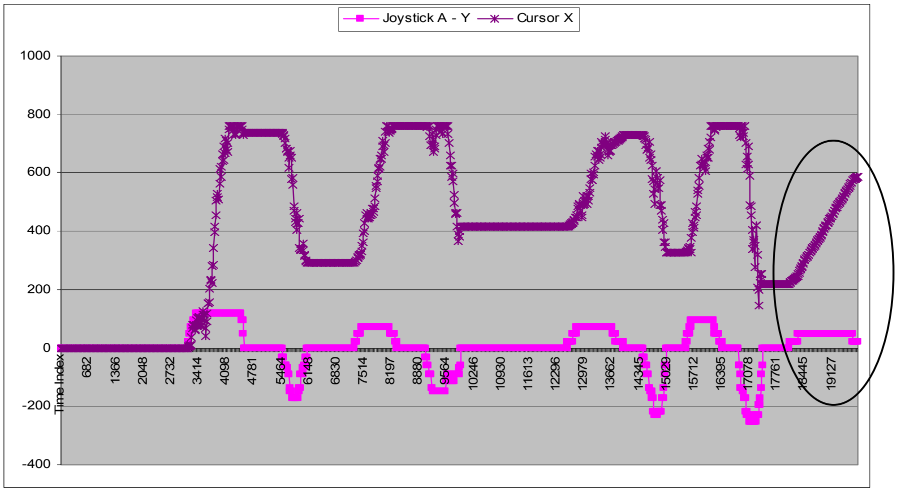


Figure 6.13 Horizontal movement in GPGC condition

Condition II: Good Physical, Poor Cognition (GPPC)

In the second condition (GPPC), the overshoots were caused by two reasons. The first was due to the fact that there was no mapping guide provided; hence participants must rely on their exploration to discover the new set of joysticks' mappings before they could learn them. The explorations led to mistakes of directions and to overshoots. The second reason is due to the augmentation effects on the cursor when the joysticks were rapidly pushed or pulled.

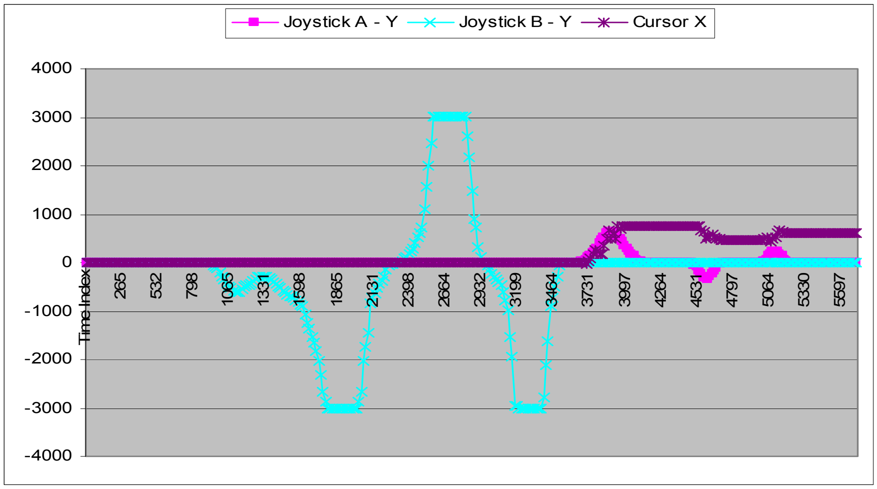


Figure 6.14 Horizontal movement in GPPC condition

Figure 6.14 shows how a participant explores the movements of both joysticks to discover the mappings of the joysticks in her first attempt. She begins with moving Joystick B up and down, but with no results on the cursor, she then pushes up Joystick A quite carefully. This action however causes overshoot. It takes her 383 milliseconds before she responds by inversing the action by pulling down the same joystick. Another overshoot occurs, which is then corrected by pushing up the joystick, 300 milliseconds after it overshoots below the target box.

Condition III: Poor Physical, Good Cognition (PPGC)

Participants were informed of the third condition's joysticks' mappings to assist them with the correct directions of the controllers before they proceed with the third condition (PPGC). But as the mappings were no longer symmetrical, as we are creating a sense of poor physical but cognitively good, we observe how participants took quite some time to learn the current mappings.

When overshoots occur, the joystick that responsible for that overshoot in most cases was drawn back to its centre. As tutorial sheet was provided on the table, participants normally took a few seconds to study the mapping before moving the joystick that was designed to reverse the overshoot.

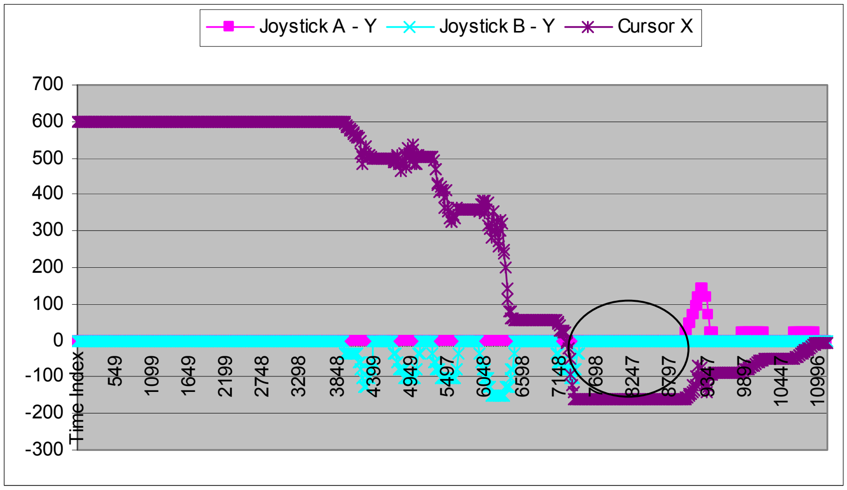


Figure 6.15 Horizontal movement in PPGC condition

This participant takes 3965 milliseconds, which is about 4 seconds before acting upon a joystick. The time was spent on referring to the tutorial sheet which was provided on the table. The joystick is moved bit by bit to avoid overshoot. Nonetheless, overshoot did occur. With the help of tutorial sheet, this participant recovers from the overshoot by moving the correct joystick, 1567 milliseconds (thinking time – shown in the circle in figure 6.15 above) after the overshoot occurs.

There are situations where participant(s) did not refer to the tutorial sheet. Instead, they simply move each joystick and see the result of the movement (see figure 6.16). This participant begins with pulling down Joystick A. With no effect, the movement is then inversed. The joystick is then pushed up little by little, until at one attempt the cursor was overshot. After about 1 second, the second joystick is now being pulled down. But, the second attempt to bring back the cursor closer to the target box overshoots the cursor.

As circled in the figure 6.16, an instant reaction (about half second) to the overshoot is the inverse of the same joystick. But, almost immediately it is followed by a movement of Joystick A (which was the correct movement). From the graph, we believe, the thinking time to move Joystick A is already begun when it was first overshot, but the inverse of Joystick B was the instant reaction to the overshoot. When overshoot occurs again, the recovery is then followed by a correct choice of joystick and correct movement.

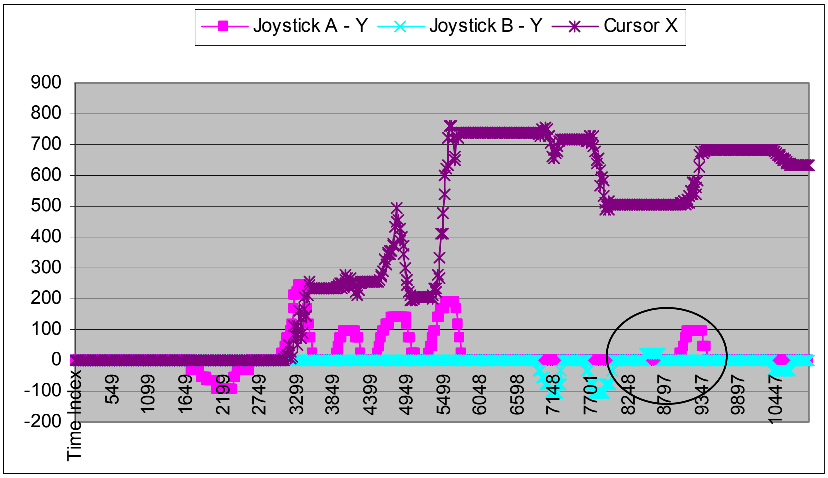


Figure 6.16 Horizontal movement in PPGC condition without reference

Condition IV: Poor Physical, Poor Cognition (PPPC)

The fourth condition was designed to be poor for both physical and cognition (PPPC). Without giving away any tutorial to participants, they had to explore the mappings' directions themselves. Exploratory movements obviously lead to overshoots. What most participants normally do at the beginning of this condition, especially in the first session (1st to 7th attempts) was using one joystick controller at a time by moving it up and down, or vice versa, to find out where the joystick took the cursor, before doing the same on the second joystick. But this also occurs throughout all fifteen attempts. Figure 6.17a illustrates this.

As the program for this condition progresses, there was a few participants who made the effort to get the directions correct by pausing for a few seconds before executing the next movement. Figure 6.17b shows how one participant overshoots the cursor beyond the target box. After 1050 milliseconds (which was the thinking time), this participant recovers from the overshoot by moving the correct joystick towards the correct direction.

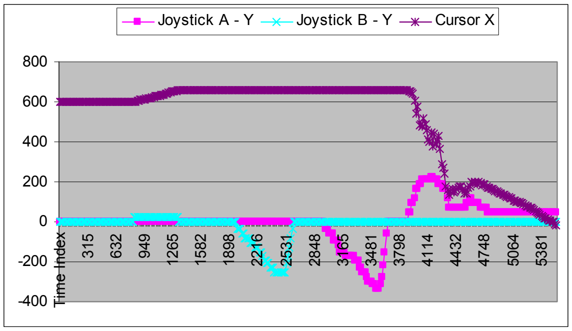


Figure 6.18a Exploratory horizontal movement in PPPC condition

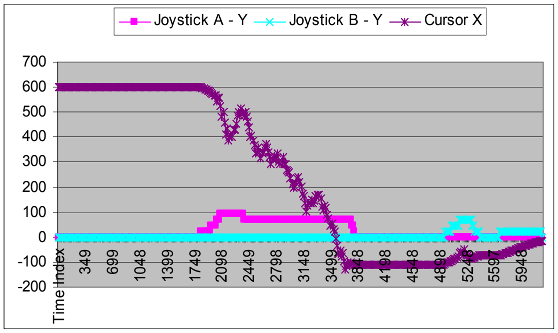


Figure 6.18b Recovering from overshoots in horizontal movement in PPPC condition

6.5 Discussion

The graphs have shown us that the types of conditions do give different result in the participants' performance, but with the ANOVA statistical analysis, it has given us confidence in confirming this fact. Furthermore, the type of sessions (first seven training attempts, or, the last eight actual attempts) one was in has also a main effect towards the performance. Whilst the interaction effect shows that type of condition does have an impact differentially on the type of session's performance. With these significance statements, we can believe that participants performed best in conditions where participants had to rely only on the physical controller and not thinking much about the cognitive aspect, based on the previous graphs analysis.

Different backgrounds of participants showed variations in the performance style of joysticks usage. Expert gamers' are not afraid of exploring and always want to make sure they perform the best in each condition. During the overshoots, the *pairing* concept that exists in GPGC and GPPC conditions seemed to assist participants in their inverse action. In some occasions, the concept of a good physicality is very hard to break, as shown by some persistent participants.

This experiment nonetheless had to rely only on the horizontal movements and had to ignore all vertical movements. The reasoning behind this, as mentioned in section 6.4, is the inconsistent data of vertical movements. As the vertical movements are of many kinds, the results were proved to be inconsistent throughout the 15 tests for each block.

The only consistent movement that occurred throughout all 15 tests were the horizontal movements, as for each vertical movement was preceded by a horizontal movement.

Eliminating the vertical movements altogether may seems to be a sensible thing to do to improve the results, due to their inconsistent data. But it would not be a wise decision, as the program would not have worked with just horizontal mappings on two joysticks. Thus, the program requires the vertical mappings to accompany the horizontal mappings in order to enable the swapping between conditions. We don't see the vertical movements as discouraging, because the logged vertical data can be explored in future study.

This study can be improved further by increasing the number of attempts per participant to show the transition effects between learning and actual attempts. Moreover, this would produce more confident results in terms of different conditions of physical and cognitive factors.

6.6 Conclusion

This chapter reports a Cruel Design, which its idea is to seek the properties that make things work well by making them difficult and annoying to use. The aim of the study is to look further into the association between physicality and inverse action. Moreover, its aim is to observe how users react to and how they can cope with conditions where their physical and cognitive mappings are swapped around.

Four conditions were designed to represent four different types of mappings. In the conditions like GPGC and GPPC, good physical condition has helped participants in getting the correct movement faster (section 6.4.1). Different types of conditions do affect the participants' performance, and condition with poor cognition ensures faster performance (section 6.4.2). It has been shown from the results that inversing an action on the same controller (regardless the type of mapping) is the natural reaction to overshoots. The time taken for inverse actions, however, was not as quick as we initially thought. We would think this could be contributed by the augmentation effects. This effects, which were perceived to be unexpected and difficult to control (see section 2.3) caused the participants to be conscious with their actions. Nonetheless, the likelihood of inverse recovery is high when the opposite mapping is retained on the same controller (section 6.4.3).

In conclusion, this chapter can be concluded as follows:

- The idea behind the Cruel Design is to seek the properties that make things work well by making them difficult and annoying to use. The actual program that was used in the experiment was preceded by two prototypes: target game using a timer, and a grid game. Due to the lack of physical manipulation in the former, and too many variations of movements in the latter, a more structured Cruel Design game was developed
- Results were analysed by using only the horizontal data movements as these movements appear consistently throughout all fifteen attempts. Vertical movements nonetheless are crucial in enabling the mappings of movements to be swapped around, and their logged data have to potentials to be explored further
- Between conditions of good and poor physical and good and poor cognition, poor cognition is the condition where participants performed best, i.e. hitting the acquired target in the shortest time. When actions were focused on the physical controllers, performance was shown to be faster
- As we have thought initially, most of the natural inverse actions to recover from overshoots occurred on the same physical controllers despite the type of the conditions. Unless when the tutorial sheet is referred to, conscious recovery actions were taken place.

In the next chapter, Chapter 7, we will see how our understanding of physicality, which we have covered so far, is relevant to design methods for Tangible User Interfaces (TUIs) and to interaction design that makes an interaction natural and fluid.

Chapter 7

From Physicality to Tangible Interaction Design

The success of good design has materialised from our study of day-to-day devices and consumer appliances, with the aim to understand how natural interactions can be used effectively in the design of tangible devices. We analysed and represented some of the rich physical interactions available on mundane appliances including a washing machine and speaker volume control, which have been elaborated carefully in Chapter 3.

In this chapter, we will uncover how the success of physical interaction can be applied to the tangible design. The following section, section 7.1, presents a brief set of related work. Section 7.2 will look at several examples of tangible devices that embody the design principles (from Chapter 3). The analysis on existing tangible devices has exposed where they exhibit natural interaction. Section 7.3 will see how these findings fit more broadly within a tangible user interface (TUI) framework, whilst section 7.3.1 will focus on the impact of the principles on the TUI framework. Section 7.4 summarises some of the broad guidelines which illustrates the situations or contexts where the principles can be applied. Section 7.5 discusses the dynamic characteristic of reversibility and why it is an essential feature in the design of tangible interaction. Discussion and conclusion sections conclude this chapter.

7.1 Related Work

Various tangible user interfaces (TUI) frameworks have emerged to enhance understanding of physical-digital linkage. Frameworks, conceptual theories and tangible device developments have significantly emerged which aimed at gaining a better understanding of the subject, such as Koleva et al.s' A Framework for Tangible User Interfaces (2003), Svanæs and Verplank's Metaphors for Tangible User Interfaces (2000) and Ullmer and Ishii's Frameworks for Tangible User Interfaces (2000), whilst Benford et al.'s Sensible, Sensable and Desirable (2003), Gaver et al.'s Ambiguity (2003) and Schmidt's Implicit through Context (2000) look at ubiquitous interaction in general. Whilst early work such as using props for neurosurgical virtualisation (Hinckley et al., 1994) and Graspable User Interfaces (Fitzmaurice, 1996) introduce and emphasise on the importance of a physical medium to manipulate virtual and digital objects and functionality.

Whereas others looked at and even developed tangible devices in search of tangible design guidelines, we are examining our physical design principles (Ghazali & Dix, 2005a) to test the principles' compatibility and their impact on the TUI framework (Koleva et al.'s, 2003), which has extended our understanding of computationally-coupled physical and digital objects. The design principles were based on our study of understanding the features of physical interaction and of the physical-logical mapping of everyday artefacts that make them comprehensible and natural (from Chapter 3), which has given us insights to understand the design of novel tangible and ubiquitous devices. What motivated us in the first place is the fact that we can learn much by studying these appliances that would be hard or impossible to learn by extensive research especially with novel devices.

7.2 Existing Tangible Devices

It is clear that good design of day-to-day appliances should offer benefits for the design of tangible devices. Having understood the principles of physical design, we now look at examples of tangible devices that embody the principles, and look at where in the design space of tangible interaction the principles can contribute to improving design.

7.2.1 Exposed State

Collaborage (Moran et al., 1999), Marble Telephone Answering Machine (Crampton, 1995) and Illuminating Light (Underkoffler and Ishii, 1997) are good examples that exploit the *exposed state* principle. Collaborage uses badges (figure 7.1), which are the tagged tokens that can be moved between the In/Out columns and on the In/Out/Away board located in the hallway to trace the users' positions. The changes are tracked by the system and are updated in the database. In the Marble Telephone Answering Machine (figure 7.2), a marble is used as the device control to play the message by dropping the marble into an indentation in the machine. The marble is also used to dial the caller automatically by placing it onto the augmented telephone. Of the three examples, the Illuminating Light exploits the exposed state principle the most. Physical models of optical elements (prism etc.) are used to create a simulated optical layout (figure 7.3). The system then simulates the corresponding light patterns. The simulated optical layout is not just about control and feedback, but is a direct representation of the actual thing.


Figure 7.1 Collaborage (Morgan et al., 1999)


Figure 7.2 Marble Telephone Answering Machine (Crampton, 1995)

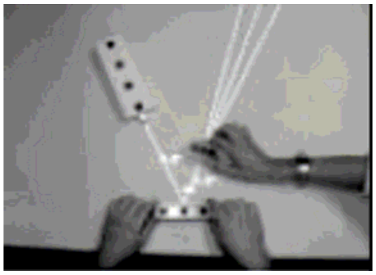


Figure 7.3 Illuminating Light (Underkoffler and Ishii, 1997)

7.2.2 Hidden State

As we already know, to ensure the natural interaction exists in *hidden state*, we have to provide additional information in order to assist the user to understand how to manipulate the device. In tangible devices, the situation is a bit different; the examples that follow seem to be using hidden state not because of the constraints of the interface but for specific purposes. The Storytent by Fraser et al. (2003) uses UV light to reveal the hidden writing on an electronically tagged paper to make the experience of unearthing the logical functions (digital) more interesting. It uses hiddenness in an exploratory experience (see figure 7.4). Super Cilia Skin (Raffle et al., 2003) is also focused on the aesthetic (figure 7.5). It is a computationally enhanced membrane, which is actuated by electromagnets, coupling together tactile/kinaesthetic input with tactile/visual output. It attempts to make the tangible-logical mapping more exciting. Both examples have aspects of natural interaction as the UV light directly points onto the surface of the turntable, and the tactile aspects of the membrane draw the users to touch it. Hartson calls these sensory affordances (Hartson, 2003).

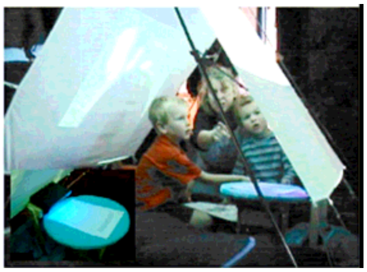


Figure 7.4 The Storytent (Stanton et al., 2003)


Figure 7.5 Super Cilia Skin (Raffle et al., 2003)


Figure 7.6 The Drift Table (Gaver et al., 2004)

7.2.3 Bounce Back

Previously, we have seen how bounce back allows the user to manipulate the physical control and use it to 'control' the logical function(s). We will look at the interaction of a piece of interactive household furniture called the Drift Table (Benford et al., 2003). This is a coffee table (see figure 7.6) that comes with an aerial view of Great Britain. The movement of the map of Great Britain depends on the amount of weight put on the table, and its duration. Load sensors at each corner of the table measure the distribution of weight. If the things on the table are slightly heavier on the right-hand side the map drifts slowly, like a balloon in a breeze to the right over the aerial view and vice versa. This is therefore a very natural mapping of direction of movement.

For the Drift Table, the bounce back does not occur in the physical appearance of the table, but on the load sensors. They do in fact give very slightly depending on the weight, but not noticeably. The only way to see whether the weight distribution of objects is neutral is to watch the view to see if it slowly changes. Furthermore, the table does not give the user any direct control or indication of overall location, just the speed of the movement and its duration. In fact where it was deployed in a home the user kept atlases nearby in order to work out where the table was. This appears to suggest the Drift Table is a very bad example of a physical control. But in fact the intention of Drift Table is not functional but aesthetic and ludic – it is a form of play. The natural mapping of direction of pressure to direction of movement while you are explicitly 'controlling' allows skillful activity, but when unattended it 'drifts' and gives a sense of happenstance.

7.2.4 Inverse Actions

Most tangible devices exploit *inverse actions*, which allow the users to undo and reverse the actions, for example, Phicons in metaDESK (Ullmer and Ishii, 1997) and Senseboard (Jacob et al., 2002). At one level the invertibility is there by virtue of the physicality of the tokens being used to control the manipulation. However, it is not a necessary property of the augmented system but depends on there being a functional relationship between the state of the physical tokens and the state of the logical system. For example, Senseboard has been used to organise conference paper sessions (see figure 7.8). It is designed to show conflicts, but an alternative design might have had the users manipulating just some of the papers physically and others being reorganised by the system to maintain constraints. When a paper is moved by the user the system would reorganise the rest, but then it could easily be the case that moving a paper and then moving it back did not lead to the same overall situation. The same thing occurs with a word processor if you move the cursor down and then up when at the bottom of the screen. It is relatively 'easy' to make tangible interfaces obey the inverse action principle, but still needs to be considered explicitly in design.

Figure 7.7 Great Dome phicon (Ullmer and Ishii, 1997)

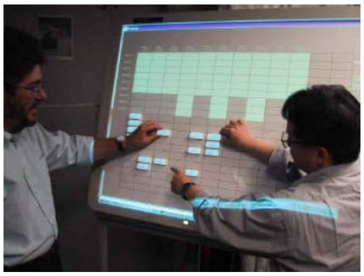


Figure 7.8 Senseboard (Jacob et al., 2002)

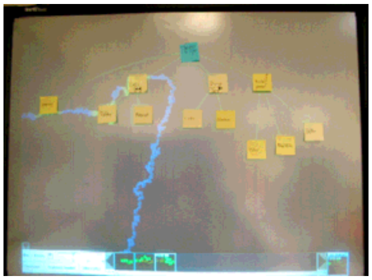


Figure 7.9 The Designers' Outpost (Everitt et al., 2003)

Although these systems support inverse action, they do not have a real ‘undo’ in that they do not provide or represent the actual “path” of movements that have been made. Thus the user performs the reverse action(s) depending solely on what they can remember. One example that actually records and displays the history of the movement to allow inverse action is The Designers’ Outpost (Everitt et al., 2003), which is about organising information of Post-it notes that are used as the physical media.

Although in some ways this is similar to GUI ‘undo’, which in direct manipulation this focuses on rapid, reversible and incremental feedback (Shneiderman, 1983), there are differences. It exposes several purposes of ‘undo’ or invertible actions in GUI systems that are usually elided:

i. to correct slips immediately,
ii. to allow ‘homing’ actions such as mouse movement or rapid cursor movement,
iii. to allow low risk exploration of alternatives,
iv. to ‘turn back the clock’ when after several actions some problem is found

In GUI, (iv) requires some form of multi-step undo menu, (ii) and (iii) are typically achieved using invertible actions, although using an explicit ‘undo’ button for (iii) is possible, and (i) may be achieved using either invertible actions or undo depending on the erroneous action. Bellotti et al. (2002) find existing sensing systems are still lacking in dealing with failure modes and errors by not providing sufficient undo for backward error recovery.

However, (iv) is most needed when there are large amounts of hidden state, or complicated computations so less relevant for tangible user interfaces (TUI). The focus in tangible interfaces is less about backward error recovery, restoring a past state, and instead more about forward error recovery, moving on from where you are towards a goal (Abowd and Dix, 1992).

7.2.5 Controlled State

Many tangible devices we have come across were under the complete control of the user, and there was hardly any limitation to the way the reverse manipulation is being constrained as we have seen in some of today's appliances (see 3.3.3). The closest example of a tangible device that has a criterion of its physical effect or feedback is being controlled by its logical behaviour rather than by its physicality is POUTS pin (Ng et al., 2005). POUTS pins use tangible technology to pop out in response to digital manipulations, for instance, a physical document which was pinned using POUTS can be ejected at a set of time (see figure 7.10). The limitation which POUTS pins have is a weak constraint, as user can still pull out the pin physically, but by doing so, it will disrupt that particular pin's application.

7.2.6 Compliant Interaction

It was quite difficult to find examples of tangible devices that have all of the properties that make one has *compliant interaction*. Most of the existing tangible devices let the user easily learn the relationship between the physical and logical states that enable the user to have control over the system actions. Often these system actions are virtual (e.g. projections as in Illuminating Light), but there are examples of physical effects being produced. For instance, Actuated Workbench moves objects (magnetic pucks) on a table in two dimensions by using magnetic forces (Pangaro et al., 2002) – see figure 7.11. The user controls the graphical output by manipulating the physical input, which is composed by positions and movements. The input is tracked and responded to by the workbench.

Rototack allows the user to have control over the system's action (Wrensch et al., 2000), thus it exhibits symmetry of interaction. Rototack (see figure 7.12) is a small computationally-enhanced tack that provides a source of programmable rotational motion provided by a small stepper motor. Although a user has control over the tack, the sense of control comes in a more subtle way, i.e. by writing a program for the tack, instead of physically manipulating the tack itself. The tack then in response runs its program and advances as desired by user. The user can stop the program at any point; even this means that the tack has not yet completed its cycle.

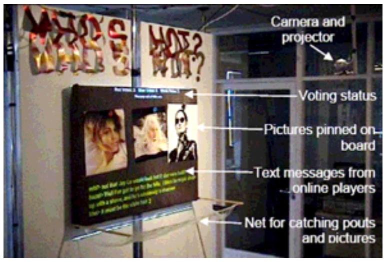


Figure 7.10 POUTS pins in operation (Ng et al., 2005)

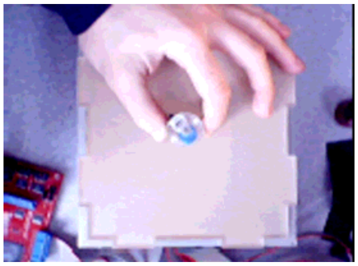


Figure 7.11 Actuated Workbench (Pangaro et al., 2002)

Figure 7.12 The Rototack (Wrensch et al., 2000)

The above examples show that the physical design principles can be used to analyse existing tangible devices and expose where they exhibit natural interaction. We now will see how these findings fit more broadly within a tangible user-interface framework.

7.3 A Tangible User Interface (TUI) Framework

We choose the TUI framework by Koleva et al. (Koleva et al., 2003), among others, because it is based around the idea of the "degree of coherence" between the physical and digital objects. We see a correlation between coherence and the design principles we are seeking. As there is a variety of tangible systems that have been developed to date that illustrate tangible interface principle, we are keen to learn what are the characteristics or features that these tangible systems have as we go along the coherence level, against our design principles, which is aimed at producing natural interaction.

The framework places TUI objects into six proposed categories of TUI types that depict the relationship of physical and digital objects. These categories are positioned along a 'coherence' scale based on five properties that are used to describe the physical-digital links. The TUI categories are as follows, moving from low coherence to high coherence:

- *General-purpose tool* – a tool that gives the user a choice to manipulate any one of many digital objects and perform different transformations. It establishes the weakest level of coherence
- *Specialised tool* – objects that have a more specialised function, yet still temporarily connect to potentially various digital objects

- *Identifier* – interface objects that act as bookmarks for retrieving computational artefacts
- *Proxy* – interface objects that are of proxy category are more permanently associated with, and allow a more extensive manipulation of their digital counterpart
- *Projection* – digital artefact that is seen as a direct representation of some properties of the physical object. Its existence is dependent on the physical object
- *Illusion of same objects* – this category has the strongest coherence. Objects that fall into this category give the illusion that the two coupled objects are one and the same

The physical-digital links can also be described in terms of their five properties:

- *Transformation* – this describes whether the effect mediated between linked objects is literal or transformed
- *Sensing of interaction* – this describes what interactions with the interface object and its surrounding environment are sensed and transmitted to the destination object
- *Configurability of transformation* – this describes whether the transformation mediated between two linked objects remains fixed for the lifetime of the link or whether it is configurable over time
- *Lifetime of link* – this describes for how long a physical and a digital object remain linked
- *Autonomy* – this describes to what extent the existence of the destination object is reliant upon the existence of the link and the source object

Although individual TUI objects and applications exhibit differing spectra of properties, there is a general correlation between the scales giving rise to an overall ‘level of coherence’ continuum. This is illustrated in figure 7.13. A range of TUI applications and devices, including most of those examined in the last section, are placed into the categories.

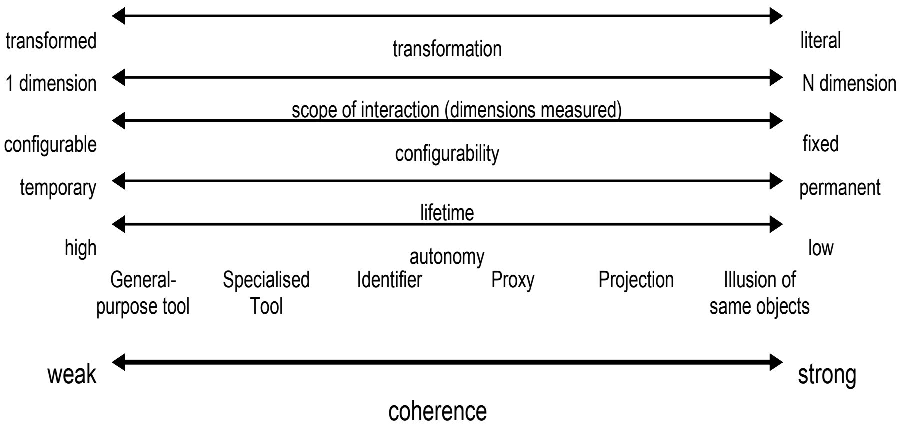


Figure 7.13 TUI categories along the coherence continuum (from Koleva et al., 2002)

7.3.1 Impact on TUI Framework

Just as individual, TUI objects vary in their spectra of coherence properties. They clearly also differ in the extent to which they satisfy the various physical design principles. In general, high coherence and satisfaction of 'good' principles are related; however, some of the principles seem particularly related to particular categories. So, we will explore the findings from the previous sections against the properties and categories of figure 7.13.

Exposed State Collaborage (identifier), Marble Telephone Answering Machine (specialised tool), Illuminating Light (specialised tool), Actuated Workbench (proxy), and Rototack (projection) all exhibit exposed state. However, when we categorise them according to the TUI categories (see brackets) the categories that exhibit exposed state the most have both strong physical-digital links and natural interaction and range from the 'proxy' category, to 'illusion of same objects' category. In addition, the examples that fall within these categories all have fixed configuration and permanent lifetime. The stronger the coherence, the more dependent autonomy the objects have (Rototack has dependent autonomy, whilst Actuated Workbench is autonomous) and of course exposed state is most effective with a fixed relationship between device state and logical state.

The Cubicle used to control the feed into the situated display in the seating area has each of the sides labelled with the possible feeds into the display. It thus exhibits the fixed configuration property suggesting the proxy category. However, this relationship between labels and functions is highly symbolic and is also malleable in the long term, rather like written labels on function keys on a keyboard. The Cubicle thus has a ‘feel’ more of a specialised tool. Although it has an exposed state the affordances are exposed linguistically rather than through its intrinsic properties.

Hidden State Identifier, Specialised tool and Generalised-purpose tool categories tend to exploit the hidden state principle because they are likely to be mapping the same physical device to different logical states. The Storytent for example, belongs to ‘specialised tool’, whilst the Super Cilia Skin belongs to the ‘identifier’ category. The nature of these three categories is that the mapping of the representation of the physical and digital is not that direct, comparing to the proxy categories and beyond. The weak coherence that the objects exhibit, for example, the Storytent, is also indicated by fixed configuration, temporary lifetime and autonomous properties.

A different experimental use of the Cubicle as AV controller uses an unlabelled cubicle and gestures to navigate between feeds and to control options for each feed (e.g. navigate in web browser, adjust volume of video playback, etc.). This is clearly an example of hidden state and more clearly belongs to the specialised tool category as it temporarily connects to many different digital objects, for example, TV tuner and fixed computer. Being able to consecutively link to different digital objects in the lifetime of the application shows that the Cubicle has the temporary lifetime property. The cubicle also embodies the fixed configuration property.

Note how the Cubicle’s classification depends on its visual decoration and application context. Both the physical interaction principles and the TUI framework properties are not about a device in isolation, but about the device in an interaction context.

Bounce Back Bounce back principle is described perfectly by these following two properties: its scope of interaction is configurable, which the transformation mediated between two linked objects is configurable over time, and, it exhibits a very strong temporary lifetime of link between a physical and a digital object. The two TUI categories which meet these descriptions are Specialised Tool and General-purpose Tool, and the Drift Table is an example of a General-purpose Tool.

Inverse Actions All tangible devices from 'identifier' category to 'illusions of same objects' category seem to exploit the inverse actions principle. However, previously we have seen that most of the tangible devices that fall in these categories do not provide the user with the actual 'path' to perform undo/redo actions, but rather a more local ability to simply 'move back'. This gives rise to a strong physical-digital mapping and exhibits natural interaction. For example, The Designers' Outpost, in particular, has a literal transformation in that its physical movement gives an effect of moving the digital object, with permanent lifetime. As we discussed when looking at consumer appliances, the inverse action principle is very important when the user does not have a clear idea of the effect of the action, allowing exploratory interaction; that is where configurability is high and lifetime low. Paradoxically inverse effects are exhibited most in high coherence objects, but perhaps required most in low coherence.

Controlled State As per described in section 7.2, the limitation or constraint found in tangible objects is not exhibited by the tangible object or tool, but rather the limitation is more likely due to the 'soft' constraint imposed by the system. What this means is even if a user can manipulate the tangible object, it is constrained by the disruption it might cause to the system. This type of limitation does not restrict to one TUI category only as all categories in some ways exhibit this 'soft' constraint criterion.

Compliant Interaction As we saw, compliant interaction is related to exposed state, which is common in TUI applications. However, in addition to this, those tangible devices that exploit this principle show a strong and symmetric coupling of the physical and digital link. The examples that most closely exhibit this, the Actuated Workbench, and Rototack, are of the 'proxy' and 'projection' categories. In general, the tangible devices that fall in 'proxy' category to 'illusion of same object' category are most likely to exhibit compliant interaction. However, as we have seen few of the tangible devices exhibit really symmetric interactions, due partly to the difficulty of engineering haptic feedback on untethered devices.

Figure 7.14 shows the property settings and level of coherence from figure 7.13 amended based on the impacts made by the physical design principles. From the diagram, we can say that the stronger the coupling of the physical and digital, the more natural the mapping, hence giving a more confident interaction.

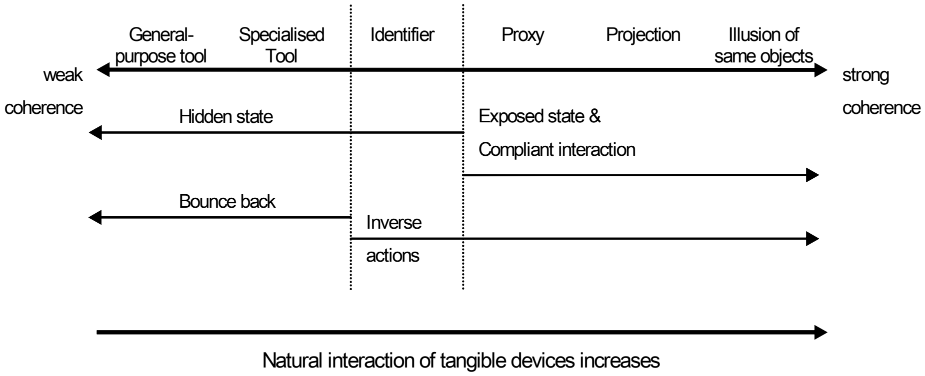


Figure 7.14 Principles of naturalness and levels of coherence

7.4 Guidelines for Tangible Controls

The analysis has given us the understanding of in what way the design for tangible control can be realised. We have summarised some of the broad guidelines which illustrates the contexts where the principles, or the design characteristics can be applied. We will precede with a meta-organisation of the principles and the implicit properties which have been mentioned in previous chapters to give us an overall view of the principles (as shown in table 7.1).

We identified two main groups: statics and dynamics to illustrate a higher level of the design principles. Exposed state, and its opposite, the hidden state, are the two statics design principles, whilst we have transitions and reversibility characteristics that described the dynamic nature. The third level of the table shows the implicit properties are shared across all these design principles.

<table>
<tr><th rowspan="2">Statics</th><th colspan="2">Dynamics</th></tr>
<tr><th>Transitions</th><th>Reversibility</th></tr>
<tr><td>Exposed State
Hidden state</td><td>Tangible Transitions</td><td>Bounce Back
Inverse Actions
Compliant Interactions</td></tr>
<tr><td colspan="3">Intrinsic exposure control
Semantic feedback
Distance, spatial
Transitory, transient state
Nowness, simultaneouity
Temporal locality
Emulation
Aesthetic, decorated control
Embodiment</td></tr>
</table>

Table 7.1 Meta-organisation of design principles and their implicit properties

In the following table, we present broad design guidelines (summary) for tangible controls. We juxtapose each of the design principles in the way how it was applied in physical and tangible devices. By doing so, we can see how the concepts were applied according to context, and consequently, we can use the information as a starting point for us to generate ideas in designing tangible controls.

Design principles	Physical devices	Tangible devices
Exposed State *visible and direct mapping between physical-logical states	Direct mapping between the physical appearance and logical state (3.2.1) Visible state of a control can only be used when there a number of corresponding number of internal states (3.2.1) Easy to apprehend – low mental requirement & strong cultural influence (5.2)	The logical (digital) is the direct representation of the actual thing (7.2.1) Recommended for objects of Proxy, Projection & Illusion of Same Objects, categories (7.3.1)
Hidden State *the absence of exposed state	When used, must be decorated to clarify states (3.2.2, 3.4.2) Can be exposed with movement(s) (4.5) Not so easy to apprehend – slightly higher (than exposed state) mental requirement, but strong cultural influence (5.2)	Adopted intentionally for specific purposes, e.g. to make the interaction more exciting (7.2.2) Recommended for objects of General-purpose Tool, Specialised Tool & Identifier categories (7.3.1)
Bounce Back *physical state remains unchanged, or return to its original position over time despite the change in logical state	Recommended in the following conditions (3.2.5): • where there are a large & variable number of logical states • where the devices are small or compact	Comes in the form of play – aesthetic & ludic (7.2.3) Recommended for objects of General-purpose Tool & Specialised tool categories (7.3.1)

	• where safety is critical • when aesthetic becomes the focal point in the design	
Inverse Actions *inverse logical effects being exploited by physical opposite states	To allow undo, or backward action to recover immediate mistakes (3.2.6) To allow exploration of the device (3.2.6) To allow overshoots in ‘homing’ or rapid target selection tasks (3.2.6) Seemed to be the most ‘natural’ feature – weak cultural influence & low mental requirement (5.2.2.4)	Allow low risk exploration of alternatives (7.2.4) Recommended for objects of Identifier, Proxy, Projection and Illusion of same objects category (7.3.1)
Compliant Interaction *shows the symmetrical aspect of user–system interaction	Enable expert users to use the device to exert fine control over the system’s action (3.2.7) Program advances using mechanical movement (3.2.7)	For passive devices, system / application can be the alternative to show the advances of movement (3.4.4) Using magnetic force, instead of mechanical movement (7.2.6) Program can be intervened in a subtler way, i.e. writing a program, instead of physical manipulation (7.2.6) Recommended for objects of Proxy, Projection and Illusions of same objects categories (7.3.1)
Controlled State *limitation imposed by the devices preventing user to return physical state to original position	Constraints mostly to do with mechanical mechanism used to emphasise the necessity of the logical process (3.2.3)	Limitations are to do with digital manipulation (7.2.5)
Tangible Transitions *the emphasis which is given to enhance the change of states	Augmenting exposed state, & exposing hidden state’s while-use (3.2.4) Useful in following conditions (3.2.4): • When designing haptic interaction • To make users aware of the transition that they are making (can also become critical transition) • When user cannot give full attention to device control, e.g. can only glance when manipulating the control	(no examples found in tangible devices) Potentially (3.4.4): • gyroscope to give controllable resistance to rotation • ball-bearing to enhance ‘joystick’ effect

Table 7.2 Broad design guidelines for tangible designs

7.5 Reversibility in Tangible Interaction

What makes inverse action design principle different from the rest is the way it requires low mental effort from the user's part and it does not depend on the conventional learnt understanding (refer to Chapter 5: Table 5.1). When physicality adopts this particular design principle, it has proven to be very useful as shown in both of our user studies: the Cubicle and Cruel Design. When inverse action design principle exists, then there is coherency between the human innate ability and physical devices. This coherency makes an interaction come naturally to user.

Inverse action can also be exploited in other kind of forms which has reversible effect, such as in bounce back, controlled state and compliant interaction. Bounce back has an intrinsic reversible effect, which can be seen in most of PC's on/off power button. Controlled state refers to the form where the inverse action is constrained or limited (e.g. toaster), but reversible effect is possible by the means of a button to reset. Whilst the washing machine, an example of a compliant interaction, has to complete a full cycle before it can have the reversibility effect. As what have just been described, the reversibility effect in these forms, however, may not be the same, as clear, or as straightforward as in inverse action *per se*.

One of the benefits of inverse action is it is extremely important to recover immediate mistakes especially in the act of exploration. And exploration is what it is all about in tangible interaction. Tangible prototypes and tangible devices always attract and invite users in their own special way to interact with them. Natural inverse, thus, is important in the tangible interaction to give a positive encouragement, recovering from mistakes and to give users a sense of control (Ghazali & Dix, 2006). Furthermore, from figure 7.14 above, the inverse action design principle within the Identifier TUI category becomes stronger in coherence as it moves towards the Illusions of the Same Objects category.

From section 7.2.4 above, we have seen the many kinds of inverse action in the tangible prototypes and tangible designs. In tangible environment, the inverse action does not act in the same way as the typical inverse action in the physical world. The reason being is, the manipulation that takes place is not with physical, but is with tangible object. Tangible objects are tied with digital functionality, in which the tangible state does not necessarily correspond to the underlying logical state. This is the case when although an object can be moved physically (or tangibly) from point A to point B and inverse it back to point A, the underlying system does not necessarily stay the same. This has definitely created more complex functionalities in the design of tangible interaction, but the downside that we are facing at the same time is the confusion the user gets with regard to forward recovery, in which the past state is not recovered (see figure 7.15).

In Voodoo I/O Kit (Villar et al., 2006), the physical and the logical settings preserve natural inverse actions. Although it is not explicitly stated in the paper of the preservation of natural inverse actions that makes it easy for users to manipulate, we think the proposed concept of *appropriable* in gaming devices (Villar et al., 2006) would be one of the ways to overcome this confusion. Appropriable concept allows users the freedom to define their own understanding of mappings between the physical (or tangible) object and the underlying functionality.

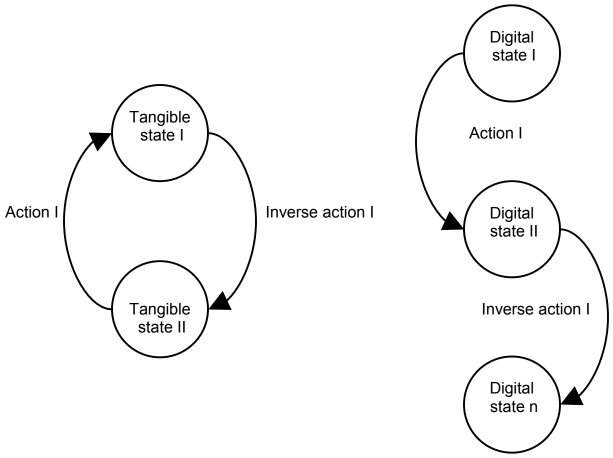


Figure 7.15 Confusion in tangible interaction

7.6 Discussion

Exposed state and inverse action seem to almost follow by course from the physicality of tangible interface objects. However, this only follows for their own physical state and not the logical functions and state influenced by them. These need to be explicitly considered during TUI design not left to chance. Compliant interaction seems to be extremely powerful where it is employed in consumer devices leading to clear state, ease of discovery and natural control. It effectively emulates the symmetry when we as people collaboratively manipulate an object with each other. However, the difficulty of symmetric haptic feedback means that few current interfaces make use of this powerful technique.

Although some of the principles are generally 'good' ones: exposed state, inverse action, compliant interaction; there are circumstances where they are and should be broken. For example, if there are many states or a variable mapping then exposed state is not possible. Furthermore, we saw that 'bad' interaction is sometimes good interaction for ludic purposes.

We have seen that many of the physical design principles and the TUI coherence properties relate not just to a device in isolation, but instead to a device with an associated physical–logical mapping. Because of the experimental nature of tangible interfaces and more broadly ubiquitous computing, it is frequently the case that a device is used in one application only. It is therefore easy to elide the intrinsic properties of a device or mode of interaction with the application for which it is used.

We believe the dynamic characteristic of reversibility, particularly the inverse action, is to be a very important principle in the design of the tangible device. It has been shown from our previous user studies (Chapter 4 and Chapter 6) that physicality that exhibit inverse action design principle makes an interaction come naturally to user. This together with its potential to assist in the act of exploration will definitely benefit in the design of tangible interaction.

Although we are aware of the fact that the novel interaction devices are already in existence, there are benefits that TUI designers can learn from our approach. The adapted TUI framework, figure 7.14, can be referred to, to inform what are the design characteristics that influence the coherence natural level of tangible devices, in the pre-development phase. Whereas the Meta-organisation, from Table 7.1, informs the behaviour of tangible devices, whether it would be static or dynamic, and what are the design and implicit design characteristics involved with these two types. The Meta-organisation works hand in hand with the Table of Interactions (table 3.1 from Chapter 3) which provides details of all the design characteristics to give a quick comparison with today's existing objects. Whilst table 7.2, the Broad Design guidelines provides clear recommendations on what ways to adopt the conceptual designs principles onto the design of tangible devices. Our approach would be beneficial in terms of providing insights toward what have been done and what are the common conceptual design features, among others, to TUI designers.

7.7 Conclusion

This chapter has enabled us to see how the principles from Chapter 3 correspond to generic categories of tangible interface objects. We also have summarised some of the broad guidelines that emerge from this discussion although we would not regard these as definitive. These guidelines emerged from examining the day-to-day artefacts and were largely followed by many of the tangible interfaces. Amongst the issues that arose are worth noting, particularly the characteristic of reversibility in tangible interaction.

In short, this chapter can be concluded as follows:

- As we believe the knowledge that we have about everyday appliances and artefacts can assist us in designing and developing novel devices, we probed into the existing tangible devices to look at where in the design space of tangible interaction the principles can contribute to improving designs, besides to extend our understanding of computationally coupled physical and digital objects
- Despite the existence of novel interaction devices, our approach provides ways or methods in improving the design of tangible interface and controls. By referring to what we have: the adapted TUI framework, and, the meta-organisation of design principles and their implicit properties, could inform the designers of the design characteristics that influence the coherence natural level of tangible devices. Furthermore, the designers would be able to assess

other potentials and possibilities by looking at the spectrums of the framework. Whilst the broad guidelines, which juxtapose how the application of the design principles exist in today's appliances and in the existence tangible devices, would assist the designers to grasp quickly the concept of the design principles

- This chapter has also among others, identifies areas that can be explored further, such as the reversibility misconception that normally exist in the tangible interaction. This is an interesting aspect as it can be both an advantage and disadvantage in an interaction

Chapter 8

Conclusions

8.1 Reflection on Methodology

The nature of approaches that have been taken to the methodology of this research work made us decided to place the methodology section towards the end of the thesis instead of at the beginning. Thus, reflecting and referring back to what have been carried out are seemed to be more appropriate, rather than describing what was supposed to be undertaken, in the beginning of the thesis.

There are two research methods which were adopted in this research work: exploratory research approach, and, experiment methodology. The following diagram illustrates the adopted research methods of this research in a glance.

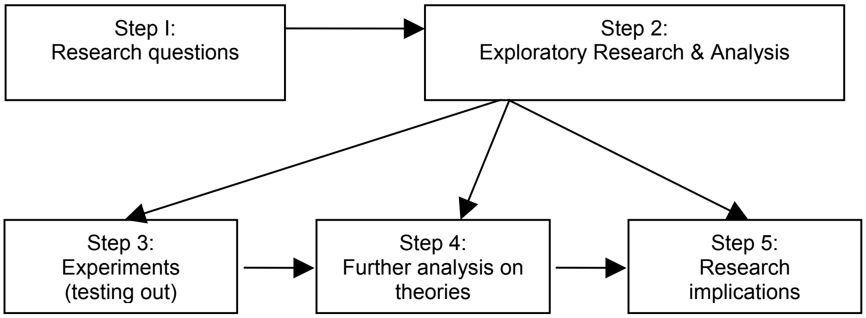


Figure 8.1 Research methods in a glance

8.1.1 Exploratory Research

> *"This is the type of research that is involved in tackling a new problem/issue/topic about which little is known, so the research idea cannot at the beginning be formulated very well. The problem may come from any part of the discipline; it may be a theoretical research puzzle or have an empirical basis. The research work will need to examine what theories and concepts are appropriate developing new ones if necessary, and whether existing methodologies can be used. It obviously involves pushing out the frontiers of knowledge in the hope that something useful will be discovered."* (Phillips and Pugh, 2000, p.50)

The nature of an exploratory approach has allowed this research to evolve and to progress, which subsequently led to new ideas and challenges. With the research goals in mind, the obligatory review of literature and available information was carried out on what were deemed to be potential areas. Topics which cover the concept of affordances, interaction designs and engaging experience were explored and research questions were raised.

Exploratory approach plays a crucial part in how we began our study on consumer appliances, inspired by our motivation which was described in section 1.4. We began by looking at the appliances we use everyday, which situate at homes and offices (which also includes flipping home catalogues such as Ikea and Argos), and also devices which are found at public spaces, to gather as much as possible examples of things we interact with everyday.

In order to derive to and to discover what could be useful from the results, the gathered information was studied and analysed.

8.1.1.1 Analytical Method

Selected literature domains, as mentioned above, and gathered information were analysed and examined thoroughly to generate and to derive to own ideas and theories. There were several kinds of analytical method that had been used on the exploratory findings. In the early stage of this research, ‘Venn Diagram’ structure was used to study a relationship by treating their conditions as sub-sets. By doing so, it allows conditions that at the normalcy, these conditions wouldn’t be considered, or being taken into discussion. A very good example of how method was used can be found in Appendix I, where a relationship between fun and engagement was studied. Ultimately, this method has helped in providing insight as to whether ‘engagement’ must exist for an experience to be considered as fun.

The second method used was the State Transition Networks (STNs) diagrams. The STNs are the most common practice in the dialog design, and are the most commonly used, and is one of the many diagrammatic notations available for the designers besides Harel’s state charts, traditional flow diagrams and JSD diagrams (Dix et al., 2004c). The STN shows states by illustrating each system state in a *circle* and connect the states with *transitions*, which are illustrated by arrows. The arrows are to show the flow of states of the system, for example, if an action is taken by a user when the system is in state 1, the arrow will direct to state 2. The STN dialogue notations are very helpful when it comes to prototyping as it illustrates the states and actions of a system and giving an idea in a glance of how a system works, or responds in the event of actions taken by users.

In this research work, simple state transition networks (STNs) were used as one of the techniques to represent separately the states of the device and of the underlying logical states, to examine the relationship between the two. Although it was stated that the STN do not have clear description in representing communication between application or presentation (Dix et al., 2004d) the approach that has been taken in this work is by showing not just the system (digital) STN states, but also by describing the STN of the physical states of the device, and having these two STNs juxtaposed to each other. By doing so, the relationship between the physical and logical states can be clearly seen. This can be found in chapter 3, which is dedicated about the relationships of the physical and logical state.

The status–event analysis is normally used to model an interactive system by distinguishing events from status. Dix et al. (2004f) describe the status–event analysis as a way to distinguish *"events that occur at specific moments of time from status phenomena that have (typically changing) values over a period of time*". We used the status–event analysis to illustrate the relationships between the user, physical and logical to identify the causes of feedback in interactions as elaborated in Chapter 5. Besides distinguishing the status and events and identifying the causes of feedback in interactions, there were few additional notations which have been added to the status–event analysis to make them more meaningful. For example, a 'triangle' is added to show the increment and decrement of sound volume as the effects of the physical knob is being changed (figure 5.9). Another example is the way we highlighted the timeline (in thicker line) in corresponds to the changes of the physical and logical states.

8.1.1.2 Theoretical Analysis

A thorough and careful analysis was taken onto findings assembled from previous analytical method in order to construct theories and ideas that would be the ground of the large part of this research work. The theoretical analysis encompasses acts and processes such as finding the most significant patterns or features, and, coining and introducing new terms. The work on Natural Interaction principles (from section 3.2) depicts this.

This particular process is not just being applied in the early stage of research work, but also in every post experiments, which are also seemed to be the crucial stage in this work. Visceral Interaction (see section 5.4) is the best example in how this was carried out.

8.1.2 Experiment Methodology

Experiment methodology is used for both user studies: The Cubicle (Chapter 4) and Cruel Design (Chapter 6), which consists of hypotheses, subjects, procedures, methods and analysis of results. Hypotheses normally come from the proposed ideas from the previous findings. These were put to test by applying them in the design and implementation of prototypes and case studies to prove their feasibility.

In the design of the Cubicle user study, the theories of ‘what makes a good design success’ were used in designing the appearance and functionality of the Cubicle (see Chapter 4 for details). Appendix III describes how the design questions were derived. Whilst hypotheses that feed into the second user study comes from the findings of Visceral Interaction from Chapter 5.

8.2 Summary

This research offers new ways to understand the design with regard to tangible controls. This research has explored natural interaction, which recently has become a favourite subject in interaction design, which its presence is seen to be crucial in preserving the interaction to be natural, i.e. easy to use, useful and effortless. In tangible computing, a plethora of tangible artefacts and devices have been developed. As the motivation behind tangible computing is about enhancement and augmentation of physical objects to be digitally linked, many of the tangible artefacts have the characteristics of physicality – which by default should come naturally to users to use. But often the design of tangible artefacts is not as straightforward as it seems, and sometimes does not come natural to users. Conventional definition of natural (interaction) and good design always find themselves to be closely associated with the concept of affordances. But, at presence, for an interaction design to be natural, there is no one clear and definite answers to this quest.

We are proposing a new understanding of natural interaction which stems on two things: (1) visceral quality of physicality in the design, and (2) innate human abilities. In the design community, the interpretation of natural in interaction is often just about the good relationship between function(s) and action(s) which should produce an easy to use and effortless system or device. In this thesis, however, we explored the nature of physicality by studying day-to-day appliances to discover good (and bad) designs that makes them comprehensible to use. This thesis then has led us to *visceral interaction* which derives from the *natural inverses* property of the design.

Invertibility characteristic or reversibility in general, fits the two criteria that makes natural interaction. This type of manipulation requires low cognitive understanding and proves to be important in exploration – reduces the chances to get it wrong (see figure 9.1 below to see the position of *inverse action*). Thus, we see natural inverses to be an important characteristic in the design of tangible interaction, as it strokes positive encouragement, recovers from mistakes and gives users a sense of in control. The challenge in the design of tangible interaction, nonetheless, lies in preserving the flow of the state changes of the functionality.

Motivated with the design of tomorrow, we began this thesis by reviewing relevant concept of affordances, mappings and meanings in interactions, engaging experience literature which provided the underlying theoretical support for natural interaction (Chapter 2). Next, physical controls of current day-to-day appliances that correspond to natural physical interactions were studied. Design principles and implicit design properties were presented (Chapter 3).

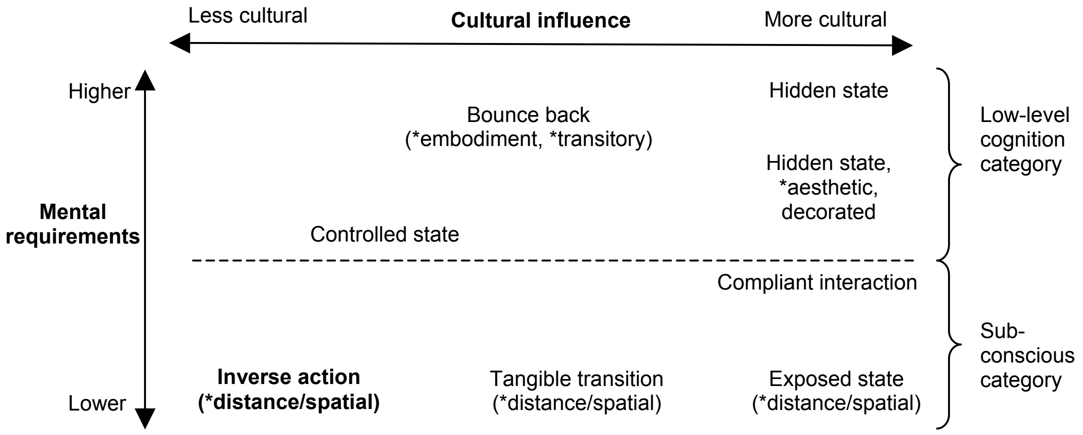


Table 8.1 Inverse action property against the rest of the design principles from the cognitive understanding perspective

Next, we described a detailed implementation and user study using the design principles for a particular novel interaction input device, the Cubicle (Chapter 4). First, a series of semi-exploratory studies was conducted to investigate whether users are able to understand 'soft', re-programmable mappings and also the playfulness of the Cubicle. Primarily, we wanted to gain insights into the four designs of Cubicle which differs in the cognitive complexity of the mapping between physical cube and on-screen cube. Although the designs differed markedly there was no measurable difference between them and instead in all cases participants failed completely to understand the mapping. However, surprisingly, the users were able successfully to manipulate the cube to select a movie and furthermore enjoyed the process. We believe this is partly due to the preservation of a key visceral quality in the design. We set out to gain further understanding of the relationship between the innate human abilities and physical characteristics.

In Chapter 5, an in-depth discussion on interaction between the physical–logical states and the user is undertook to observe the implications of the design principles and the implicit design features on the relationships from the perspectives of cognitive understanding, i.e. amount of mental effort one has to put in, and feedback i.e. as to see what causes the feedback: user and/or physical and/or logical states. Whilst these reflect the important of coherency and calibration between the three states, the momentary mapping from the Cubicle study proves how natural inverse comes naturally to users to help them in situations where there is no calibration going on between the physicality one is controlling and to what is being controlled – Visceral Interaction.

Chapter 6 is a user study which follows up the relationship between the physical and cognitive mappings. In the Cruel Design experiment, we wanted to look further into the association between physicality and inverse action. Most importantly we wanted to observe whether there is any difference in users' actions in different conditions where the cognition and the physical mapping is swapped around. The results show that condition with poor cognition helped participants in getting the correct movement faster. Whilst inversing an action of the same controller (regardless the type of mappings) is the natural reaction when there are overshoots.

An analysis on how the successful of physical interaction can be applied in the tangible design is undertaken by examining several examples of tangible devices that embody the design principles (Chapter 7), and the impact on an existing TUI framework is examined. A broad guidelines are presented that should assist in designing tangible controls. In particular, the design feature of inverse action, or reversibility in general, is thought to be something that is worth noted in developing tangible controls to produce natural interaction.

8.3 Contributions

The main contribution of the thesis is the exploration of physicality to understand natural interaction and how this understanding can be applied onto a bigger picture – novel tangible devices.

We believe our research has successfully made a number of novel contributions. The objective to understand physicality in order to make us understand better the interaction between the physical and digital, though was thought to be similar to what Donald Norman did in his book *The Design of Everyday Things* (2002), provides deeper understanding of everyday things. We focused on the use of physical design and identification of physical design characteristics. Furthermore, our notion of understanding physicality is expanded from the concept of fluidity – as described in section 2.4 and 3.2, which looks very closely at the physical and logical relationships.

We have also presented the concept of natural interaction with regards to physicality. Certain physical properties can recruit our innate human abilities. Natural inverse plays an important role in creating momentary mappings to help users in achieving their tasks. We call this Visceral Interaction. In addition, human abilities to perform inverse action in random mappings do not highly rely on good cognition. Instead, between physical and cognition, participants performed best when all they have to rely on is the physical controllers.

In the bigger picture, our findings provide theoretical grounding for tangible design. Despite the fact that there are already novel tangible devices in existence, the TUI designers can find our theoretical grounding beneficial in many ways. Whether the TUI design has already been carried out, or is about to take place, the adapted TUI framework that we proposed and the meta-organisation table (which works together with the Table of Interactions) that we presented are able to inform the designers of the design characteristics that influence the coherence natural level of tangible devices. Furthermore, the designers would be able to assess other potentials and possibilities by looking at the spectrums of the framework. Thus, these can help the designers either to improve the existing tangible devices, or, to explore the way they want to present the design of the TUI.

Although to some extent the applicability and scalability of modelling approach of finite state diagram can be adapted to the tangible devices – as we did to the Cubicle, we however don't encourage this step to be taken, as most of tangible devices characteristics are different to today's physical controllers. The theoretical grounding that has been presented would be the recommended approach in applying the findings of the design principles on tangible devices.

Having carried out this research, we believe we have achieved our objectives, which were outlined in chapter 1 (section 1.5). With the aim of informing the design of tomorrow, particularly in the context of tangible devices, we have taken the foray to understand the physical and digital interactions by taking a step back and look at the physicality to understand what physicality really is. Despite of the certain aspects that we had to encounter with, such as in terms of the range of today's appliances and the question of when to stop looking when it comes to the analysis stage, a number of tangible devices which are already in existence and how this would affect our theoretical grounding for tangible design, and another example of qualitative question - such as our justifications in gathering information of the usage of today's appliances via informal discussion with users in spite of including the product designers, we are confident that our findings have discovered aspects that we usually overlook, that if these are properly analysed and applied can be beneficial and useful in a different and bigger context. In our study, the properties of everyday things do not just made us aware of the characteristics that make our interactions fluid and natural, but few of these properties can also recruit our innate abilities. The application of the theoretical findings in the tangible design aspect should be promoted to TUI designers to further inform them the options that are worth considering when developing and designing tangible artefacts.

Overall, the contributions of this thesis can be summarised as follows:

- Inverted the usual structure of tangible media/ubiquitous device design studies. Rather than design and develop a device to explore the design space of tangible devices, physical interactions with everyday artefacts were studied.
- A set of good design principles and implicit properties of physical controls.
- Showed how coherency of mappings between physical and logical states is crucial in producing fluidity in interactions.
- Experimental on the Cubicle discovered how momentary mapping during visceral interaction helped in situations with no coherency of mappings.
- Refined the set of design principles from the perspectives of cognitive understanding and feedback.
- Explored inverse actions in conditions where their physical and cognitive mappings are incoherent. Experimental between four conditions in the Cruel Design shows good physical condition and poor cognitive condition (doesn't necessarily have to be both at the same time), produces better performance. Inverse actions on the same physical joystick, regardless the type of condition, is the normal behaviour when overshoots.
- Analysed the design principles on TUI framework, which produces a broad guidelines for tangible control design.
- Proposed natural inverses (or reversibility features in general) in the design of tangible interaction.
- Proposed the understanding of natural interaction to be stemmed on two things: (1) visceral quality of physicality in the design, and (2) innate human abilities, so that interactions can be understood by all, and can be made available to all: "technological-universality".

8.4 Future work and Further Issues

In many ways, this work is still an early attempt to discover what natural interaction is to shed lights in designing tangible devices. And, there are still plenty of things which can be improved and added to be part of our future work. As this thesis is carried out, we have encountered several issues which we wish to consider and deliberate here, and discuss how these can be improved. In addition to this, we will also be discussing how we would like to carry our work further.

8.4.1 Improvements

Earlier in this thesis, we have seen the flow of this research work, in which it shows how the discoveries such as Visceral Interaction and the physical over cognitive performance, were derived from the two user studies. Both user studies were designed and implemented in every possible controlled way, which gave us confidence in the findings. Nonetheless, we think there are still some areas for improvement in both user studies.

The technology of the cube in the Cubicle user study can be improved in the way that all axis should be able to sense x, y and z axis rotations respectively to be able to properly evaluate the design principles. Although a comparison between the suggested and the actual design principles have been carried out in the study, we felt that if the improvement is done, re-evaluation may suggest something which we may have missed out. Furthermore, this was seen as a follow up work to the Cubicle user study which was planned in advance – Cubicle part II, but we chose to adhere to the deterioration of mapping to discover the relationship of mappings between users and the Cubicle.

In the Cruel Design study, eliminating the vertical movements altogether may seems to be a sensible thing to do to improve the results, due to their inconsistent data. But the program would not have worked with just horizontal mappings on two joysticks, as it requires the vertical mappings to accompany the horizontal mappings in order to enable the swapping between conditions. Nonetheless, this study can be improved by reducing the number of vertical's target boxes. The screen will now show only four boxes instead of six. Thus, we can have just one type of left and right horizontal movements, and just one type of up and down vertical movements. In addition, by extending the length of the experiment would also improve the results.

For both user studies, it is very important for us to increase the number of participants or subjects. In retrospect we feel the lack of number of participants which involved in both user studies respectively was due to the length of the user study, and the absence of incentive in money form discourages people from taking part.

8.4.2 Further Work

This thesis has led us to see the importance of natural inverse in the design of tangible control. We feel this as only the beginning to many other possible venues of research work. There are three central important areas which this work can be carried out further.

8.4.2.1 Get Physical: Physical Visceral Qualities In-depth

By using physicality to understand what makes our interaction natural and fluid has led us to find a set of positive design characteristics. There are plenty of potentials in both static and dynamic design principles and their implicit properties, that we wish to examine further, which can be contributed to the conceptual design theories. In addition to this, the analysis of their impact on TUI framework can also be extended. Apart from having known their coherence impact on the framework, we would like to explore the behaviours and characteristics of each of the design principles in relation to the five properties of physical-digital links (section 7.3).

8.4.2.2 Observe, Examine, Analyse: Natural Inverse in Tangible Devices

In the last chapter we have covered quite a number of tangible devices and observed some interesting points when it comes to natural inverse behaviour. For instance (from figure 7.15), the unsynchronized mapping often creates confusion to users. We would like to carry out a wider observation on tangible devices which focuses on natural inverse, or reversibility feature, to study other kind of behaviour that we may have missed out due to a small set of examples. Furthermore, as per outlined in page 146 (last sentence of inverse action), we would like to further examine why this is so and we see this as a design challenge.

8.4.2.3 Live Experience: Evaluating Tangible Interaction

Evaluating tangible interaction is more than just about efficiency and usability. As we are promoting interaction which stems on innate human abilities, evaluation should be measured in the way how positive or engaged an experience is. Although there are already methodology on how to evaluate product designs and experience, we feel we can contribute toward developing the process of evaluating a 'good' tangible devices.

8.5 Concluding Remarks

Our research into finding the appropriate ways to designing tangible devices through everyday appliances encourages us to reflect upon how we interpret natural interaction. In the context of interaction, people often interpret something as natural when it fulfils one's intention naturally. As it stands now, there are many reasons to the way people shape their meaning of natural, which can be due to the cultural reason, or familiarity, i.e. conventional learned.

Our initial approach in understanding what makes things natural and fluid in everyday appliances adheres heavily to the concept of coherency of mappings between the physical and logical states. The findings recognises characteristics such as exposed state, inverse action, controlled state, tangible interaction, bounce back and compliant interaction, which tell us there are so much more to physicality. By focusing on physicality and its visceral qualities in both user studies and analyses, have somehow changed our perception about mappings. Incoherency that exists in mapping cannot always be assumed as failure. Visceral quality of physical artefacts recognises the importance of natural inverse in prevailing in an interaction.

We believe this thesis proposes a significant contribution in interaction between human and computing. By acknowledging the visceral quality in physicality and our innate human abilities, we will be able to deliver a natural interaction. The concept of natural inverse which emerge from this research promotes one idea which crosses all culture and disciplinary: technological-universality.

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Appendix I

Engagement and Fun: using Venn diagram to explore the relationship to enhance user experience

When a user experiences something, an engagement is presumed to exist in order for it to develop the experience. And, the element of fun is essential to keep the engagement lasts.

To seek whether there is any truth to the above statement, we will be using the Venn diagram to explore the relationship between these two elements: engagement and fun. We first begin with definitions of each term.

There are many descriptions of engagement which have been brought forward. Laurel (Laurel, 1991) describes engagement as user's feeling of being in control of interaction. Whilst Csikszentmihalyi defines engagement as *flow*, in which he describes during a flow "… the individual experiences a sense of control, attention focus, curiosity, and intrinsic interest…" (Csikszentmihalyi, 1992).

The word fun, pleasure, enjoyment, and enchantment, are often used interchangeably when it comes to describing fun experiences. There have been, however, some studies which attempt to clarify the definition of fun by distinguishing this term with pleasure (Blythe & Hassenzahl, 2003), and a study of enchantment in its own right (McCarthy & Wright, 2002). For this particular exercise, we will adhere to the definition of fun found in the Cambridge Dictionary, which brings meaning to *pleasure, enjoyment, amusement*.

1. Exploring the relationship

A Venn diagram is used to identify areas which represent the different natures of the relationship which each area will be used to exemplify examples. The identified areas are: engaging and fun, engaging and not fun, not engaging and fun, and not engaging and not fun. The following Venn diagram illustrates this.

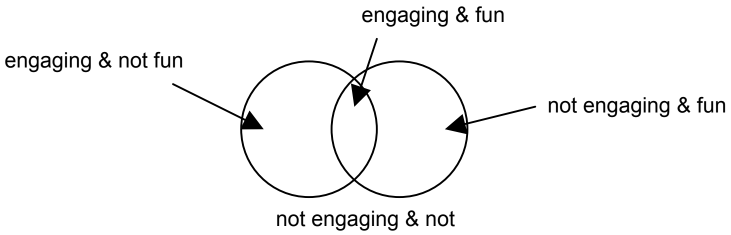

Figure A.1 Venn diagram of engaging & fun

i. engaging and fun

Experiences of this category consist of both engaging and fun elements. Examples include, children playing in the playground, singing karaoke with friends, girls on their shopping spree, playing video games on Play Station 3, a mother baking a birthday cake for her son, spectators watching a spectacular fireworks, teenagers having a slumber party, and playing bumpers cars.

ii. engaging and not fun

In this category, the fun element is absent from the experience. Amongst of the examples include, an artist painting on a canvas, a student revising his notes, a group of teenager watching a horror movie, an act of praying or worshipping, driving a car in the midst of heavy rain, a cyclist pushing it to the limit to win a race, and sitting in examinations.

iii. not engaging and fun

This category refers to the type of experience which is not engaging and yet fun, and found to be the most difficult area to come up with examples that exemplify the nature of the relationship. Nonetheless, the one example that we found is, an experience of a thrilled ride at a theme park. When people are on this particular or similar ride, they try to deviate their attention to something else to overcome their fear. Thus, the engaging experience of the ride is not happening, but the fun experience of the thrilled ride does exist.

iv. not engaging and not fun

The type of experience of this category is an experience without the existing of fun and engaging elements. Examples include, waiting for a kettle to boil, queuing in a line, stuck in traffic, and stranded in a desert or any unfamiliar places.

Further analysis is carried out on the identified categories by pushing each of the examples to the boundaries. We push the experiences from one category to another by transforming the experiences.

2. Transformation

Some alterations have been made on the examples to enable us to see how each of the examples transforms from one category to another. The following describes a few of the examples which have been previously mentioned that have undergone the process of transformation.

i. Waiting for the kettle to boil

This experience is a mundane experience. As we are already aware, people normally turn their kettle on and leave them to boil, rather than waiting next to the kettle. Here, we are not trying to persuade people by the kettle until the water is boiled, but yet, we are attempting to transform this experience to something that is more engaging and fun.

The process of boiling water in a kettle won't be the same when we have a cute little bird (toy that is) sits inside the kettle. When the water starts to boil, the pressure of the water slowly raises the bird to the top of the kettle. The bird then appears from a small lid in the middle of the kettle and starts to chirp and dance, until the water finishes boiling.

This injects fun to the experience of boiling water in a kettle. Although the moment of engaging is short, it somehow shows that the transformation of the nature of the experience is possible. The engaging experience can be made longer is the transformation is done a transparent kettle.

ii. Queuing in a line

The experience of queuing in a long line in a post office for instance does somehow or rather test our patience, especially when it moves very slowly (this experience also applies to stuck in a traffic). This experience is certainly neither engaging nor fun. We transform the experience to engaging by providing them something to interact and play with.

What we are doing is basically applying the definition of engagement which is described earlier in the section in order to transform the experience to somewhat engaging.

iii. A boy playing a video game

Engaging and fun experience can also be transformed to engaging and *not* fun. From this particular example, a boy is enjoying himself playing a video game. But while he is engaging and having fun, his mother asks him to stop playing and do his homework. If he continues playing, engagement still continue to occur, but without the element of fun. He is now feeling anxious to finish off the game quickly and feels a little tense remembering that the only reason he has to terminate the game is to do his school work.

From the above examples, we see that it is not impossible to mutate the nature of experiences, i.e. the transforming an experience from one category to another. This process is possible to take place provided that we understand the experience and are able to identify the salient features that can mutate the experience. Nonetheless, there are several issues that are associated with this process of mutation that are worth pointing out. The following section elaborates this further.

3. Issues

There are three major points that we would like to highlight related to the mutation process.

i. Fun in an experience

Although the examples are not extensive, we can say that engaging is necessary in an experience. This is not the same with fun. In section 1 (ii), we could see that engaging experience can also exist without the presence of fun. For instance, there are also some other kind of experience like sad experience, horror experience, pleasure, enchanted, wonderful and many more. Therefore, fun in an experience is not an essential entity, whereas, on the contrary, engaging has to be part of the experience.

ii. Internal and external motivations
Example given in 2(iii) has mutated to not fun when his mother interferes his concentration on the game. This is an example of an external factor that influences negatively toward the experience, which this we refer to external motivations.
Let's now look at an example of internal motivation. Most of the students dislike sitting for Math exams. They obviously see this as not fun, yet the experience is engaging. This experience can be transformed to a fun experience if these students can set in their minds that Math is easy, so long as they know how to apply the concepts and formulae. This particular internal motivation could lead to a change in the experience.

Both external and internal motivations, which can be either positive or negative, can be influential in the process of mutation of experiences.

iii. Multi-experiences
The last point that we would like to highlight is the moments when there is more than one experience happening at the same time. In 1(ii), there is an example which shows that a person is fully engaging in his driving in the heavy rain, and, he is driving very carefully to avoid the unwanted accident.

If we closely look at this example, it consists of two experiences: one is driving a car, which was supposed to be fun and enjoyable, and second, driving in the midst of the heavy rain. The driver could only be in one experience due to what is called as 'selective attention' (Norman, 1988). During this situation, the ability of conscious attention is limited, which means, one can focuses on one thing and reduce one attention to others.

The same scenario occurs when there are two young girls on the swings in the playground, and they both are chatting at the same time. The fun experience coming from riding the swings is less or absent because the attention is given to the conversation. The experience is said to be engaging, yet not fun (in reference to riding the swings experience).

The three issues discussed above have given us more insights towards the engaging and fun relationship. At this point, we now know that engaging experience can exist even without the presence of fun, internal and external motivations have the ability to mutate experiences and human can only experiencing one experience at one time due to selective attention.

Having known the four states and understood the process of transformations or mutations, and the highlighted issues, have triggered us to also explore how exactly the experience mutate to become another type or category of experience. For instance, at which point exactly does the experience of engaging and not fun becomes engaging and fun. The following section discusses this further.

4. Critical Points

The exploration exercise is not as discrete when compares to the process of mutation in the sense that the boundary is not as distinctive as the former. The points where these changes occur are what we described as the critical points. The examples of experiences are once again used to assist us in exploring and seeking the critical points.

i. Boiling water in a kettle experience
As we already know, this particular experience is a mundane experience. It is neither engaging nor fun. Now we are about to see how this experience mutates. Adding a feature of a little bird in the kettle changes the category of the experience. But how exactly does the experience mutate from not engaging and not fun by adding this new element?

As we add the little bird into the kettle, and design it in such a way that when the kettle boils, the pressure of steam pushes the little bird towards the lid. This would make the little bird pops up and begin to sing and twirl.

Although the engaging experience only occurs at perhaps the moment the little bird pops up, the new design of the little has successfully adds the fun element to the original experience. Thus, in this example, the critical point would be the aliveness characteristic of the little bird which mutates the experience.

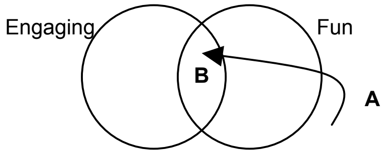

Figure A.2 A (not engaging & not fun) mutates to B (engaging and fun)

ii. Interacting with a device whilst queuing
From the example given in 2(ii), we mentioned that the particular experience could be mutated provided there is an interactive device (or some sort) for the people to interact and play with whilst waiting, which lets them to have engaging experience. Now, we would like to see at which point the experience mutates to fun experience.

We believe that by adding a variety of functionality into the device would it more fun. This is due to the facts that a selection of functionality that is of different levels would produce challenges, and according to Brandtzæg et al. (Brandtzæg et al., 2003) and Blythe and Hassenzahl (Blythe and Hassenzahl, 2003), some people found pleasure and fun from challenges. In addition, users are of different abilities and skills. Thus, the challenges of many different levels in the device are the critical point in this particular example. Some may find fun when encountering higher level of difficulty of challenges, and some may find fun by doing things that are of easy and simple, as long as both eventually reach their satisfactory level.

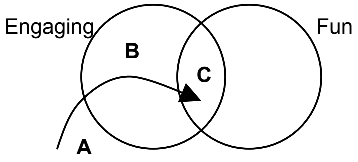

Figure A.3 A (not engaging & not fun) first mutated to B (engaging) then to C (engaging & fun)

iii. Playing a video game
In the example where we have a boy who is really engaging in the game he is playing, we have seen that internal and external motivations can influence one's engaging experience (3(ii)).

Now let's imagine a situation in which the boy is currently at level 8 and is trying to cheat to get to a higher level. Normally, cheating a game would an easy thing to do. But somehow this time, the game does not allow him to cheat. He is furious, yet is still engaging with the game as he is still wants to find a way to get around it. The experience of fun that he initially had has now mutated to something else: annoyance.

So what has exactly changed his experience of fun to less or no fun at all? The critical point of this mutation would be the interference of factor(s) that does not support or concur to what one interprets what fun experience is. If the interference continues, and one cannot overcome the interference, the fun element, is not possible to exist.

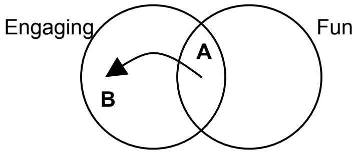

Figure A.4 Figure 4: A (engaging & fun) mutated to B (engaging & not fun)

The critical points that we have discovered have given us some insights toward how to make experience more engaging (or less) and/or more fun (or less). The following section describes how we can actually benefits from the exploration of the relationship.

5. Heuristics

By referring to the outcome of the discussion of the critical points, heuristics are outlined which should be able to assist in making experience more engaging and more fun. The heuristics are as follows:

i. aliveness characteristic

Jack in a box, which has the element of surprise, and a ballet dancer in a musical box, which has an excellent influence in enchanting people, are amongst the examples that have the aliveness characteristic presence in them. People like and prefer to see things that physically move, which this would leads to engaging. In the case of the musical box, the longer the ballet dancer dances, the longer the person get engaged to it. The element of surprise in the object which has aliveness characteristic leads to fun experience.

ii. interactions

When interaction takes place, it would exist at least a two-way action, and it could also lead to engaging experience. Feedback plays an important role in interaction. Feedback, as Norman (1988) points out in one of his chapters, the Principle of Feedback, is very important factor in which it must exist in an interaction. By providing feedback in an interaction, the user can get to know what is happening, and this gradually develops engagement.

It is worth mentioning here that interaction does not necessarily mean that user has to interact much with a medium or a device. As long as a user perceives and understands what is taking place from feedback, that is all that matters.

iii. Challenges

By providing challenges of different levels, users can experience fun, especially when they able to overcome the challenge. Demands as fun, which include challenges, as what has been described in (Norman, 1988), states that people take pleasure in contesting intellectually and variation. As challenges are of different levels, we can provide certain settings to either make it more fun, or less fun. This, of course, are varies on different individuals.

iv. Motivations

There is no doubt that internal and external motivations have such influence on leading where the experience might heads. By knowing the positive motivation(s) that can be integrated into the medium or device, we are able to make the experience more fun. At the same time, we can make the opposite experience by identifying the negative motivations.

Appendix II

Examining Fun Experiences between Two Cultures, English and Malay, to Supporting Diverse User Communities

Abstract

Irrespective to the globalisation that hits the world today, the diversity of user communities is still very clear. By relating this directly with 'funology' and enjoyable experiences, this paper investigates how and in what way the emotions when we experienced fun is different between cultures. We examined how two different cultures, English and Malay, as expressed in the words they use, perceive fun and in what way they show or express fun. These examples of sentences and situations allow us to explore the emotional landscape and uncover subtle differences and nuances of 'fun' experiences.

Keywords

Fun, enjoyable, experience, emotions, cultures, domestic

INTRODUCTION

Globalisation hit us hard. The world we live in today is totally different with the world we once knew. The world today knows no border, yet this does not mean that people are all the same. In the work setting convergence seems the norm; if you walk into an office in Cambridge, Kuala Lumpur or Canberra it will look very similar. However, in domestic settings, at home, with friends, having fun, the differences become apparent; the colours, the food, the sense of humour, the social relationships. Even back in the office look at the attitudes and the social structures within the work environment; the diversity of user communities is clear.

There are many examples that prove the existence of diverse backgrounds in the computing world. Nearly every usability study requires the investigators to identify participants' background. We use the information to tell us whether the results of the experiments or studies may be influenced by the diversity affects. Whilst in other work the differences are the focus of the design or experiments, for example long standing work on internationalisation and national culture (Del Galdo et al. 1996), or Desmet et al. (2000) who acknowledge between-culture differences by measuring emotional responses to products.

This emotional response is critical. Both in work-oriented products, where individual efficiency is closely linked to personal motivation, and even more in domestic, entertainment and e-commerce areas, the importance of the user experience is becoming important if not paramount. For some this sort of issue has been a long term interest (Fogg, 2003) but it has increasingly become 'mainstream' in HCI textbooks and the launch of the ACM ACE conference. In particular, the term 'funology' has recently been coined in response to this new perspective that tries to move usability to enjoyment, or fun (Blythe et al., 2003b).

So whilst we acknowledge the existence of diversity amongst the user communities, we would like to relate this directly with funology and enjoyable experiences. This paper attempts to discover in what way (if any) the emotions when we experienced fun is different between cultures. To address this, we focus on the terminology of 'fun', by comparing its definitions with the closest words in the Malay language that give similar meaning. We have chosen Malay language partly due to the conspicuous differences of eastern and western culture. This makes it interesting to identify and understand the context of fun from the English and Malay points of view: do the definitions correspond to one another, and what are the contexts that only exist in one culture that cannot be described in another? In addition, one of the authors is herself Malay. It is difficult, or perhaps impossible, to study these issues of felt experience without some direct knowledge of cultures involved.

It is important this to understand these differences for two reasons. On the one hand it highlights a problem: we need to be able to design 'fun' interfaces that can support diverse user communities. On the other hand it offers us an opportunity: by seeing the words in the different languages take a different 'cut' through the conceptual landscape of 'fun' and help us to understand finer details and distinctions. The difficulty with studying common felt experience is that it is just too common, too tacit. The differences between languages foreground otherwise hidden issues.

WHAT IS FUN?

For many years, usability has focused on efficiency and robustness, concepts such as tasks, efficiency, ease-of-use, and ease-of-learning. However, new ideas of usability include issues of aesthetics, enjoyment, play and, user experience (e.g. Blythe et al., 2003b). These ideas are valuable as they won't just make the designs better but would also create a more exciting interaction with the technology compared to the days where the ultimate aim is to get the operation and precision correct.

Increasingly research in software application, games, learning and even consumer devices is paying attention to enjoyment in user experience: for example, improving eLearning by making the online course fun and engaging (Neal et al., 2004), investigating playful characteristics of the World Wide Web (Atkinson et al., 1997), the role of competition as enjoyment in video games (Vordener et al., 2003), and fun and enjoyable experience in consumer electronics by adding animated characters (Diederiks, 2003).

So, what is fun anyway? From Cambridge online dictionary (Cambridge, 2004), 'fun' as a noun form is defined as pleasure, enjoyment and amusement, whilst 'fun' as an adjective is defined as enjoyable. If we observe our daily conversation, fun sometimes is used interchangeably with pleasure, enjoyment and playfulness, and is very much about emotion. Whilst the broad issues of adopting fun are entering HCI, little work has attempted to differentiate one concept from another, with exceptions (Blythe et al., 2003a) distinguishing fun and pleasure.

What we would like to concentrate on at this juncture is not about the differences that distinguish fun from similar English words, but the relations or associations of the word 'fun' with similar words in the Malay language. From the many Malay words listed below, the words *seronok* and *riang* are the ones that have the closest meaning to the word fun. But how far true is this? How can we be so sure that everything that fun describes can be exactly described into Malay language by a mere translation? And are there conditions where the words in Malay illustrate situations that the word fun doesn't?

English: *Fun, pleasant, enjoyable, amusement, entertaining, playfulness*
Malay: *Seronok, riang, gembira, hiburan, gurau-senda, sukacita, ceria, bahagia*

SERONOK OR RIANG?

Rather than simply looking at the Malay 'dictionary' translation of fun – *seronok* and *riang*, we need to examine how the words are really *used* to enable us to identify the emotions involved and the conditions where the emotions are normally shown. In order to illustrate these, Tables 1 and 2 give example sentences, together with a checklist of (English) emotions that associate with the sentences.

	Seronok	**Equivalent meaning in English**	*F*	*E*	*P*	*A*	*O*
(a)	"*Seronok* sekali melihat semuanya berjalan dengan lancar."	"So *happy/glad* to see everything goes well according to plan."			√		√
(b)	"Saya berasa amat *seronok* berjumpa dengan rakan-rakan lama."	"I'm so *happy* to see my old friends." "It's *fun* to meet my old friends."	√		√		√
(c)	"*Seronok*nya bermain dengan permainan ini!"	"It's *fun* playing with this game."	√	√		√	
(d)	"*Seronok*nya!"	"It's so much *fun*!"	√	√			
(e)	"Keramaian semalam sungguh *seronok*."	"Last night's party was *fun*."	√				
(f)	"Saya *seronok* bekerja di tempat baru."	"I *enjoy* working at the new place."		√			
(g)	"Perlawanan bolasepak itu *seronok*."	"The football match was *fun/great*."	√				√
(h)	"*Seronok* mak ayah melihat kejayaan anaknya."	"His success in studies gave his parents much *pleasure*."			√		
'seronok' is used to ***express*** *fun, happiness, excitements, and enjoyment*							

F: fun, E: enjoyment, P: pleasure, A: amusement, O: others

Table 1: *Seronok* alongside the equivalent English sentences and associated emotions

	Riang	Equivalent meaning in English	*F*	*E*	*P*	*A*	*O*
(a)	"Kanak-kanak bermain dengan *riang*nya."	"The children are playing *cheerfully/buoyantly*."	√	√			√
(b)	"Suasana yang *riang*-ria / *riang*-gembira."	"A *joyous/fun* atmosphere."	√				√
(c)	"Berjoget dengan *riang*."	"Dances *jovially/cheerfully*."		√			√
(d)	"Hatiku *riang*." "*Riang* rasa di hatiku."	"My heart is full of *joy*."					√
(e)	Dia tersenyum *riang*."	"She smiles with *glee*."					√

'riang' is used to ***describe*** *fun/joy/happy atmosphere/situation, and to describe action(s)*

F: fun, E: enjoyment, P: pleasure, A: amusement, O: others

Table 2: *Riang* alongside the equivalent English sentences and associated emotions

Note that although there is a lot of overlap between, for example, soronok and fun, there are also differences (e.g. in English one would not say that it is 'fun' that something is going to plan). We can think of the words as delineating areas of a conceptual emotion landscape (see Fig. 1), where the languages take different 'cuts' through the landscape. The points of intersection and difference can help us to understand the fundamental attributes of the emotions, rather like the attributes of a particular experience (virtual crackers) are uncovered in Dix (2003). Although we cannot explore this in full in this paper, we can start to look at a few issues the approach uncovers.

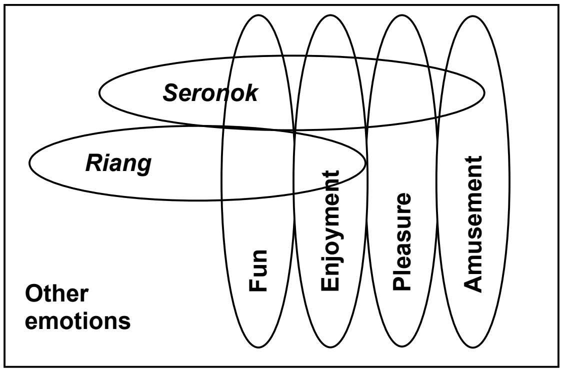

Figure 1: The emotion landscape (schematic only: the words *soronok* and *riang* overlap in meaning as do the English words with one another)

One clear point from emotional landscape is that relative to fun, and its related words, there are certain emotions of *seronok* and *riang* which do not encompass in any of the four English words. Between the two Malay words, s*eronok*, is the word that comes closest to fun, as the word is used to describe or to express fun, pleasure and enjoyment. This word is also used to express or to show happiness, gladness and excitements, which apparently are not what fun is about.

Although *riang*, from the sentences given above, shows no close correspondence to the word fun, *riang* however is commonly used to describe a happy atmosphere, setting or situation or one's expression of happiness. Another interesting remark when constructing examples for the word *riang* is the fact that it is ordinarily addresses children rather than the adults. It is uncommon to hear the word *riang* describing the happy behaviour shown by an adult. To some extent this also reflects childlike or childish connotations of the word fun in English, hence the reason why examples (a) and (h) (from Table 1) do not sound like 'fun'.

It is also interesting to see how 'seronok' and 'riang' correspond to amusement. There is a direct translation of 'amusement' in Malay, the word 'hiburan'. For example, 'amusement park' that is translated directly into Malay as 'taman hiburan'. Nonetheless, when a suffix is added to the word 'seronok' it is changed to 'menyeronokkan' which also means to entertaining or amusing.

DISCUSSIONS

We have seen that emotions play such a large part in defining the application of each word. In the Malay culture, the word *seronok* is expressed when one expresses the fun that he/she is experiencing, enjoyment, happiness, and even excitements. From the investigation, in contrast to the Malay word, the word fun alone can not describe one's emotion when *experiencing* fun. Imagine you are enjoying a ride at a theme park. To describe your 'emotion' in English you either say, "This ride is fantastic!", or, "I'm having so much fun!" But when it comes from a Malay, the answer would be no more than one word, which is, "Seronok!" The word *seronok per se* able to express one's emotion, one word answer is sufficient to describe the whole emotion one is experiencing.

It is fascinating indeed to see that there is more than just a mere translation at work. Seeing what fun really means from two different horizons gives us insight into the way each culture perceives and applies 'fun'. Although in the beginning it seemed as if *seronok* suits perfectly as fun's description, it turns out that the Malay word is not just used to express the experience of fun, but also to express excitements, happiness and enjoyment. Furthermore, *seronok* is different from fun in a way that *seronok* itself can be used to express emotions.

The Malay culture is different to the English in many ways. East vs. west says it all. When we look deeper, the reason why the single word *seronok* has the ability to express emotion may be due to the way the Malay culture expresses itself. Unlike the English, the Malay culture expresses many things with 'feelings', rather than 'thinking'. For instance, in English culture, one normally expresses things by saying, "I think…", but in Malay culture, one says, "Saya rasa…" which translates to "I feel…" Possibly the ability to show emotions of fun in the Malay and English *languages* is all down to how each culture expresses itself (or visa versa). Perhaps Wittgenstein's phenomenological view of language is due to an English obsession with external appearance!

Malay → 'feel' = shows ***fun*** as emotions
English → 'think' ≠ shows ***fun*** as emotions

CONCLUSION

Starting with a focus on experience in usability and 'funology' has inspired us to examine how two different cultures, English and Malay, as expressed in the words they use, perceive *fun* and in what way they show or express *fun*. We identified contexts in which the words seronok and riang appear in Malay conversation and how they compare with the English word 'fun' and related terms. These examples of sentences and situations allow us to explore the emotional landscape and uncover subtle differences and nuances of 'fun' experiences.

At one level the closest word in Malay to fun is seronok, but the differences suggest highlight the individual ways in which culture shows or express their emotions. Whereas the Malay word seronok is more about feelings the English word fun is about experiences. It is open to discussion (and coffee room argument!) whether this betrays a more fundamental difference between Malay expressing itself in feeling as compared with English in thought or appearance.

This study certainly provides us insights that tell us that fun experience cannot be accepted as something that is the same to everyone. It is part of our broader investigations into how technology in domestic settings of different culture could affect the way users want the technology to be integrated into their homes. We believe that as a an analytic technique, the use of multiple languages can be a touchstone and probe to uncover subtle differences between cultures and also to help us build richer vocabularies of the felt experience.

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Appendix III

Cubicle Design Questions: Applying Design Concepts to a Novel Device

Cubicle Design Questions: Applying Design Concepts to a Novel Device

Concept	Design Questions	Exploration	Usability/Task Analysis	Additional Questions
Exposed state • On/off, up/down	What are the exposed states? What is the directness of effect? What is the locality of effect? What is the visibility of state?	1. How does user manipulate the cube? 2. What kinds of physical manipulations does the user desire? 3. Can the user map the logical state to the physical state?	1. How easily does user manipulate the cube? 2. How easy/difficult is it for the user to map logical and physical state? 3. How do we measure this?	How can we show exposed state? How do we best provide for this? How does this change with various types of users?
Hidden state • Eg. Speaker bump	What are the hidden states? What is the directness of effect? What is the locality of effect? What is the visibility of state?	How does the user attempt to expose hidden states?	1. How easily does the user expose hidden states? 2. When does the user not understand hidden states? 3. How do we measure this?	How can we show hidden state? How can we best provide this? How does this change with various types of users?
Control of state • physical control	How is control enforced? What is the directness of effect? What is the locality of effect? What is the visibility of state?	How does a user control the cube?	1. How easily does the user control the cube? 2. When does the user lose control of the cube? 3. How do we measure control?	How can we regulate control? How can we best provide this control? How does this change with various types of users?
Inverse actions • Undo • feedback	What kinds of inverse actions exist? What is the directness of effect? What is the locality of effect? What is the visibility of state?	How does the user attempt to inverse their actions?	1. How easily does the user inverse their actions? 2. When does the user fail at inversing their actions? 3. How do we measure this?	Does the presence of an inverse action reduce user exploration? What kinds of inverse actions are needed? How can we best provide these inverse actions? How does this change with various types of users?
Compliant interaction • Mechanical-machine controlled • Move with transition from one state to next	What kinds of compliant interactions exist? What is the directness of effect? What is the locality of effect? What is the visibility of state?	How does the user explore compliant interaction?	1. How easily does the user perceive compliant interaction? 2. When does the user fail at comprehending this? 3. How do we measure this?	Does the presence of compliant interaction change user interaction? What kinds of compliant interactions are needed? How can we best provide these compliant interactions? How does this change with various types of users?
Tangible transition • Feltness • resistance	What kinds of tangible transitions exist? What is the directness of effect? What is the locality of effect? What is the visibility of state?	How does the user explore tangible transition?	1. How easily does the user comprehend tangible transition? 2. When does the user fail to comprehend this? 3. How do we measure tangible transition?	How does tangible transition affect interaction? What kinds of tangible transitions are needed? How can we best provide for tangible transitions? How does this change with various types of users?
Bounceback	What kinds of bounceback exists? What is the directness of effect? What is the locality of effect? What is the visibility of state?	How does the user explore bounceback?	1. How easily does the user use bounceback? 2. When does the user fail to use bounceback? Why? 3. How do we measure this?	How does bounceback affect interaction? What kinds of bounceback is needed? How can we best provide for bounceback? How does this change with various types of users?

Appendix IV

Cubicle User Study: Rating Scales

Dependent Rating Scale

General Indices	Test 1					Test 2 (Worse –1; Same 0; Better+1)		
	Negative .Positive					Test 2	Test 3	Test 4
	1	2	3	4	5			
1. Operational smoothness								
2. Physical effort								
3. Mental effort								
4. Reaction time								
5. Physical fatigue								
6. General comfort								
7. Overall operation								
8. Fun experience								
9. Frustration level								
10. Reliability								

Independent Rating Scale

1.	**Smoothness during operation:** **1 2 3 4 5 6 7** Very rough Very smooth
2.	**Physical effort required for operation:** **1 2 3 4 5 6 7** Very high Very low
3.	**Mental effort required for operation:** **1 2 3 4 5 6 7** Very high Very low
4.	**Reaction time:** **1 2 3 4 5 6 7** Very inaccurate Very accurate
5.	**Physical fatigue:** **1 2 3 4 5 6 7** Very tired Not tired
6.	**General comfort:** **1 2 3 4 5 6 7** Very uncomfortable Very comfortable
7.	**Overall operation of input device:** **1 2 3 4 5 6 7** Very difficult (to use) Very easy (to use)
8.	**Fun experience:** **1 2 3 4 5 6 7** Very fun Not fun at all
9.	**Frustration level:** **1 2 3 4 5 6 7** Very frustrated No frustration
10.	**Reliability:** **1 2 3 4 5 6 7** Very reliable Totally unreliable

Appendix V

Cubicle User Study: Post-test Questionnaire

Participant # **Date:**

1. What did you like/dislike about the usability study?

2. What did you think about the length of the study?

3. What did you learn from the study?

4. Did you prefer the red or blue test? Why?

4. Did you prefer the numbered or unnumbered test? Why?

5. If you had to use one of the cubes you preferred from the previous two questions in your everyday activities, what features would be important to you?

6. If there was anything you would change or add to the cube, what would it be?

6. Please add any additional comments here: