The Effects of Intuitive Interaction Mappings on the Usability of Body-based Interfaces

by

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Abstract

A key challenge with designing controls for Natural User Interfaces (NUIs) is the wide range of input actions they support along with the little affordance they have on which of these actions lead to successful system effects. In this thesis I report the findings of a comparative study between three design strategies for a whole body system. I compare the strategies on usability, intuitiveness and their ability to engage a participant about the content domain. From this study I found that while certain design approaches enhance a users' performance completing tasks, the lack of discoverability of the interaction model left the user feeling incompetent and unsatisfied. From these findings, I discuss the role of intuition within interface design. I provide the benefits and limitations of each design along with empirically grounded guidelines on how to use the different designs to achieve a balance between usability and intuitive interaction.

Keywords: Intuitive interaction; whole body systems; conceptual metaphors; interaction design; mixed-method experiment

Dedication

First and foremost, I dedicate this thesis my grandmother Rosario who passed away days before I began my masters program.

This thesis is also for my mother Maria who is open and supportive towards most decisions I make in life, my sister Elaine who is a constant source of motivation and encouragement, the rest of my family who together establish my sense of belonging, my close friends who inspire, support, and brighten my life, and my partner Dave for simply being there during the most stressful months of my thesis.

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List of Acronyms

HCI	Human Computer Interaction
CMT	Conceptual Metaphor Theory
IR	Infrared
LED	Light Emitting Diode
NUI	Natural User Interface
UI	User Interface

Glossary

Concept	Mental structure that shape how we think about and act within the world. (Lakoff & Johnson, 1980).
Conceptual Metaphor Theory	A theory that states that people make sense of abstract concepts by metaphorically mapping them to image schemas (Lakoff & Johnson, 2003).
Conventional Mapping	Mappings adapted from previous practice and commonly found in product interfaces.
Effectiveness	The user's ability to complete tasks using the system (Wixon & Wilson, 1997).
Efficiency	The amount of resources used in order to achieve a user's goal (Wixon & Wilson, 1997).
Image Schemas	Mental structures formed from recurrent sensory-motor experiences (Hurtienne, Stößel, & Weber, 2009).
Intuitive Thinking	Thinking that is fast, unconscious and often automatic (Kahneman, 2011).
Intuitive Interaction	Interaction with an unfamiliar system in which a user knows how to act quickly and automatically, using unconscious effort and attention (Macaranas, Antle, & Riecke, 2012a).
Isomorphic Mapping	One-to-one literal spatial relations between the input actions and resulting system effects.
Metaphor	A mechanism for understanding and experiencing one kind of thing or experience in terms of another. (Lakoff & Johnson, 1980, 2003).
Metaphoric Mapping	Mappings that structure input actions based on image schemas and system effects based on related conceptual metaphors.
Natural User Interface	A series of interfaces that take gestures or body movement as a source of input for system controls (O'Hara, Harper, Mentis, Sellen, & Taylor, 2012).
Perceived Competence	A user's confidence in using the system.
Usability	The effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments (ISO 9241).
User Satisfaction	The feelings a user has towards the use and aesthetics of an interface (Wixon & Wilson, 1997).

1. Introduction

Natural User Interface (NUI) is an umbrella term for interfaces that utilize gestures and sensed body movement as input for system controls (O'Hara et al., 2012). These interfaces have been popularized with the release of the Microsoft Kinect and the Apple iPad. NUIs present three challenges that can make them difficult to learn for novice users. First, there are very few conventions available for designing NUI controls. In other words, there's no set way to design a mapping between an action and a related control that transcends to multiple NUI devices (Norman & Nielsen, 2010). Because of this, users cannot take knowledge they've gain from using one NUI device and use it to understand a similar NUI device. Second, NUI's have very few affordances. Users can move in various ways and in most cases, the system only responds to a few of these actions (Hornecker, 2012). Last, gestures and movements for NUI controls can mimic actions from everyday experiences or conventions from previous analog devices (Buxton, 2010a, 2010b). Do users leverage from older systems or everyday experiences when trying to learn how to use a NUI system? This last challenge is the focus of this thesis.

Designers can create NUI controls by following established conventions from analog or physical controllers or by leveraging existing knowledge from our everyday gestures in the world. For example, home stereo systems use a convention of turning a physical dial clockwise to increases the volume of music. Designers can apply this convention to a NUI so that a clockwise rotation of a finger or arm increases the volume of the system. Or, they can make raising an arm or a device increase volume – actions similar to a conductor raising her arms to encourage an orchestra to play more loudly. Should a NUI volume control involve a rotation or an upward motion? This type of question is a common problem in the design of new interface forms for both the users and designers.

Currently, there is little research that explores the benefits and limitations of the different strategies for designing NUI action-control mappings. As with many new technologies, designers often focus on exploring the potential possibilities and methods of creating action-control mappings (Buxton, 2010a, 2010b). In most cases, there is little rationale to why a mapping was designed a particular way (Norman & Nielsen, 2010). As technologies mature, designers and researchers learn the benefits and limitations of different design strategies. Older digital input devices (e.g. mouse, pen) now have well-established design guidelines that have been developed from years of research and industry experience. Is there a way to establish design guidelines for NUIs without making the same design mistakes already made in older interface forms?

By using the lessons learned from older interface forms, designers and design researchers can quicken the process of establishing design guidelines that match the way users make sense and interact with NUI systems. When controls work as a user expects, using them is intuitive – an attribute associated with NUI systems but with little evidence supporting this claim (Norman, 2010).

In this thesis, I present a summary of theory that explores the meaning of intuition within Cognitive Science and Human Computer Interaction (HCI). More specifically, I explain the meaning behind “intuitive interaction” as well as the different strategies researchers have used to facilitate it. Based on the aforementioned theory in tandem with an extensive game analysis, I introduce three common strategies for mapping input action to controls and a whole-body system in which I implement these strategies. I describe a mixed-method study design for measuring the usability and “intuitiveness” of interaction for NUIs. I define the constructs and variables used to measure usability and intuitiveness. I also describe the tasks that I used in the experiment to collect these measures. I review the quantitative and qualitative methods taken to analyze the data and the results of the analysis. From these results, I share implications on designing action-control mappings for NUIs as well as the first iteration of design guidelines for other whole-body systems and NUIs.

For this thesis, I was interested in doing a deductive, confirmative, theory driven approach. This top-down approach compliments previous work on the bottom-up approach that has been used in previous work for NUIs (Bakker, Antle, & Van den Hoven, 2009; Wobbrock, Morris., & Wilson., 2009).

In this thesis, I explore the concept of balance depicted through body movement and abstract meaning. One of the goals of this thesis study was to explore ways of using body movement to understand abstract concepts. Balance is perceived in both a bodily sense (e.g. standing straight with both feet on the ground) and in a conceptual sense (e.g. being objective while having a degree of open mindedness). For this reason, I chose balance as a suitable medium for this study. Furthermore, there is a series of work that have already analyzed the concepts of balance (Johnson, 1987; Lakoff & Johnson, 2003) and integrated it into interface design (Antle, Corness, & Bevans, 2011, 2013). This thesis study was designed to build on these previous works.

The work described in this thesis contributes to the development of NUI control design guidelines and standards in various ways. First it operationalizes the concept of intuition and provides a framework that design researchers can use to understand and measure this construct. Second, this work makes three possible mapping strategies explicit. Designers can compare these mapping strategies with their own approach and explore how these strategies affect the usability and intuitiveness of their own designs. Third, a methodology for measuring usability and intuitive interaction is described in detail, breaking each into constructs, variables, tasks, measures and analysis. Design researchers can use, validate or modify this methodology within their own studies. Last, the results from the study provide initial implications on the benefits and limitations of the different mapping strategies. While these implications are limited to the whole body system used in the study, these implications can be compared to future studies that implement the three different mapping strategies in other whole-body systems and NUI devices. This thesis ends with empirically grounded design guidelines that suggest successful approaches to fostering intuitive interaction with NUIs.

2. Related Work

In this chapter, I provide an overview of the body of research from Psychology, Cognitive Science, Linguistics and HCI on intuitive thinking and interaction and its varying roles in user interface (UI) design. I begin with two popular but opposite views on embodiment: Cartesian Dualism and Phenomenology. I show how these two views have been used in the design of various interface mediums. I provide an overview of intuitive thinking within Cognitive Science and introduce Conceptual Metaphor Theory (CMT) as one way to explain intuitive thinking. I review different definitions of intuitive interaction within HCI and the various approaches researchers have taken to support intuitive interaction within NUIs. I summarize the knowledge gaps in this area and present the goals of the thesis study as preliminary steps to address those gaps. I end this chapter with the specific research questions of the thesis and the overall contribution of the thesis study to NUI design research.

2.1. Intuition in Cognitive Science

2.1.1. Embodiment and Intuitive Thinking

To design effective whole body interaction, designers need to understand the relationship between the mind and body. They need to be aware of the different perspectives on this relationship and how these perspectives have affected interface design. The notion of Cartesian Dualism was prevalent amongst cognitive scientists for many years (Johnson, 1987; Lakoff, 1987; Rohrer, 2007). Cartesian Dualists separated the mind from the body, claiming that reality exists outside of our minds and that subjective bodily experiences do not contribute to the overall truth of the world (Johnson, 1987; Lakoff, 1987). Cartesian Dualists established truth through repeated scientific experiments that collected empirical data. They confirmed hypotheses through inferential data analysis and expressed their findings as a fact. For example, Cartesian Dualists accepted the concept of gravity after many repeated experiments that tested its existence and effect on objects. They did not consider subjective bodily experiences of gravity (i.e. an apple falling on Newton's head) as proof of gravity's existence.

More recently, researchers in cognitive science, psychology, education, and HCI are beginning to accept a more subjective and embodied view on cognition. Philosophically, this view ties closely with Kant's perspective on cognition and Merleau-Ponty's perspective of Phenomenology (Johnson, 1987; Lakoff, 1987; Rohrer, 2007). Phenomenologists view physiological, cultural, perceptual and developmental experiences as integral parts of shaping our thoughts and inferences about the world (Lakoff & Johnson, 2003; Rohrer, 2007). This differs from a Cartesian Dualist's perspective on an absolute truth, which is grounded in empirical data. From a Kantian or Phenomenological lens, Newton's experience of the falling apple hitting his head is an instance that illustrates the existence of gravity. Seeing the apple fall, feeling the apple hit his head, hearing the apple land on the ground are all factors that would have shaped Newton's subjective understanding of gravity.

The design and interaction behind traditional Graphical User Interfaces (GUIs) rely heavily on Cartesian dualism. The mind is the key processor. Physical interactions are confined to the mouse and keyboard and are irrelevant to cognition. Tangible, gestural and other NUIs leverage body movement and action as a component of cognition (Dourish, 2001). Designers need to understand how bodily experiences shape knowledge generation so they can create NUI systems that reflect the ways users understand and interact within them. Whole body systems in particular have little affordances since the body replaces the controller. The body can move freely in various ways and it is unclear what movements are supported by each system. It is important for users to understand how their actions, orientations, and positions within the system environment map to controls and meaningful system effects.

A principal concept within embodiment theory is that low-level cognitive processes are involved in interpretation. In Rohrer's theoretical framework for embodiment, he states that we mainly use the central nervous system, neurotransmitters, and synapses to understand our interactions and surroundings (Rohrer, 2007). If we accept this theory, than the majority of our knowledge is gained outside of our explicit attention. To better understand how we use previous experiences to interpret unfamiliar situations, we must understand the various ways in which we think.

There are two types of thinking: intuitive and rational. Daniel Kahneman, a Nobel prize winner known for challenging the rational model of judgement describes intuitive thinking as fast, unconscious, and often automatic (Kahneman, 2011). This differs from rational thinking, which is slow, conscious, and deliberate (Kahneman, 2011). Rational thinking in an objectivist sense is simply the use of formal logic (Johnson, 1987). However, recent research suggests that the majority of our thinking occurs outside of our consciousness – or more precisely – is intuitive (Myers, 2002). Intuitive thinking is the cognitive process of using information previously perceived by the senses (Bastick, 1982). This sensory information is used to make insights, recognitions and judgments (Bastick, 1982). How is sensory information used in high-level cognitive processes such as insights or judgments? The following theory explains one way we use sensory information to understand and interpret our experiences and structures about the world.

2.1.2. Conceptual Metaphor Theory

Lakoff and Johnson, researchers in philosophy and cognitive linguistics, introduced *Conceptual Metaphor Theory* (CMT) as a mechanism for explaining how humans come to understand and reason with abstract concepts. Before getting into the theory, it is important to understand what a metaphor is. According to Lakoff and Johnson, a metaphor is the process of "understanding and experiencing one kind of thing or experience in terms of another" (Lakoff & Johnson, 2003). Metaphors move beyond language – they shape how we think, act and talk about a particular topic (Lakoff & Johnson, 1980, 2003). A metaphor used by Lakoff and Johnson to illustrate this point is ARGUMENT IS WAR. When we are in an argument with another person, we see them as an opponent; we can win or lose arguments; we attack their points while defending our own. These actions reflect the way we talk about arguments in terms of war (e.g. You shot down all my supporting points, I've never won an argument against her). This metaphor also structures the way we feel about arguments. We can feel offense from someone's rebuttal or a sense of accomplishment from having a successful counter-argument. This metaphor also shapes the way we act within an argument. We try to be strong and concise when defending our points and can be aggressive and loud when attacking someone else's points. Metaphors like ARGUMENT IS WAR are so ingrained in the way we perceive certain experiences to the point that they go unnoticed and are often not thought of as metaphors (Lakoff & Johnson, 1980, 2003).

Along with metaphor, it is important to understand what a conceptual system is. Concepts are the mental structures that shape how we think about and act within the world (Lakoff & Johnson, 1980). Our conceptual system is the collection of concepts that reflect our previous experiences. Lakoff and Johnson make two claims about our conceptual system. First, it is something we use on a subconscious level (Lakoff & Johnson, 1980, 2003). We often think and act on an automatic level – utilizing previous knowledge and experiences almost instantaneously. Second, they claim that our conceptual system is metaphorical in nature (Lakoff & Johnson, 1980, 2003). We make sense of new and unfamiliar experiences by relating them to more grounded and familiar ones. This is the underlying foundation behind CMT.

CMT states that humans make sense of abstract or new experiences by using mental structures laid down during recurring sensory-motor experiences (Lakoff & Johnson, 2003). These mental structures are known as *image schemas* and are the source domains for metaphors we use to understand abstract concepts (Hurtienne et al., 2009). For example, our experiences with body orientation and physical activity are used to help us understand health in terms of verticality. We jump up when we are joyous. We lay down when we need to rest. Based on these types of experiences, we use the image schema of UP to understand the concept of HEALTHY and can structure this relationship through the metaphor UP IS HEALTHY. Consequently, we use this metaphor in the way we think and talk about a variety of contexts such as coming down with a cold, or being in top shape.

Image schemas are important for understanding and working with CMT, as they are structures we can use to understand more unfamiliar and abstract experiences. Image schemas are dynamic patterns that structure perception, images, and events (Johnson, 1987). They take the form of generalizations and abstractions as opposed to rich images (Johnson, 1987). A classic example used to illustrate this abstraction is the concept of a triangle. Various people will have a mental image of a shape with three vertices and sides. However, the length of the sides and angles between them would vary for each person (Johnson, 1987; Lakoff, 1987). We can see this level of abstraction with the image schema of *out*. This schema involves a landmark and a trajectory, where the trajectory moves away or *out of* the landmark (Johnson, 1987). We can perceive this in a physical sense. For example, in the sentence “I went out of the room”, the person saying this statement is the trajectory moving away from the landmark (i.e. room). We can also see this schema in a more abstract sense. The statement “I poured my heart out” takes a person’s feelings as a trajectory leaving the symbolic landmark of a heart and reaching the other person. Furthermore, the trajectory can be an object, being taken away from the landmark (i.e. he was cut from the team) or as an abstraction, moving away from the landmark, becoming centralized and focused on (i.e. the secret was out in the open). All these different variations of *out* are grounded in our everyday experiences of seeing objects or moving ourselves in and out of spaces, with the viewed objects or our bodies as the trajectory or landmark (Johnson, 1987).

Previous literature have identified different lists of image schemas (Hampe, 2005; Johnson, 1987; Lakoff & Johnson, 2003). Currently, there is no universal list of image schemas. Hurtienne and Israel state that there are approximately 30 to 40 image schemas that appear in most of the published literature amongst the different researchers (Hurtienne & Israel, 2007). Both Hurtienne and Israel (2007) and Evans and Green (2006) have attempted to consolidate the image schemas that appear across various researchers. Table 1 is Macaranas et al.’s combined version of Hurtienne and Israel’s and Evans and Green’s previous attempts at consolidating these lists (Macaranas et al., 2012a).

When we subconsciously use conceptual metaphors to understand unfamiliar experiences and concepts, we do so quickly and automatically. Because this process works at a subconscious level, we spend our conscious attention on performing the activity, while our subconscious works on understanding the meaning behind it. The cognitive process of using conceptual metaphors aligns with Kahneman’s definition of intuitive thinking as both result in quick, automatic and subconscious interaction (Kahneman, 2011). Therefore, it can be said that conceptual metaphors are one way for supporting intuitive thinking and interaction (Antle, Corness, & Droumeva, 2009a).

Table 1. ***Image Schema List: A consolidated list of image schemas sorted by their physical property. Taken from Macaranas et al. (2012a).***

GROUP	IMAGE SCHEMAS
Attribute	Heavy-Light, Dark-Bright, Big-Small, Strong-Weak, Warm-Cold, Rough-Smooth
Balance	Axis Balance, Twin-Pan Balance, Point Balance, Equilibrium
Basic	Substance, Object
Containment	Container, In-Out, Surface, Full-Empty, Content
Existence	Bounded Space, Cycle, Object, Process, Removal
Force	Attraction-Compulsion, Balance, Blockage, Counterforce, Diversion, Enablement, Momentum, Removal or Restraint, Resistance, Source-Path-Goal
Identity	Face, Matching, Superimposition
Process	Cycle, Superimposition, Iteration
Spatial	Up-Down, Front-Back, Left-Right, Near-Far, Scale, Centre-Periphery, Contact, Path, Straight-Curved, Verticality, Location
Unity / Multiplicity	Merging, Collection, Splitting, Iteration, Part-Whole, Count-Mass, Linkage.

2.2. Intuition in Human Computer Interaction (HCI)

2.2.1. Defining 'intuitive' within HCI

Various researchers have pointed out that previous work in HCI make claims on the "intuitiveness" or "naturalness" of a system without providing operational definitions or substantial data (Antle, Corness, & Droumeva, 2009a; Blackler, Popovic, & Mahar, 2002). These claims are becoming even more prevalent with the popularization of the iPhone and other touch-screen phones and tablets (Norman & Nielsen, 2010). Gestural devices like the iPhone use direct touch interaction, which differs from mediated interaction with a controller. Norman and Nielson state that interface designers are mistaking the direct touch interaction of gestural devices as natural or intuitive (Norman & Nielsen, 2010). Various developers are creating their own conventions or methods for designing basic functions for smart phone applications assuming they will be intuitive (Norman & Nielsen, 2010). Because of this, there is no consistency or established convention across all smartphone platforms, making these devices very frustrating and –

unintuitive – to use (Norman & Nielsen, 2010). More importantly, in this article Norman and Nielson illustrate that all gestures are not intuitive in their meaning or function. Gestures and other input actions must be grounded in prior experience or use previously attained knowledge for users to see them as natural or intuitive.

In 2000, various researchers in Queensland University of Technology began exploring the concept of intuitive interaction as a means to make systems feel more familiar to more users. Blackler et al. conducted a series of studies where users performed various tasks on a number of similar systems and described which systems, features, or functions felt intuitive (Blackler & Hurtienne, 2007). From the results of these studies, they define intuitive use as interaction that is fast, generally non-conscious and utilizing prior knowledge (Blackler & Hurtienne, 2007; Blackler et al., 2002).

In the mid 2000's, Technische Universitat Berlin formed the Intuitive Use of User Interfaces (IUUI) research group (Blackler & Hurtienne, 2007). IUUI focused on designing systems that supported intuitive interaction so that interfaces were more usable and leveraged knowledge from everyday experiences. They defined intuitive interaction as instances when the unconscious application of pre-existing knowledge leads to successful system effects (Blackler & Hurtienne, 2007; Hurtienne & Israel, 2007). Also in the mid 2000's, Spool described intuitive interaction as one of two situations: either the user has the knowledge he or she needs to use the system effectively or the design features of the system are 'naturally' providing the user with the knowledge they need to use the system effectively (Spool, 2005).

In 2008, O'Brien et al. provide a definition and framework for Intuitive HCI as a way for HCI researchers to understand the concept and apply it to their own practice (O'Brien, Rogers, & Fisk, 2008). They define intuitive interaction as interaction that uses a combination of prior knowledge and feedforward methods to complete certain tasks or goals (O'Brien et al., 2008). In 2009, Antle et al. define intuitive interaction as moments when users perform appropriate input actions unconsciously or automatically (Antle, Corness, & Droumeva, 2009a). In 2012, Macaranas et al. adapt Kahneman's definition of intuitive thinking and define intuitive interaction as interaction with an unfamiliar system where the user knows how to act quickly and automatically and with unconscious effort and attention (Macaranas et al., 2012a; Macaranas, Antle, & Riecke, 2012b) .

Two main concepts come from the analysis of the various definitions of intuitive interaction. First, various researchers suggest that intuitive interaction requires the use of prior knowledge (Blackler et al., 2002; Hurtienne & Israel, 2007; Macaranas et al., 2012a; O'Brien et al., 2008; Spool, 2005). Second, intuitive interaction involves the use of unconscious reasoning to shape actions (Antle, Corness, & Droumeva, 2009a; Blackler et al., 2002; Hurtienne & Israel, 2007; Macaranas et al., 2012a; O'Brien et al., 2008; Spool, 2005). An interesting observation from the different definitions is the connection between intuitive interaction and usability. Hurtienne & Israel's, Spool's, O'Brien's and Antle et al.'s definitions discuss the concept of completing a task or using the system successfully – i.e. effectiveness – a construct of usability as per ISO 9241 ("ISO 9241 Part 11: Guidance on usability," 2001). Furthermore, the researchers in IUUI tie many concepts and aspects of intuitive interaction to usability measures defined by ISO 9241 (Blackler & Hurtienne, 2007).

Intuitive interaction is desirable in HCI because cognitive resources are used on completing a task or goal and not on controlling or learning an interface (O'Brien et al., 2008). Another suitable area for intuitive interaction is NUI systems design. NUI systems such as an interactive art installation or museum exhibition can consist of an open area with minimal affordances and a walk up and play atmosphere. In these situations, users must rely on previous knowledge in order to understand how the interface works. However, this open-nature of NUIs and whole body systems can also cause issues. Using the example of a previous study, Hornecker illustrates how prior experiences in the physical world can generate expectations on interactions not supported by the system (Hornecker, 2012). She states that designers must address the hybrid nature of systems that have physical and digital spaces and create interaction mappings that have clearer connections between the physical and digital space (Hornecker, 2012).

It is important to note that intuitive interaction may not be desirable on systems where the physical control matters or when the goals of the system include reflection and conscious learning. Hornecker suggests that automatic and literal interaction does not always foster learning and reflection, which may be ideal for certain systems (Hornecker, 2012). For example, simulation surgery applications aim to teach the novice surgeon the functions and proper use techniques of each tool. This knowledge needs to be explicit and consciously learned so that surgeons can reflect and improve on their current practice while reliably leveraging this knowledge during real surgery. The suitability of intuitive interaction for different applications is beyond the scope of the research presented in this thesis. However, designers may not need to make system controls unintuitive to generate reflective behaviour. In the gaming industry for example, game designers often add cut scenes or special events to have players reflect on the their actions in the previous round or level. Furthermore, controls that match the concepts being portrayed by the system may result in richer reflections since the concepts are partially understood by previous bodily experiences.

2.2.2. Designing Intuitive Interaction

Literal features

In the first years of an interface form's existence, many designers turn to what Smith refers to as *literalism* to make an interface easy to learn. Interfaces that are easy to learn allow users to have a more intuitive understanding of the system: spending less time learning the interface and more time performing their goals and tasks. Smith describes literalism as instances when interface features are true to the designer's mental model (Smith, 1987). Based on this, *literal features* are control mappings where the physical and digital representations match up perfectly in behaviour and function. For example, in his experiences with the Alternate Reality Kit (ARK), Smith describes a feature within the interface where the movements of the physical mouse match the movements of the digital hand on screen – thus being literal (Smith, 1987). Graphical, tangible and natural UIs have physical and digital counterparts – making the blends between the digital and physical space unavoidable. In this study, literal mappings are described as *isomorphic* since there is a one-to-one mapping with the physical and digital representation. In other words, the physical and digital representations share the same structure. Svaenes suggests that system structures mapped to physical spaces or temporal time should ease learning and use (Svanaes, 2001).

Because of their clear mapping, literal features have high learnability. However, there are instances when mimicking the behaviours of the physical object is inappropriate in the digital system (Hornecker, 2012). Furthermore, what if the task at hand requires a feature that does not exist in the physical world? Smith describes mappings that break out of the designer's intended mental model as *magic* and features that support these mappings as *magical features* (Smith, 1987). Magical features require some instruction to learn. However, they provide the required functionality needed for abstract tasks. In ARK, Smith describes a dynamic button that inherits the ability to modify an object's properties when a user drags that button over that object (Smith, 1987). The concept of a dynamic button is fairly magical and useful for executing the same command on different objects within ARK. Though this behaviour does not normally exist in the physical world, users had little difficulty understanding this feature once it was explained to them. This is likely due to this feature adhering to the Gestalt laws of proximity and association (i.e. close objects are related to each other) (Ware, 2008).

Designing interfaces that are easy to learn and support abstract tasks requires a careful balance of literalism and magic. Besides literalism, what other strategies can designers use to make novel interfaces easy to learn – thus supporting intuitive understanding and interaction? Like magic, how well do these strategies support abstract tasks?

Leveraging conventions

As an interface form becomes more developed, common features found in similar systems become established conventions. Following these conventions may foster intuitive interaction since users have been exposed to them in previous systems. Blackler et al. used the results from four empirical studies over the span of five years and provide three principles designers should follow to support intuitive interaction (Blackler & Hurtienne, 2007; Blackler, Popovic, & Mahar, 2005). These principles act as guidelines on how to make the function, appearance or location of any given feature familiar to new users. The first principle advocates the use of conventions from previous systems to facilitate intuitive interaction (Blackler et al., 2005). The second principle states that when conventions do not already exist, designers should use other strategies such as metaphor to make the feature more familiar (Blackler et al., 2005). The final principle states that any strategy used (whether convention, metaphor, or another) should stay consistent throughout the whole system (Blackler et al., 2005). Table 2 is the list of these three principles.

Table 2. Principles for Designing Intuitive Interaction. Taken from Blackler & Hurtienne (2007)

1	Make function, location and appearance familiar for features that are already known. Use familiar symbols and/or words, put them in a familiar position and make the function comparable with functions users have seen before.
2	Make it obvious how to use less well-known features by using familiar things to demonstrate their function, appearance and location.
3	Increase the consistency within the interface so that function, appearance and location of features are consistent between different parts of the design. Use redundancy in order to maximize the number of users who can intuitively use the interface and the ways in which they can choose to complete their tasks.

With these principles, Blackler et al. also suggest a continuum of five strategies that designers can use to support intuitive interaction (Blackler & Hurtienne, 2007 - Figure 1). I list the strategies below, which vary in complexity in cognition and design. Strategies closer to the top of the list (Figure 1, left side) use more innate knowledge and require less familiarity with technology (Blackler & Hurtienne, 2007). Strategies closer to the bottom of the list (Figure 1, right side) use more complex knowledge and require more experience with a variety of technology.

- **Body reflectors:** features that mimic the body and utilize knowledge obtained from an early age (Blackler & Hurtienne, 2007). An example of a body reflector is a doorknob. The knob's rotation mimics the rotation the hand makes to rotate it and uses our previous knowledge about the ways we can move our wrists.
- **Population stereotypes:** conventions rooted in knowledge based on culture – often taking the form of metaphorical associations. An example of such knowledge is having horizontality associated with quantity. This knowledge heavily deals with the way we culturally perceive time (right is forward, left is backwards) and can be seen when we read (gazing rightwards shows us more words to the story and advances the narrative) or when we navigate a song or movie (rewind << and fast-forward >>).
- **Conventions from the same domain:** familiar features that can be found across various systems of the same medium (e.g. flash function in cameras, "X" close button in GUI windows).
- **Conventions from different domains:** familiar features that can be found in systems of different mediums (e.g. rotating dial on radios, and thermostats).
- **Metaphors:** a structural tool for representing one thing in terms of another. An example of a metaphor is ZOOM FUNCTION IS MAGNIFYING GLASS. This

metaphor allows us to use our previous experiences with magnifying glasses to understand how to increase or decrease an image's size on our screen

Figure 1. ***Strategies for Designing Intuitive Interaction Continuum. Taken from Blackler & Hurtienne (2007).***

Strategies on the left refer to more innate and accessible knowledge while strategies on the right refer to more complex mechanisms.

Blackler suggests that designers need to consider the user group and their familiarity with technology when designing features for systems (Blackler & Hurtienne, 2007). Rather than expertise, Blackler et al. noticed that a user's familiarity with technology affected the user's ability to use an object intuitively (Blackler et al., 2002, 2005). Furthermore, certain conventions may be inappropriate for certain cultures and contexts. For example, the mailbox icon for many e-mail systems is irrelevant for European users since these mailbox designs are not seen in Europe (Blackler et al., 2005). Furthermore, older users exhibited less instances of intuitive interaction because they were familiar with technologies which are now obsolete (Blackler et al., 2005).

Combining Blackler et al.'s principles and strategies give us the following implications. When possible, designers should utilize knowledge a user has obtained from their experience with previous systems (cultural and system conventions) and design affordances that match the way our body moves (body reflectors). Designers should make the location, appearance and function of a system feature similar to an established convention if one exists and is not difficult to enact and remember. This way, users can use their knowledge of previous systems to understand the new system (Blackler et al., 2005). If there is no similar feature or convention that exists, or if the current convention is hard to enact and remember, designers should use more complex methods such as leveraging from other domains or creating blends and/or metaphors (Blackler & Hurtienne, 2007).

Currently, there are very few conventions for whole body systems. In the past, designers borrowed an established convention from an older domain if no convention existed for the new domain. For example, the analogue convention of using a dial to increase or decrease a value (i.e. the radio dial to increase or decrease radio frequency) was transformed into the gestural convention of rotating a finger in a circular motion to browse forward and backwards through songs on the original model of the iPod.

Beyond conventions

Winograd suggests that designers should look beyond systematic conventions and consider how society and culture shape our knowledge, beliefs and ways we interact with the world and the objects around us (Winograd, 1995). We develop an understanding of interactive systems from our everyday experiences – not just our experiences with other systems. When the design of a system contradicts our understanding, the system loses its usability or affordance, creating confusion (Winograd, 1995).

Metaphors in HCI

Metaphors are one way to move beyond systematic conventions. Weinschenk et al. describe the metaphor as a tool designers should use to connect complex systems to a user's everyday world (Weinschenk, Jamar, & Yeo, 1997). By metaphorically mapping a person's everyday experiences to action-control mappings, a user can use their knowledge from previous interactions with the environment and objects to understand unfamiliar systems. Early graphical interfaces leveraged metaphors between the physical and digital world. A classic example of this is the desktop metaphor. Designers used objects found in a typical office setting (e.g. trash bin, file folder) to help users understand controls in a typical operating system (e.g. delete function, digital file structures).

From a survey paper on metaphor use in HCI during the 1980's and 1990's, Neale and Carroll describe metaphors as being *concrete* or *abstract* (Neale & Carroll, 1997). The metaphor DELETE FUNCTION IS TRASH BIN is concrete. The source domain (delete function) exhibits the same properties and functionality as the target domain (trash bin). The metaphor NEW FUNCTION IS BLANK PAGE is abstract. The target domain (blank page) is an abstract representation of the source domain (new function). The new object does not necessarily have to be a blank page. Experienced users have an easier time understanding metaphors that rely on abstract representations. Novice user's find abstract metaphors difficult to pick up quickly and use effectively (Neale & Carroll, 1997). Experienced users were able to recognize the metaphor because they were able to tie it to previous experiences with other systems. If designers used abstractions from everyday experiences as opposed to previous systems, abstract metaphors may be more accessible to novice users.

In a similar survey paper that analyzes two decades of metaphor use within HCI, Blackwell identifies two popular but contradicting views of the metaphor. Some view the metaphor as an enabler of freedom and creative thought. Designers and researchers holding this view see metaphors as a tool that allows for multiple interpretations (Blackwell, 2006). Designers treat the user as pilot or explorer of the interface, allowing them to have freedom of navigation and interpretation. This view is closely related to the Phenomenological view of embodiment and Piaget's model of learning (Rohrer, 2007). Others view the metaphor as a tool to rapidly communicate the designer's mental model to the user's head (Blackwell, 2006). Designers treat the user as a computational machine that translates the visual elements of an interface into an internal data representation within his mind (Blackwell, 2006). This view is closely related to the Cartesian Dualist's view of embodiment.

The Cartesian Dualist approach to metaphor believes in a single or absolute interpretation of any given metaphor. Deviation or alternate interpretations from the designer's intended mental model is undesirable. To avoid misinterpretations, holders of this view state that designers should strictly follow and represent the target domain within the source domain (Blackwell, 2006). The Phenomenological approach to metaphor critiques the Cartesian Dualist approach, stating that it typecasts the user into an archetypical role. The desktop metaphor typecasts users as office workers and typists. Furthermore, a single or absolute mental model fails when a user fails to pick up or understand the target domain (Blackwell, 2006). For example, a visualization system that uses relational database as a target domain for a metaphor will not be accessible to users who are unfamiliar with databases.

Standing in between the Cartesian Dualist and Phenomenological views of metaphor is the notion of a conceptual blend (Imaz & Benyon, 2007). Blends combine multiple source domains to create a target domain with functions non-existent in the physical world but understable to the user (Imaz & Benyon, 2007). We can view the modern smartphone as a conceptual blend between a telephone, camera and personal organizer. Blends allow for multiple interpretations while following a loose mental model.

Blackwell leans towards the Phenomenologist view of metaphor. He refers to Lakoff and Johnson's work on CMT (Lakoff & Johnson, 2003) as the most substantial theoretical support for metaphor use in HCI (Blackwell, 2006). Humans make sense of abstractions through embodied metaphorical images. For this reason, mental models using embodied metaphorical images should be accessible to the user as both designer and users are embodied thinkers (Blackwell, 2006). The creative nature of a metaphor that allows for multiple interpretations should result in creative user experiences (Blackwell, 2006). This is similar to Johnson's views on the conceptual metaphor as a instigator of imagination and creative thought (Johnson, 1987).

Svaenes and Verplank explore the use of metaphor as a design tool that takes epistemology and culture into consideration while bridging the gap between user expectations and system interaction. In their search for new metaphors for tangible interface design, they found two realms of metaphors that did not exist in GUIs (Svanaes & Verplank, 2000). The first realm transposes human relations onto physical objects (i.e. physical closeness is emotional closeness). The second uses interpretations of magic or "paranormal phenomena". For example, imagine two floor tiles with Light Emitting Diodes (LEDs). Standing on one tile turns on the LEDs for that tile. Standing on the other tile turns off the LEDs from the previous tile and turns on the LEDs of the tile being stepped on. We can interpret this as magic (i.e. the user has a magical source of light). We can also see this as a conceptual metaphor using the CONTAINER scheme (i.e. body is light source). Svanaes and Verplank state that systems, which have a magical nature, are easy to understand because they match a user's "tacit expectations towards magic" (Svanaes & Verplank, 2000). This is similar to the magical features described previously by Smith (1987).

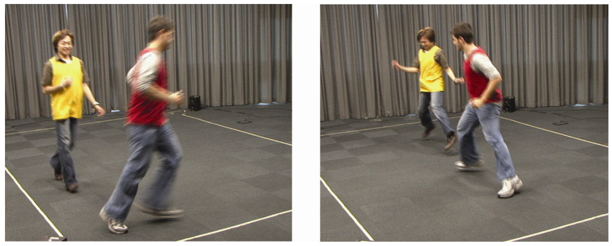
Both Blackwell and Svanaes and Verplank illustrate ways of making abstract representations accessible to the novice user by moving away from systematic conventions and towards metaphorical relationships rooted in everyday experiences. While Svanaes and Verplank refer to their approach as magical, both groups of researchers use CMT as a mechanism for metaphorically mapping everyday experiences into UI system controls (Blackwell, 2006; Svanaes & Verplank, 2000).

Conceptual Metaphors in UI Design

Antle et al. have extensively explored the use of CMT in tangible and whole body systems (Antle et al., 2011; Antle, Corness, Droumeva, van den Hoven, & Bevans, 2009; Antle, Corness, & Droumeva, 2009a, 2009b; Bakker et al., 2009; Bakker, van den Hoven, & Antle, 2011). These studies revolved around three prototypes: Sound Maker (Antle et al., 2009b), MoSo Tangibles (Bakker et al., 2011) and Springboard (Antle et al., 2011). Sound Maker (figure 2a) and MoSo Tangibles (figure 2b) were designed to teach children different sound parameters (e.g. pitch, tempo, rhythm). For Sound Maker, Antle et al. explored how conceptual metaphors could help reveal the possible actions users could do in a whole body system (Antle, Corness, & Droumeva, 2009b). From this study, they found that interface designs using conceptual metaphors led to more accurate actions and verbal explanations (Antle, Corness, & Droumeva, 2009b). However, the mappings between the input actions and system controls also need to be discoverable before they can even be understood (Antle et al., 2009a, 2009b).

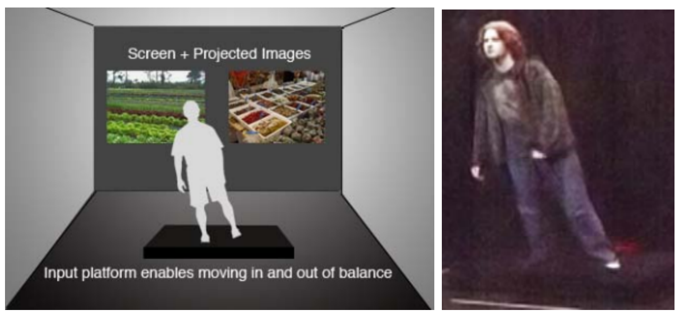
Using Mo-So Tangibles, Bakker et al. explored how a tangible object with many conceptual metaphor-based mappings compared with a tangible object with a single conceptual metaphor-based mapping in helping children learn music theory (Bakker et al., 2011). Based on the results, Bakker et al. suggest that there is no significant difference between multiple metaphors and single metaphor-based mappings (Bakker et al., 2011). Surprisingly, children did not get confused with objects that had multiple metaphor-based mappings. For both the Sound Maker and MoSo Tangibles studies, Antle et al. and Bakker et al. were interested in exploring how to use CMT to design UI mappings that can act as a mechanism for learning (i.e. manipulating the pitch of sound to understand the concept of pitch).

Figure 2. Sound Maker (a), MoSo Tangibles (b) and Springboard (c)



a)

b)



c)

Springboard (figure 2c) used the user’s physical and spatial balance to depict different balance states within the context of social justice (Antle et al., 2011). The balance depicted by the user’s body movement (i.e. body balance) was metaphorically mapped to the conceptual balance depicted between a pair of projected images (i.e. meaning balance). Antle et al. used the Twin Pan Balance image schema and CMT to connect body balance to meaning balance. The Twin Pan Balance schema has two downward force vectors and a fulcrum point directly midpoint of the vectors. When the vectors are of equal force, there is balance (Johnson, 1987). Objects that use the twin pan schema are teeter-totters or beam balance scales. Antle et al. compared how adult users used physical and spatial balance to understand the system controls and issues of social justice – the content domain of the system (Antle et al., 2011). During post task interviews, Antle et al. asked participants to explain how to use the system and the meaning behind the images. From these interviews, Antle et al. noticed that many who had difficulty explaining the system controls verbally were able to perform actions successfully during the experiment (Antle et al., 2011). This suggests a tacit understanding of the interface. Unlike the Sound Maker and MoSo Tangible studies, Springboard studies focused on using CMT to help users understand abstract meaning through bodily interactions with the system. In Springboard, Antle et al. used CMT to create action-meaning mappings rather than action-control mappings.

Antle et al. designed three prototypes that used CMT-based mappings and ran a case study to analyse the similarities and differences between the three systems through user experiments. (Antle, Corness, Droumeva, et al., 2009). From this study, they summarized that users consider several conceptual metaphors at once when making sense of a new interface. They also found that users related their body position within an enclosed space more easily to conceptual balance than their physical weight distribution. Antle et al. suggest that designers should make conceptual metaphors easily discoverable by creating affordances in design constraints, physical layouts, and salient feedback (Antle, Corness, Droumeva, et al., 2009). Furthermore, the affordances and system feedback should focus on supporting image schematic action. For example, showing the detection of movement through a change in sound pitch for Springboard acted as salient feedback for users to know that spatial and/or physical balance was recognized by the system and was the key component in controlling the images (Antle et al., 2011). The specific design constraints in MoSo tangibles limited the way children could interact with each object. For example, one object responded to rotation (figure 2b – right image), while another responded to pulling and pushing (figure 2b – centre image). These constraints acted as hints for the children to understand how to use each sound making tool (Bakker et al., 2011).

Antle et al. focus on using CMT in UIs that have concepts represented through the manipulation of the system. They use CMT to help novice users understand abstract concepts by allowing users to experience these concepts through system use. This differs from using CMT to help users learn how to use a system.

Hurtienne et al. also extend Lakoff and Johnson's work on CMT and use it to inform interface design (Hurtienne & Israel, 2007; Hurtienne et al., 2010, 2009; Hurtienne, Weber, & Blessing, 2008). In an early theory paper, Hurtienne and Israel explored how to use CMT to create taxonomy for describing various interactions available within a tangible interface (Hurtienne & Israel, 2007). From this paper, Hurtienne and Israel showed how conceptual metaphors could be used successfully to describe tangible interaction. Furthermore, Hurtienne and Israel suggest the use of conceptual metaphors as a strategy for moving beyond literal one-to-one input-control mappings as well as a means to support abstract data manipulation (Hurtienne & Israel, 2007).

Hurtienne, Weber and Blessing expand on this work and explore ways designers can use CMT in user-centred design (Hurtienne et al., 2008). They describe intuitive use as the subconscious use of prior knowledge that leads to effective interaction (Hurtienne et al., 2008). They also suggest conceptual metaphors as one way for supporting intuitive use (Hurtienne et al., 2008). They ran a study in which they compared an invoice messaging system to a redesign that used CMT in the every stage of the design process. To understand the context of use and user needs, they generated a list of image schemas from (1) the steps users took to complete tasks within the system, (2) the interface design of the previous system, (3) the user's observed interaction within the system and (4) the user's mental model (Hurtienne et al., 2008). To identify the requirements of the new design, Hurtienne et al. looked at the steps necessary to complete the primary task (i.e. invoice verification) and the related image schemas associated with those steps. They also looked at the user's mental models and the image schemas associated to those models (Hurtienne et al., 2008). When ideating the redesign, they sketched several solutions for each image schema listed in the requirements phase. During the evaluation of the system, they compared image schemas from system instances to the image schemas from the requirements list to understand the strengths and weaknesses of the redesign (Hurtienne et al., 2008). Through a usability walkthrough and questionnaire, Hurtienne et al. found that most users rated the redesign higher in preference and usability (Hurtienne et al., 2008). From this work, Hurtienne et al. provide an online database in where they define a set of image schemas and illustrate their use in an existing interface ("ISCAT | Image Schema Database," 2008).

Following this work, Hurtienne, Stößel and Weber empirically test the strength of various attribute image schema-based metaphors in the context of tangible objects (Hurtienne et al., 2009). They ran a study where they gave participants two sets of objects and asked them which set best represented a given adjective. The two sets represented an image schema pair (e.g. HOT – COLD) and only one within the set coincided with a conceptual metaphor (e.g. HOT IS ANGRY). They repeated this task 28 times, testing a total of 29 metaphors (Hurtienne et al., 2009). From this study, they found that the majority of participants' choices agreed with 66% of the metaphors (Hurtienne et al., 2009). This study focuses on using CMT as a means of expressing abstract meaning, which differs from work that focuses on using CMT as a means of designing system controls. This specific study is similar to Antle et al.'s Springboard studies as both focuses on creating action-meaning mappings. Currently, Hurtienne et al. are exploring CMT's use within the design of gesture-based interfaces (Hurtienne et al., 2010).

Another researcher who has used conceptual metaphor in practice but less extensively is Holland. Similar to Antle et al., Holland used CMT to create UI controls that illustrated theories behind abstract concepts (Holland, 2010). In this research, the abstract concept was tonal harmony and music composition. He redesigned an existing interface for teaching tonal harmony and replaced the keyboard and mouse with pressure sensors and accelerometers to make the system's input body-based. The redesigned mappings tied movement to music theory using the spatial group of image schemas and CMT. He compared the original design to the redesign through a case study. In this study, he found that designers could use low-level reasoning inherent in conceptual metaphors to teach novice users the concepts of tonal harmony. Furthermore, novice users were able to use these concepts effectively in composing music within the system (Holland, 2010).

Findings from studies that use CMT in interface design suggest that designers can create effective and efficient mappings by using prior knowledge based on sensory-motor experiences. This approach enables users to unconsciously apply knowledge gained from everyday patterns and relationships with space, movement, and physical properties in their interactions with NUIs. It provides designers with a systemic way to inform their designs rather than uncritically relying on conventions from physical, analogue or digital systems. Furthermore, these studies illustrate how CMT can be beneficial in systems that enable "learning through doing". CMT-based mappings that tie abstract concepts (e.g. social justice, tonal harmony) to image schematic actions make those concepts accessible to novice users. Users can learn these concepts by experiencing and manipulating them through system controls. Lastly, CMT is a design tool that can be used to create mappings between input action and system controls (i.e. action-control) and mappings between input action and abstract meaning (i.e. action-meaning).

2.3. Comparing the Different Design Approaches for Intuitive Interaction

As designers and design researchers move away from Cartesian Dualism and integrate a Phenomenological approach to a system's interaction model, they need a greater understanding of how people think and interact with the physical world (Buxton, 2010b; Winograd, 1995). Due to the digital-physical nature of NUIs, designers and researchers need to know how people use previous experiences with older systems and their everyday surroundings to make sense of new technology (Buxton, 2010b; Hornecker, 2012). Many design researchers turn to intuitive interaction – the subconscious application of previous knowledge to effectively use an unfamiliar system – to make NUIs accessible to novice users (Antle, Corness, & Droumeva, 2009a; Blackler et al., 2005; Holland, 2010; Hurtienne et al., 2008; Svanaes & Verplank, 2000). Different researchers used different approaches to create systems that support intuitive interaction including: literalism, magic, single or multi-domain conventions, conceptual blends and concrete, abstract or conceptual metaphors.

Designers need to find a balance between making an interface accessible to a novice user and supporting complex tasks (Smith, 1987). Blackler et al. described a continuum of strategies that can support intuitive interaction and described conventions as the ideal tool for supporting intuitive interaction (Blackler & Hurtienne, 2007; Blackler et al., 2002). However, conventions fail to leverage knowledge people make from their everyday experiences with objects, society and culture (Winograd, 1995). Metaphors can bridge new technology to a user's everyday world (Weinschenk et al., 1997). However, metaphors that rely on an absolute mental model or technical experience to understand the target domain require conscious attention and time to learn and integrate into automatic practice (Blackwell, 2006; Neale & Carroll, 1997). Various researchers turn to CMT to (1) make metaphors automatic and accessible to novice users and (2) create UIs that teach abstract concepts by integrating them in UI controls (Antle, Corness, & Droumeva, 2009b; Holland, 2010; Hurtienne & Israel, 2007; Svanaes & Verplank, 2000).

While many researchers provide definitions for intuitive interaction (Antle, Corness, & Droumeva, 2009a; Blackler & Hurtienne, 2007; Hurtienne et al., 2008; Macaranas et al., 2012a; O'Brien et al., 2008; Spool, 2005), very few provide a concrete or standardized way of measuring it. Furthermore, no research has compared how different mapping strategies support intuitive interaction, make an interface accessible to novice users or help users understand abstract concepts.

The study described in this thesis will inform the designer of various strategies they can use to create mappings between bodily actions and system controls, how each mapping may affect the usability of the system, as well as how well each mapping may support intuitive interaction. While the literature review identified various mapping strategies, this thesis focuses on three: conceptual metaphors (i.e. metaphoric mappings), literalism (i.e. isomorphic mappings) and conventions (i.e. conventional mappings). I chose these strategies for their prevalence within the literature review as well as their use in whole body games (discussed in the next chapter). Previous studies suggest the possibility of increased awareness and impact from using systems that facilitate intuitive interaction (Antle et al., 2013). I further explore these constructs to validate the previous research and to extend it to various mapping strategies. Based on these goals, I had the following research questions:

R1 How do whole body systems with metaphoric, isomorphic and conventional mappings compare in usability?

R2 Do whole body systems with metaphoric, isomorphic, or conventional mappings foster intuitive interaction? Which mappings?

R3 How do whole body systems with metaphoric, isomorphic and conventional mappings affect the user's awareness of abstract concepts embedded in action-meaning mappings?

R4 How do whole body systems with metaphoric, isomorphic and conventional mappings affect how the user is impacted by the abstract concept embedded in action-meaning mappings?

In chapter 3, I introduce systematic ways of designing metaphoric, isomorphic and conventional mappings for whole body systems. These design strategies are grounded in previous literature and have the potential to support intuitive interaction. In chapter 4, I describe a methodology for measuring intuitive interaction with emphasis on a user's mental model, cognitive focus and performance. In this study, I also explore how learning to use a system, learning abstract concepts and intuitive interaction support or conflict with each other, extending the work of Antle et al. (2009b), Hornecker (2012) and Holland (2010). Results from this study contribute to creating design knowledge for NUI systems. Designers can use this knowledge to understand how different strategies reflect a user's expectations with unfamiliar NUI systems. The application of this knowledge can bring NUIs closer to feeling more intuitive and natural – as their name suggests.

3. Research Instrument

The following chapter describes the research instrument that was used to answer the research questions that were presented in the previous chapter. It begins with the design requirements the instrument needed to answer the question. It then continues to describe the prototype that was redesigned to fit these requirements and the rationale behind the redesign.

3.1. Design Requirements

To answer the research questions presented in the previous chapter, I required a research prototype in the form of a whole body system. I wanted tasks to be similar to previous studies (i.e. finding a specific state or moving through a sequence of states – similar to Antle et al., 2011 and Antle, Corness, & Droumeva, 2009b). I developed a list of design requirements to identify the type of system needed. First, I identified general requirements that would help the experiment design:

- **Simple but flexible tasks**: so they can be done within a metaphoric, isomorphic, and conventional interface design.
- **Representative but similar UI designs**: designs had to represent each mapping strategy but be similar enough to allow empirical comparisons. Designs that were too different could introduce confounds that may cause irrelevant differences between the mapping strategies.

Next, I generated a list of requirements from the research questions:

- **Distinct states**: to clearly indicate when users got a task right or wrong. This will help with usability measures. [R1]
- **Variability in functions:** to have tasks with varying difficulty. Difficult tasks challenge the participant and separate those who had partial understanding of the system from those who had full understanding. [R1]
- **Simple input actions:** so extensive time or effort isn't spent on performing the movement. Unfamiliar postures like standing on one leg require effort and

attention to do properly. This takes a participant's focus away from the task or abstract concepts portrayed by the system. This will help with intuitive interaction measures. [R2]

- **Validated representation of abstract concept:** through complimentary studies or literature. This will help elicit impact and awareness on the abstract concept embedded in the UI controls. [R3, R4]

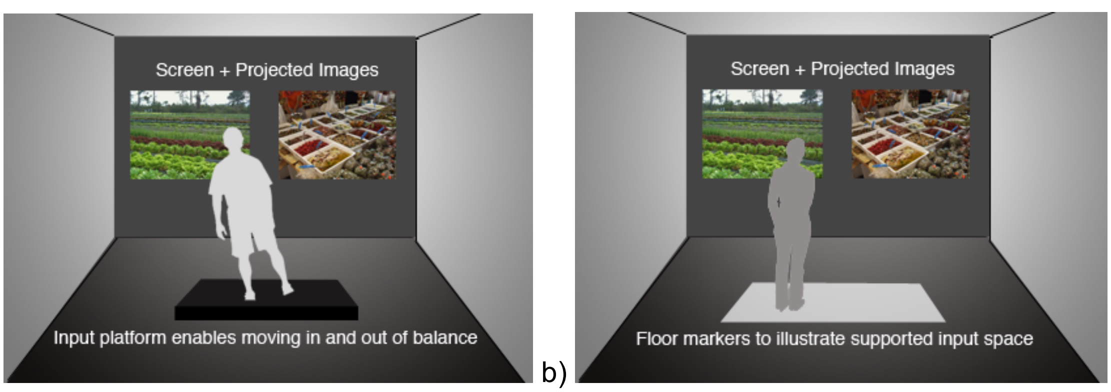
After some discussion with my supervisory committee, I decided that a re-design of an existing system would meet the requirements listed above and require less time than building a new system. Next, I discuss the system chosen for the thesis study.

3.2. Springboard

I chose Springboard as a suitable research instrument for this thesis study. Springboard is a whole body system that uses the user's spatial balance (figure 3b) or physical balance (figure 3a) to control the pair of images displayed on the screen (Antle et al., 2011). The pair of images displayed on the screen at any given time represents one of five possible states of balance in either food management, security, and housing development (Antle et al., 2011).[1]

Figure 3. The original Springboard system (left) vs. the redesign (right)

a) b)



The user on the left is shifting his physical weight to manipulate his body balance. The user on the right is changing her spatial position to create spatial (im)balance within the rectangular space. Both are using *body* and *spatial balance* to see a state of *meaning balance* from the images.

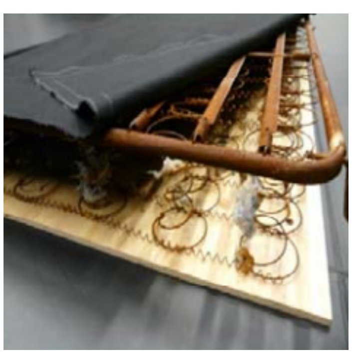
[1] I discuss the original Springboard UI design and previous studies using the system in the previous chapter: section 2.2.2, page 20.

The main function of Springboard – mapping the user's body balance to the system's meaning balance of the content domain – was simple and flexible enough to be done in a metaphoric, isomorphic and conventional interface design. The distinct states of balance made it easy to design tasks that had clear right and wrong answers. There were enough states to design tasks that varied in difficulty. The input actions in the original design were simple and allowed users to concentrate on the abstract concept and tasks versus their movement. Most importantly, the pairs of images which depicted the different states of balance in social justice issues were validated in the design process of previous studies (Antle et al., 2011). The approach to creating the three UI designs and ensuring empirical comparability is discussed throughout this chapter.

3.2.1. Previous Designs

Previous versions of Springboard used three different input designs: a spring-enabled platform (figure 4a), sliders (figure 4b – top), and dials (figure 4b - bottom). Users used one of the input designs to navigate through image pairs depicting different states of meaning balance. These interfaces build on physical balance, spatial position and controllers as ways of perceiving meaning balance. In a previous study that compared body versus spatial balance, it was found that users interpreted the system using spatial balance more readily than body balance (Antle et al., 2011). For this reason, the redesign used spatial position for all three interface designs. By limiting input actions to spatial position for all conditions, differences in style of input actions would not be a possible confound that could result to a false positive hypothesis.

Figure 4. Input controllers for the original Springboard system: spring-enabled platform (a) and controller (b)

a) 

b) 

Rotating dials are located at the top of the controller while sliders are located at the bottom.

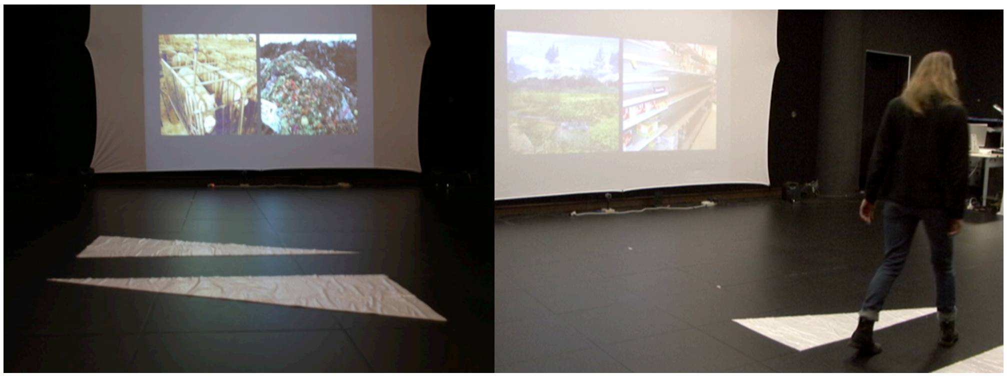
Springboard used audio feedback to signal successful interaction and a change in balance state. The sounds themselves are meant to be ambient. The user's main attention should be focused on the images. The sounds are abstract combinations of pitch sequences. Each balance state played a different sequence with a different combination of high and low audio tones. Users can use these sequences to differentiate between the different states. The audio system also provided feedback on immediate change. When a user shifted their weight, changed position, or manipulated a slider or dial, the system emphasized tonal change. This helped users identify effective input actions. Audio changes were programmed to occur synchronously to the image changes.

3.2.2. Redesign

The redesign kept the visual aesthetic of projecting a pair of images on the wall. It kept the sounds used in the original version to give users feedback on detected input actions and a change in balance state. The redesign did not use the platform or controller from the original design. These were replaced with three different floor markers – one for each UI design. The original input controllers supported actions of shifting body weight from side-to-side, moving around and off the platform, and manipulating sliders and dials. The redesign allowed users to do any type of movement possible in an empty space but only used the user's spatial position as meaningful input. Figure 3 illustrates the differences and similarities between the original and new design. A link to a video of participants using the redesign can also be found at: http://annamacaranas.com/research/12.

I used floor markers to create clear differences between the three UI designs. While these markers acted as an affordance for the supported input space, they did not restrict users to act within those affordances. Users were free to do any type of action such as running in and out of the floor markers, jumping, or waving their arms. This lack of affordance on supported movement was an important design feature because it represented a trait many current whole body systems and other NUIs have (Hornecker, 2012). It is true that some whole body systems have no affordances (i.e. empty floor space). Findings from this study may not be transferable to these systems. Future work could repeat this study with no floor markers. Figure 5 shows the implemented redesign and an example of it being used.

Figure 5. The Springboard redesign: implementation (left) and in use (right).



I use the image sets from the previous design as they were already validated in previous studies to depict distinct states of social justice. While there was three image sets available, only one set (food management) was used in the redesign. This was done to avoid image set as a possible confound in the experiment design.

Food management refers to the way a community produces food to sustain the given population. The left image represents varying levels of environmental preservation. The right image represents varying levels of food production. The amount of food a community produces has a direct impact on the environment. The balance relationship between how much food should be produced and how much of the natural environment should be preserved is the underlying issue portrayed in the images. The images together display a distinct amount of food production and the impact it has on the environment. I describe each level of food production and resulting level of environmental preservation as a *balance state*. The five states could be placed on a spectrum of extremes. One extreme has full environmental preservation and no food production while the other extreme is the exact opposite. In between the two extremes is a state where the environment is being preserved to a considerable degree but there is enough food production to sustain a community. Table 3 is a breakdown of the different balance states, along with an example of images that the user would see for that state.

Table 3. ***Balance states in food management and their visual representations***

BALANCE STATE		**IMAGE REPRESENTATION**	
Environmental Preservation	Food Production	Left Image	Right Image
High	Low	 Preserved land	 No food production
Moderately High	Moderately Low	 Low Impact Farming	 Minimal food production
Moderate	Moderate	 Medium Impact Farming	 Moderate food production
Moderately Low	Moderately High	 Medium -> high impact farming	 Above average food production
Low	High	 Monoculture	 Excessive food production resulting in dumping

3.3. Technical Implementation

I used Cycling74 Max MSP (*Max MSP*, 2011) to implement the Springboard redesign. Springboard uses camera tracking to detect a person's position within the physical space. Two Imaging Source ("The Imaging Source," 2012) cameras were installed in the study space: one in the front of the room and one on the ceiling 3 metres away from the projector screen and centred. The camera in the front of the room tracked horizontal motion while the camera on the ceiling tracked a person's horizontal movement (range more limited than the front camera) and depth movement (towards and away from projector screen). I determined camera placement by the interface designs and the range of movement detection needed. The front camera was for the metaphoric and isomorphic mapping condition. The ceiling camera was for the conventional. Both cameras had an array of infrared (IR) LEDs attached around the camera lens. IR detection is a common approach for blob detection and computer vision programming in low lighting situations.

The LEDs emit IR rays in the physical space. A person's body reflects the IR light and creates a blob within the program. The program uses background removal to make the person's body more prominent and clear. It assigns (x,y) coordinates to the centre of the blob in relation to the visible viewport of the camera. The viewport is cropped to only include the space of the floor markers and is pre-divided into 5 different sections to represent different balance states. The person's (x,y) co-ordinates is compared to the different sections of the viewport and assigned a decimal number from 1 to 5. This number represents the balance state the person's position falls under. A partial number such as 3.5 indicates that the person is equally in between states 3 and 4. A randomized fraction (positive and negative) is added to the person's recorded balance state to blur the boundary lines predefined in the program. I did this to add a sense of variation and allow for multiple interpretations. Pilots for the original design of Springboard showed that this variation allowed users to place more attention on the meaning of the images and interaction versus specific images or positions in the space.

Each balance state has three left images and three right images. These are randomly chosen and allow 9 possible image pairs for each state. This adds some complexity to the design and makes participants think about the meaning behind the images versus associating one image with one state. The images shown when a person is in between two states is also unique. For example, when a user has a balance state of 3.5, they see mostly equal image sets from 3 and 4. When a user has a balance state of 2.8, they see more image sets from 3 than 2. There is a bit of noise added to the image set distributions to keep consistent with the abstraction introduced in other aspects of the design. Each image pair stay on the screen for 1.5 seconds before switching to another image pair, unless the person changes balance states. When a user moves, the system takes approximately 4/5 of a second to change states. This was chosen based on the feedback from the pilots. Other combination of numbers resulted in participants feeling that the change was happening too fast or too slow. A gradient between image changes helped the transition as well.

The audio feedback handled balance through tuning, clarity and movement. Users perceived balance in tuning through changes in pitch. States with greater emphasis on food production had lower tones while states with greater emphasis on environmental preservation had higher tones. The middle state had an equal mix of each. Users felt balance in clarity through the frequency bands of the audio. States with an unequal emphasis on production and preservation sounded muffled or obscured. To feel balance in movement, audio movement matched body movement. The audio change was perceived immediately and was the way participants initially noticed that the system registered their movement within the system (Antle et al., 2011). More details on the audio system can be found in (Droumeva, Antle, Corness, & Bevans, 2009).

3.4. Industry's Approach for Designing Whole Body Systems

Springboard heavily uses the concept of balance in body movement and abstract meaning. It was important to integrate an element of balance in the UI redesign. I did an in-depth game analysis to see how game designers created controls for whole body systems that had aspects of balance in the control or gameplay. I narrowed games down to those that involved physical, spatial or conceptual balance to some degree. This game analysis was designed to compliment the literature review and to provide further information on which mapping strategies were being practiced in industry. I chose games because they are a common form of whole body systems widely accessible and used outside of research.

3.4.1. Games Analysis

In this analysis, I analyzed 27 games that used the Wii Balance board. The genres of these games ranged from racing, gravity-based mazes, sports simulations, puzzles and balance-driven games[2]. I did a close reading analysis because it is an appropriate first-person technique to understand the design details of a game, such as mappings between input actions and game responses. It also allowed me to use multiple lenses in the analysis process. Close reading involves multiple playthroughs of a game to better understand the narrative embedded within the design (Bizzocchi & Tanenbaum, 2011). The player acts as both gamer and game researcher during gameplay. The analytical lens of gamer and researcher can be worn simultaneously during a play session or separately in sequential play sessions.

I identified a set of metrics to frame the game analysis. These were:

- Input actions involved
- Game output
- Interaction style (e.g. metaphoric)
- Balance's role in the game
- Cognitive dominance (body movement vs. task completion)

During the formal analysis, I played each game three times and collected data based on the metrics. I did the first playthrough as a gamer. I did the second playthrough as a researcher. I used a combination of both analytical lenses for the final playthrough. I answered each metric with open-ended responses. After all the close readings, I analyzed the metrics across all games for emergent trends and themes.

The majority of balance-based games used conventional mappings, which mimicked existing devices and activities (e.g. snowboarding, driving a car). For games

[2] The full list of games analyzed and a chart outlining the results of the analysis can be found in Appendix A.

that involved unfamiliar tasks with no real-world representation (e.g. navigating a bubble in a virtual world), the user's actions were mapped directly to an avatar or object isomorphically. No input action represented an image schema that was metaphorically tied to a concept within the game. For this reason, no games within the analysis used conceptual metaphors as a means of mapping interaction. Conceptual metaphors are a promising tool in UI design but under-represented in industry practice. They were kept as a mapping strategy for the study to better understand the benefits and limitations of conceptual metaphors in UI design. This understanding can help integrate CMT-based UI controls into industry practice.

3.5. Strategies for Designing Input-Control Mappings

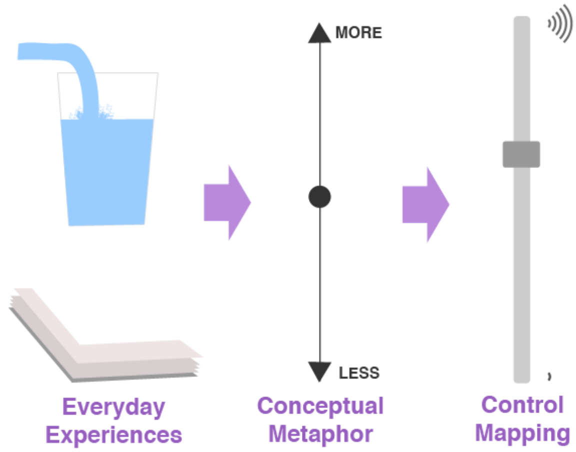
I based all three interface designs on the different strategies prevalent in previous research as well as observations I made from an in depth analysis of whole body games that had some element of balance within the gameplay. The mappings themselves had to be similar enough to be comparable in an experiment setting. They also had to be clear examples of the mappings they were representing. However, users could still interpret each interface design in multiple ways. The material of the floor markers needed to be simple and the colour needed to be neutral to minimize the material's effect on the user's interpretation on the space and interface. For example, material such as gold or carpet and colours such as yellow and red have strong and differing socio-cultural connotations that would affect each user's interpretation of the design. The final interface designs are the results of four months of brainstorming and three revisions.

3.5.1. Metaphoric

Image schema-based conceptual metaphor or *metaphoric mappings* are those that structure input actions based on image schemas – mental models formed from repeated patterns in everyday experiences – and system effects based on related conceptual metaphors. I can explain this through an example. A primary image schema all humans develop early in life is UP-DOWN. This image schema forms the basis for many metaphorical interpretations. A simple example is the metaphorical association of

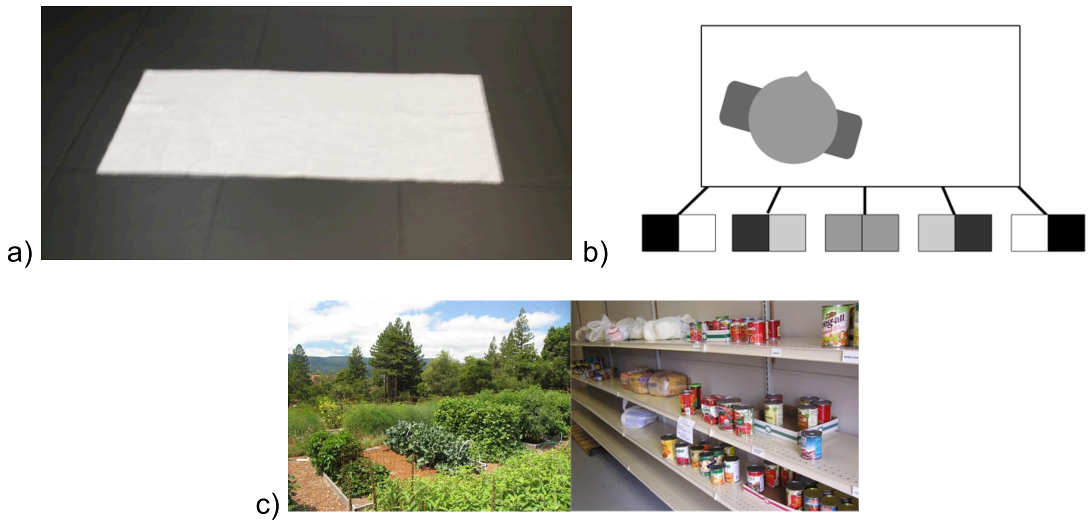
UP-DOWN with quantity. That is "up" is associated with "more" and "down" with "less". When we fill a cup or add objects to a pile, we notice the substance or object grow in height. The metaphor UP is MORE is a cognitive structure based on these everyday experiences and used – subconsciously – to understand a variety of more abstract concepts. For example, we use this metaphor to make sense of system controls (e.g. raising the sound volume by moving the slider up). Because this understanding is processed below the level of conscious awareness, we call it "intuitive" and interaction based on it, "intuitive interaction". Figure 6 illustrates the concept behind metaphoric mappings.

Figure 6. Metaphoric mapping example



The metaphoric UI for the Springboard redesign uses the BALANCE image schema (table 1 – pg. 8) and a rectangular floor marker (figure 7a). The BALANCE schema is mapped to the user's position within the rectangular space (figure 7b). The conceptual metaphor that ties the user's position to the different states of Springboard is CENTRE POSITION IS BALANCED. When the user stands in the centre of the floor marker, the rectangular space is symmetrically balanced. As a result, Springboard displays images with equal levels of environmental preservation and food production (pg. 32: table 3, third row). As the user moves further away from the centre of the rectangle, she creates an imbalance in the rectangular space. This input action results in an imbalance between the levels of environmental preservation and food production depicted in the images (figure 7c). This differs from the conventional horizontal slider, which has a single construct that decreases or increases in one direction. In Springboard, there are two constructs that have an inverse relationship (as one construct increases, the other decreases).

Figure 7. ***Top view of metaphoric input space (a) sample input action (b) and resulting image pairs (c)***



The gray box pairs represent resulting image pairs from the different positions within the rectangular space. The resulting state for (b) is high environmental preservation and low to medium food production.

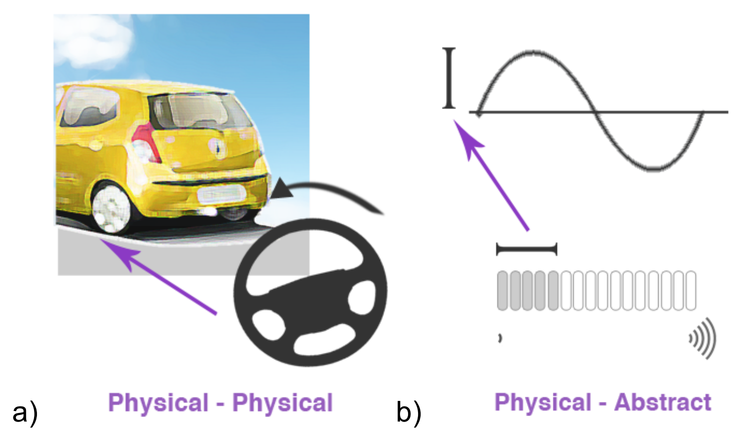
The viewport for the metaphoric UI was divided horizontally into five rectangular sections. The section on the most left was that of excess environmental preservation and no food production (table 3, first row; state 1). The section on the most right was of no environmental preservation and excess food production (table 3, fifth row; state 5). The third section was the state of balance between both preservation and production (table 3, third row; state 3).

3.5.2. Isomorphic

Isomorphic mappings are one-to-one literal spatial relations between the input actions and resulting system effects. The most common form of isomorphic mappings is physical-physical (figure 8a). An example of a physical-physical isomorphic mapping is the steering wheel. Turning the wheel left results in the car going left. The direction of the wheel rotation is the same as the direction of the car rotation. However, these physical-physical mappings may not be possible in more complex systems. Another form of an isomorphic mapping is physical-abstract (figure 8b). For example, one could map sound volume to an abstract array of hollow ticks. Each tick represents a constant amount of amplitude. Increasing the system's sound volume involves filling in a tick. Sound volume is mapped to the area of ticks filled in. Physical-abstract isomorphic mappings use an analogy (e.g. AMOUNT OF SPACE (filled in) IS LIKE AMOUNT (magnitude) OF SOUND VOLUME). This differs from a conceptual metaphor and the previous example of sound volume control (i.e. UP IS MORE VOLUME). Furthermore, this example should not be mistaken for the conceptual metaphor RIGHT IS MORE VOLUME. The input action does not involve right movement but the filling in of hollow ticks, which happen to be arranged horizontally.

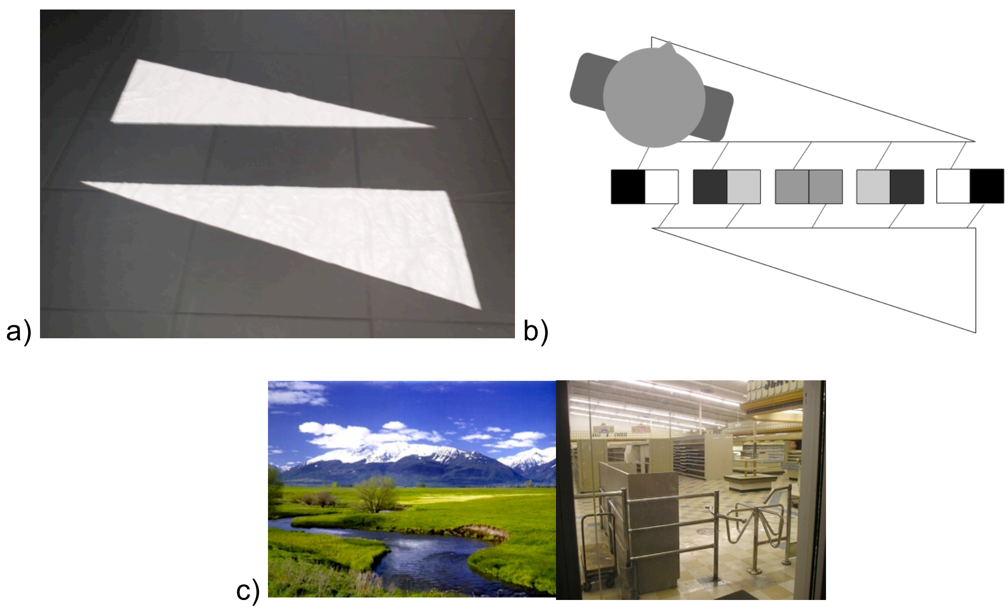
For both examples, the input action and system response have the same – isomorphic – structure. Isomorphic mappings can be intuitive if the user understands the nature of the structure being controlled by the interaction. For example, the array of ticks may not be intuitive for a user who does not think of volume as a parametric value that could be increased at a constant rate.

Figure 8. ***Physical-physical (a) and physical-abstract (b) isomorphic mappings***



The isomorphic UI for the Springboard redesign uses two triangular floor markers (figure 9a). The quantity of the spatial area of the triangles is isomorphically mapped to the quantity of the abstract concept related to food management (i.e. environmental preservation or food production). The user's position in relation to the two triangles results in different balance states. For example, imagine a user standing on the left side of the top triangle (figure 9b). He is closest to the top triangle segment with the largest area and the bottom triangle segment with the smallest area. The area of the top triangle segment is mapped to the amount of environmental preservation depicted by the left image. The area of the bottom triangle segment is mapped to the amount of food production displayed by the right image. His position within the two triangles results in the display of high environment preservation and low food production (figure 9c). While both metaphoric and isomorphic UIs use input positions, the isomorphic UI did not use the balance schema as its primary interaction model. Preservation and production were directly linked to different triangle segment areas.

Figure 9. ***Top view of the isomorphic input space (a), sample input action (b), and resulting image pairs (c)***

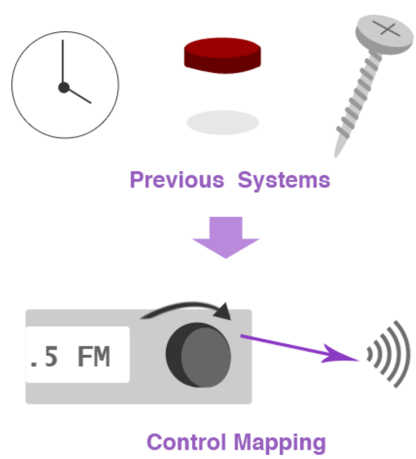


The viewport for the isomorphic UI was exactly the same as the metaphoric UI. Despite using the same viewport, the floor markers suggests different mental model of the physical space for the metaphoric and isomorphic UI.

3.5.3. Conventional

Conventional mappings are those adapted from previous practice and commonly found in product interfaces. In order to differentiate conventional from metaphoric and isomorphic mappings, conventional mappings in this study are limited to those found in other systems but NOT based on image schema-based metaphors or one-to-one mappings. Since they are the conventions in many products, they are familiar to many users – however in most cases, the grounding behind their structuring is unknown to the user and/or may feel random. An example of such a convention is the arrangement of letters on a QWERTY keyboard. Typically, conventional mappings have to be learned and take time to become established in design practice. An example of a conventional mapping for sound control is the previously mentioned physical dial that increases volume with a clockwise rotation. Associating clockwise movements with increased quantities comes from our experience with clocks, radio dials, screws and jars – clockwise rotation increases time, numeric values, and tension. Conventional mappings can be intuitive since they are based on our experience with previous systems. However, the structures of these mappings may be arbitrary. Very few conventional mappings exist for NUIs but past history has shown that conventions can be transferred from one medium to another (i.e. dial to iPod wheel). Figure 10 illustrates the concept behind conventional mappings.

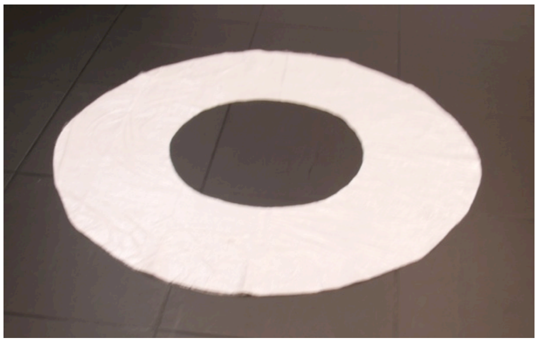
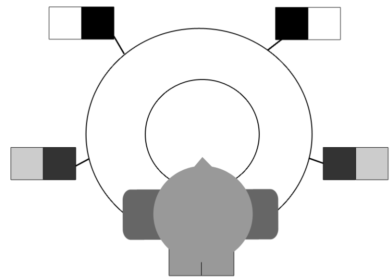
Figure 10. Conventional mapping example



The conventional UI in the Springboard redesign uses a circular floor marker (figure 11a). The path outlined by the marker is similar to a dial or iPod wheel. Starting from 1 o'clock on the wheel and moving clockwise, the participant slowly increases the emphasis on food production and lowers the amount of environment preservation.

Standing at 6 o'clock (figure 11b) results in a balance state of moderate environmental preservation and moderate food production (figure 11c).

Figure 11. ***Top view of the conventional input space (a), sample input (b) and resulting image pair (c)***

a)  b) 

c) 

The viewport for the conventional UI was cropped into a square to frame the circular path. The system draws a circle in the viewport whose diameter matched the length of the viewport. The system then draws a line from the edge of the circle at 12 o'clock to the centre of the circle and another line from where the user was standing to the centre of the circle. The angle between the first line and the second line determined the user's balance state. The 360 degrees within the circle was equally divided into five to define the five different states. For example, 0 to 71 degrees represented excess preservation and no production (state 5). 144 to 215 degrees, or roughly 6 o'clock displayed equal amounts of preservation and production (state 3).

With the development of the redesigned Springboard system, the next step in the thesis study was to use the redesigned system to answer the research questions through a user experiment. The methodology behind this experiment is discussed in the following chapter.

4. Study Methodology

I conducted a between-subjects comparative experiment in the Shared Virtual Environments (SVE) Lab at Simon Fraser University Surrey Campus. I designed this study to answer four research questions (table 4). I identified four constructs from the research questions: usability, intuitive interaction, awareness and impact. Usability and intuitive interaction represent the two primary research questions and are measured by four dependant variables each. Awareness and impact are secondary research questions and are represented with one dependant variable each.

Table 4. Research questions and the constructs that represent them

#	Research Question	Construct
R1	How do whole body systems with metaphoric, isomorphic and conventional mappings compare in usability?	Usability
R2	Do whole body systems with metaphoric, isomorphic, or conventional mappings foster intuitive interaction? Which mappings?	Intuitive Interaction
R3	How do whole body systems with metaphoric, isomorphic and conventional mappings affect the user's awareness of abstract concepts embedded in action-meaning mappings?	Awareness
R4	How do whole body systems with metaphoric, isomorphic and conventional mappings affect how the user is impacted by the abstract concept embedded in action-meaning mappings?	Impact

The following describes the methodology of the study including participants, procedure, tasks, measures, and data analysis methods.

4.1. Participants

Thirty-two participants (13 m, 19 f) from the greater Vancouver area volunteered to participate. Their age ranged from 18 to 55 years old (M=26.9 SD=8.3). Twenty-three participants (72%) were university students (15 undergraduate, 8 graduate). Two (6%)

were in their last year of high school. The remaining seven (22%) had degrees and were working in industry. Twenty-four participants (75%) used a computer and a smart phone daily. Others simply used a computer or a conventional cell phone daily. Twelve participants (37.5%) used tablets (i.e. iPad) daily or weekly. No participated listed any whole body systems (e.g. Xbox 360 Kinect) as a technology they use regularly. Ten participants were randomly assigned the metaphoric condition, eleven the isomorphic condition and the remaining eleven the conventional condition. One participant for the metaphoric condition did not show up, thus making the distribution unbalanced.

4.2. Procedure

Participants were required to perform five sets of tasks and two interviews. The first interview occurred after the first task. The second interview occurred at the end of the experiment. Participants also filled out a questionnaire at the beginning and the end of the study. The study had an estimated duration of 60 minutes but most participants completed it in 45 minutes. Participants were compensated with $10 for their participation. This was given either in the form of cash or as a gift card from the local coffee shop.

4.3. Tasks

In this section, I describe the five task sets used in the experiment. Each task set is associated with a reference code (e.g. T1). These codes are used throughout chapters 5 and 6 to refer to the different tasks sets. Following these descriptions is the rationale behind each task set design. The experiment script with all possible tasks for each set is located in Appendix B.

4.3.1. T1: Exploration

Exploration is the first task and can be thought of as a low-risk exploration period where the participant can familiarize herself with the system. Participants were given five minutes to explore the interface and observe how their movements affected the images on the screen. Questions regarding the interface were not answered because it was important to see how the participant understood the system with the given affordances and no instructions. Once a participant felt comfortable completing tasks using Springboard, she could begin the next task. Otherwise, she was told when five minutes was up.

4.3.2. T2: Perfect Balance & First Interview

After the exploration phase, participants were asked to make the left image and right image show equal states of food management. There was no time limit for this task. Participants had to tell the experimenter when they thought they had completed the task. After this task, participants were asked to tell us how they would teach a friend to use Springboard as well as what they thought the images represented. This task and the two interview questions measured their initial mental model and understanding of the system.

4.3.3. T3: Specific States

For this task set, participants were asked to show specific states on the screen. An example task from this set is "*Please show an above average amount of environmental preservation and below average food production*"[3]. They were told that more than one image could represent a state and that they did not need to look for a specific image. The experimenter also explained what was meant by environmental preservation and food production to avoid misinterpretations about the question. Participants were told to indicate when they had completed the task. Participants were asked to show three different states in total. The state and the order in which they had to display them were randomized.

4.3.4. T4: Relative Change

For this set of tasks, participants were asked to go to a starting location in the input space. Starting from this location but being able to move, participants were asked

[3] All possible task questions for each task set are listed in Appendix B

to increase or decrease the amount of environmental preservation or food production. An example of task instruction for this set was "*From your current position, please increase the level of food production*". Participants did this a total of three times. Though the specific location and order were randomized, each participant had to start in a position of perfect balance, a position where environment preservation dominated food production and a position where food production dominated environmental preservation.

4.3.5. T5: Sequential Change

For the final set of tasks, participants were asked to show a four-part sequence of states. Participants were instructed to indicate when they achieved a part of the sequence before moving to the next part. To ensure that participants were more focused on showing the sequence as opposed to memorizing it, they could ask the experimenter to repeat the next part of the sequence if they forgot it. Since this was the most difficult set of tasks, participants only needed to show two sequences. One sequence only included different levels of either environmental preservation or food production. An example of this type of sequence is "*Please show us minimal environmental preservation, balanced food management, minimal environmental preservation, moderately high environmental preservation*". The other sequence included different levels of both. An example of this is "*Please show moderately low environmental preservation, excess food production, balanced food management, and moderately low environmental preservation*". This was done to see if they could think of the constructs independently and if sequences that only focused on one construct were easier to do. Each sequence included one repetition of a previous state as well as the perfect balance state.

4.3.6. Rationale Behind Task Design

These tasks sets were the result of four months of brainstorming sessions with the supervisory committee. Each task was designed to create a situation in which I could measure one or more dependant variables associated with the constructs defined by the research questions. As stated earlier, T1 acted as an opportunity for the participant to engage in low-risk exploration of the system. This was designed as the first task so that participants would feel more comfortable completing the later tasks, which were being graded and timed. T1 was also a good opportunity to see if participants were doing natural random movements or slow and reflective movements to gain a better understanding of the system. This gave initial feedback on how much intuitive thinking and interaction each participant demonstrated.

T2 represented the key feature of the Springboard redesign – which was showing different states of balance in food management. Being able to do this task correctly symbolized an understanding of the abstract concepts portrayed within the images as well as the controls. This was chosen as the second task to see how well the user understood the key features of the system after T1. Understanding the system by this point in the experiment was a good indicator of intuitive interaction, since the user was able to pick up the system controls quickly and with minimal instructions. Measuring intuitive interaction beyond this task became more difficult because learning would occur as participants completed more task sets.

T3, T4, and T5 were specifically designed for usability reasons. These tasks range from easy (T3) to difficult (T5). The difficulty increased to match the expected learning effect that would naturally occur as the participant interacted more with the system. T3 was seen as the easiest task because it asked for an explicit state of balance. The user only had to know how to get that state within the input space to get the tasks correct. T4 was more difficult because participants had to know how each state related to each other in order to get the tasks correct. T5 was agreed as the most difficult task set because participants needed a mastery of the different states and the relationship between each state in order to make successful sequences.

Participants who had an intuitive understanding of the system should have high scores for each task set, regardless of difficulty. Those who demonstrate instances of learning should have task scores that improve over the duration of the experiment. For example, a participant who received average task scores of 0% in T2, 50% in T3 and 82% in T4 is learning the controls of the system with each proceeding task set.

4.4. Measures

The following section provides operationalized definitions for the four research constructs outlined in the beginning of the chapter. Each definition is taken from previous literature. The dependent variables that measure each construct are also included.

4.4.1. *Usability*

I operationalized usability using four dependant variables: effectiveness, efficiency, user satisfaction and self-perception of competence (table 5). The first three variables are based on the International Organization of Standardization (ISO)'s definition of usability ("ISO 9241 Part 11: Guidance on usability," 2001). I added the fourth variable based on previous studies that suggest a positive correlation between users who feel confident in completing tasks and satisfaction with using a system (Deci & Ryan, 1985). Table 5 summarizes each variable associated with usability and its corresponding data collection and analysis method. I elaborate on the data collection methods in the following text. I elaborate on the data analysis methods in section 4.5.1.

Table 5. Variables associated with the Usability construct and the approach taken to analyse them

Variable	Collection Method	Data Type	Analysis Method
Effectiveness	Task Score	Ratio	ANOVA
Efficiency	Completion Time	Ratio	ANOVA
User Satisfaction	System Usability Scale	Ordinal	Kruskal-Wallis test
Self-perception of Competence	Perceived Competence Scale	Ordinal	Kruskal-Wallis test

I use Wixon and Wilson's definitions for effectiveness, efficiency and user satisfaction (Wixon & Wilson, 1997):

- **Effectiveness:** the user's ability to complete tasks using the system (Wixon & Wilson, 1997).
- **Efficiency:** the amount of resources used in order to achieve a user's goal (Wixon & Wilson, 1997). In the case of this study, the key resource was time.
- **User satisfaction:** the feelings a user has towards the use and aesthetics of an interface (Wixon & Wilson, 1997).

I use Ryan and Deci's views on self-perception of competence to create an HCI-based definition:

- **Self-perception of competence:** a user's confidence in using the system.

In this study, I measured effectiveness by the total amount of tasks a participant completed correctly. This is represented by a percentage value since some tasks can be marked as partially correct. I measured efficiency by the time it took each user to complete each task. I measured effectiveness and efficiency for all task sets but T1 as it was not being counted towards usability. I used the System Usability Scale (SUS) (Brooke, 1996) to measure user satisfaction. The SUS is 10-item Likert scale that measures a user's feelings toward a system. I used the Perceived Competence Scale (PCS) to measured self-perception of competence (Deci & Ryan, 1985). The PCS is a 6-item Likert scale that measures the user's feelings on how well they completed tasks using the interface. Both the SUS and the PCS were given to the user in the form of a single questionnaire at the end of the study.

4.4.2. Intuitive Interaction

I operationalized intuitive interaction using four constructs: perceived intuitiveness, expectation, conscious attention, and subconscious actions (Table 6). Perceived intuitiveness and expectation refer back to Spool's research and definition of intuitive (Spool, 2005). Conscious attention and subconscious action refers to Bastick (1982) and Lakoff and Johnson's (2003) work. They represent how well participants understood the interface, how much effort and attention they used to learn and use the interface, and if they understood the system and the abstract concepts portrayed on a conscious or subconscious level. Table 6 summarizes each variable and its corresponding data collection and analysis method. I now discuss the data collection methods for intuitive interaction here. I discuss the data analysis methods for intuitive interaction in section 4.5.2.

Table 6. ***Variables associated with the Intuitive Interaction construct and the approach taken to analyse them***

Variable	Collection Method	Data Type	Analysis Method
Perceived Intuitiveness	Likert Scale	Ordinal	Kruskal-Wallis test
Expectation	Verbal answer	Nominal + Qualitative	Descriptive Statistics Thematic Analysis
Conscious Attention	Verbal answer, Likert Scale	Qualitative + Ordinal	Triangulate with effectiveness, Kruskal-Wallis test
Subconscious Action	Video recording	Qualitative	General Observation

Unlike usability, intuitive interaction does not have a standardized method of evaluation. The variables above were the result of taking different aspects of intuitive interaction theory discussed in previous literature. There were no well-established definitions available for the variables, resulting in my own definitions. While these definitions are my own, they are based on previous literature about intuitive interaction. They are defined as followed:

- **Perceived Intuitiveness:** the user's explicit opinion on how intuitive the interaction with the system felt.
- **Expectation:** how well the interface matched with a user's expectations on how they anticipated it to work and behave
- **Conscious attention:** the amount of conscious effort a user must exert to use the interface.
- **Subconscious action:** any gestures or movement the user does unconsciously that indicate a tacit understanding of the interface mapping.

I measured perceived intuitiveness by asking the participant to rate how intuitive she found the interaction with Springboard was on a 7-point Likert scale. This question was part of the post-study questionnaire. I measured expectation by asking the participant to state whether the interface design behaved in a way she expected and if not, how she expected the interface to behave. This question was part of the second set of interview questions asked at the end of the final task set.

I measured conscious attention two ways. The first method was a comparison between a participant's understanding of the system against his task scores. I measured a participant's understanding by assessing his first interview responses. A verbal demonstration of understanding the system controls is an example of conscious understanding. The questions asked during the first interview were:

> "If you were going to teach a friend how to use Springboard, what would you say?"
>
> "What do the images represent?"

By knowing how well he verbally understood the system, I could better assess how much conscious attention was coupled with a participant's actions. For example, a participant who showed poor verbal understanding but had good task scores was assumed to have a more tacit understanding of the system. Tacit understanding may still involve conscious understanding but shows less explicit knowledge of how the system works, and may also involve less conscious attention on using the system.

The second method for assessing conscious attention was a measure of where a participant's focus was located during each task. This took the form of a 7-point Likert scale rating given by the participants after T2, T3, T4, and T5. A rating of 1 indicated that all her attention was placed on her movement. A rating of 7 indicated that all her attention was on completing the task. A rating of 4 indicated an equal distribution of attention between movement and completing the task. Movement in this case was the main input method for Springboard. Focusing on movement was considered equivalent to focusing on using the interface. Ratings that were more focused on using the interface (i.e. 1-3) represent conscious attention on actions. Ratings that were more focused on task completion (i.e. 5-7) suggest more automatic body movements that required less conscious attention.

I examined subconscious action through observing what gestures and body movements the participant did during the interview sessions. I placed special attention on sections where participants were discussing the system. Previous work has shown that participants who used interface designs using CMT subconsciously mimicked the controls of the interface through body movement while verbally describing how the controls worked (Antle et al., 2011).

4.4.3. *Awareness*

Awareness was one of two constructs used to see how different mapping strategies affected the way a participant understood and was affected by the abstract concepts embedded in the UI controls of the system. In the context of this study, *awareness* refers to the user's awareness about issues in community food management[4] - an aspect of social justice. I measured awareness by asking the participant to self-rate his awareness of issues on social justice on a 7-point Likert scale. He gave these ratings before and after using the interface. This construct was included because previous studies with Springboard showed a significant increase in awareness for participants using a whole body system designed with metaphoric mappings versus participants who used a controller (Antle et al., 2013).

4.4.4. *Impact*

Impact is the second construct used to assess how different mapping strategies affected a participant's perception on the abstract concepts embedded in the UI controls of the system. Impact refers to the degree a user's opinion on social justice is changed based on her experience with Springboard. Impact was measured by asking the participant how willing she was to complete a co-op work term for a company that advocated better food management. She was asked this before and after using Springboard. Her response took the form of a rating on a 7-point Likert scale. Similar to awareness, I included this construct for its significant change before and after interface use in a previous study that compared whole-body systems and controllers for abstract domains (Antle et al., 2013).

4.5. Data Analysis

I collected both quantitative and qualitative data from the study. As such, data analysis ranged from descriptive and inferential statistical methods to thematic analysis and general observations. Due to the low sample size, I interpreted the results from the

[4] Refer to page 31 for a detailed description on how food management was represented within the research instrument

descriptive statistics and inferential tests cautiously. Tables 5, 6, 9 and 10 are a summary of the different variables, how they were collected, their data type and the approach taken to analyse them. A more detailed explanation behind the analysis method for each variable can be found below.

4.5.1. Usability

All variables within the usability construct are quantitative and were analysed using statistical methods (refer to table 5, pg. 48). The first two variables, effectiveness and efficiency, are ratio values. For this reason, I used a one-way ANOVA to see if there were any significant difference between the three action-control mapping strategies and these two variables. User satisfaction and feelings of competence are ordinal values and were analysed with the Kruskal-Wallis test.

4.5.2. Intuitive Interaction

Intuitive interaction is less straightforward to measure than usability and has a mix of quantitative and qualitative variables (refer to table 6, pg. 50). The first dependant variable, perceived intuitiveness, is an ordinal value and was analysed with the Kruskal-Wallis test. The second variable, expectation, is a qualitative value that takes the form of a verbal response and video data. I used descriptive statistics and thematic analysis to analyze this data. Conscious attention is a combination of an ordinal value and verbal responses. I used a Kruskal-Wallis test, descriptive statistics, and thematic analysis to analyze this data. I triangulated my findings with the effectiveness measures from usability. Subconscious action is a qualitative value that takes the form of user actions recorded in the video data. I analyzed this data using general observations.

The next subsections describe the qualitative analysis process for expectation, conscious attention, and subconscious action.

Expectation

I coded interview responses about expectation as “Yes” (i.e. met user’s expectation) and “No” (i.e. did not meet user’s expectation”. I used descriptive statistics to analyze the distributions of this coding across all mapping conditions. I did this to see if there were any trends between action-control mapping strategy and expectations. If there were trends, I would have used inferential statistics to see if these were significant. Mapping strategies that meet the majority of participants' expectations suggest the support of intuitive interaction (Spool, 2005). I analyzed user responses that indicated unmet expectations for any common themes that occurred across multiple users.

I reviewed the user's recorded input actions from the video data. I wanted to see if there were any recurring actions that suggested common unmet expectations across many users. I also reviewed the video data for inferences that implied an expected mapping strategy, which contradicted a user's assigned condition. To do this, I reviewed each user's actions during the experiment for possible mental models the user may have had about the system. For example, participants who would lean side to side suggest a mental model of physical balance towards the system. Likewise, participants who try to control the left image with the left hand and the right image with the right hand suggest an isomorphic model. For each study session, a participant's initial mental model (i.e. expected mapping strategy by the end of the exploration phase), predominant mental model (i.e. expected mapping strategy during the majority of the study), and final mental model (i.e. expected mapping strategy during the final task) were extracted from the video data where possible.

I coded all experiment sessions twice. The first coding was done immediately after the experiment. The second coding was done four months after. This time span gave me distance from the experiment and got me closer to being a naïve coder. Being the only coder is seen as a limitation but was unavoidable due to limited time and resources.

Conscious Attention

I analyzed conscious attention in three steps. First, I reviewed the first interview responses to infer each participant's level of understanding of the system and controls. Second, I compared this understanding to their task scores to identify participants who demonstrated an intuitive understanding of the system. Last, I reviewed the attentional ratings of participants with high task scores to differentiate between learnable and intuitive behaviour. I further describe each step below.

Each question in the first interview was designed to provide information on the participant's understanding of the system controls and the abstract concept embedded in the UI. The first question (if you were going to teach someone how to use this system, what would you say?) provides information about the participant's understanding of the system and its controls. The second question (what do the images represent?) provides information about the participant's understanding of the content within the system (in this case, the relationship between food production and environmental preservation). Each questions is scored out of two: 0 for no understanding, 1 for partial understanding, and 2 for good understanding.

The total score of these two questions represented a participant's overall understanding of the system controls and abstract concepts. 4 represents strong understanding, 3 represents good understanding, 2 represents partial understanding, 1 represents poor understanding and 0 represents no understanding of the system controls or content. This method of quantifying understanding from verbal data was inspired by previous research from Antle et al. that used similar questions and scoring system to measure a user's understanding of Sound Maker (Antle, Corness, & Droumeva, 2009b).

I compared the numeric value representing a participant's understanding to her task score (table 7). I predict that participants, who showed a strong or good understanding about the system, should also demonstrate a high task score (table 7, top left). This prediction is based on the premise that participants, who have a good understanding of the system, should be able to use it effectively. In this study, a high task score was categorized as 80% or higher. This number was chosen since it is the threshold of a grade of A- or above average work in most grading systems. I reviewed participants who demonstrated a strong or good understanding but had a low task score (table 7, bottom left) for reasons behind the discrepancy. Participants who had partial, poor or no understanding of the system and a high task score (table 7, top right) suggest an intuitive or learnable experience. Participants with partial, poor or no understanding and a low task score (table 7, bottom right) suggest an experience where the system was not easy to learn, unintuitive and difficult to use. I examined the interview responses and video data of these participants for possible reasons behind their poor understanding and performance.

Table 7. Comparisons between a participant's understanding and their task score and its associated implications

Result: Participant describes control/content correctly and has a high task score Implication: -> Analyze attentional ratings	Result: Participant describes control/content incorrectly or partially and has a high task score Implication: -> Analyze attentional ratings
Result: Participant describes control/content **correctly** and has a **low** task score Implication: **-> Demonstrates a strong understanding but poor execution. Either the tasks or the interface are problematic. This state is undesirable.**	Result: Participant describes control/content **incorrectly or partially** and has a **low** task score Implication: **-> Demonstrates a poor understanding of the system. This does not suggest intuitive interaction.**

Participants who demonstrated a high task score were analyzed further based on their attentional ratings (table 8). Participants who (1) had a high task score, (2) spent the majority of their attention on the task versus their movement and (3) had high task scores for most of the task sets suggest the use of minimum conscious attention (table 8, right). This minimal use of conscious attention suggests the use of intuitive interaction. Participants who (1) had a high task score, (2) spent the majority of their attention on their body or equally on task and body, or (3) show tasks scores that improved over time do not suggest intuitive interaction but an interface that is easy to learn (table 8, left and centre).

Table 8. Comparisons between high task scores and attentional ratings and its associated implications

Result: Participant's focus was mostly on movement, less on task. Task scores improved over time. Implication: -> Used conscious attention to learn the interface. Does not suggest intuitive interaction.	Result: Participant's focus was on movement and task equally. Task scores improved over time. Implication: -> Used conscious attention to learn the interface. Does not suggest intuitive interaction.	Result: Participant's focus was mostly on the task and less on movement. Task scores were consistent Implication: -> Used less attentional resources and had a low cognitive load. Suggests intuitive interaction.

Subconscious action

Subconscious action was a qualitative observation and took the form of a user's actions during the first and second interview sessions. In particular, I was interested in instances where the participant subconsciously mimicked the interface control while describing the abstract concepts embedded in the UI. Instances of subconscious action suggest a tacit understanding of the system that has not made it to a conscious level and thus cannot be verbalized. In previous work by Goldin-Meadows, children were able to demonstrate knowledge through actions, but were unable to describe the knowledge with words (Goldin-Meadow & Wagner, 2005). Other work in HCI had participants who could not properly describe the interface but could mimic the correct interaction model of the system with body gestures (Antle et al., 2013). This mismatch between knowledge demonstrated through actions and knowledge demonstrated through words shows the difference between tacit and explicit knowledge. In some cases, tacit knowledge may be a step in the learning process that occurs before explicit knowledge.

4.5.3. Awareness

I operationalized awareness using a single variable with an ordinal value (table 9). I collected this data before and after the study in the form of a 7-point Likert scale. Analysis of this data is two fold. First, I used a repeated-measures Wilcoxon test on the pre and post task ratings of each mapping strategy to see if there was a significant change in awareness before and after using Springboard. Second, I used a Kruskal-Wallis test on the post study ratings for all mapping strategies to see if there are any significant differences between mapping strategy and the user's change in awareness of social justice.

Table 9. Variable associated with the Awareness construct and the approach taken to analyse it

Variable	Collection Method	Data Type	Analysis Method
Topic Awareness	Likert Scale	Ordinal	Wilcoxon test, Kruskal-Wallis test

4.5.4. Impact

Impact was operationalized using a quantitative variable with an ordinal value (table 10). I used a method identical to the awareness variable to analyze this data. I used a Wilcoxon test on the pre and post study ratings for each mapping strategy condition. Second, I used a Kruskal-Wallis test on the post study ratings of all three mapping conditions to see if there was a significant difference between mapping strategy and its influence on the participants' feelings towards social justice (and how willing they are to be involved in social justice).

Table 10. Variable associated with the Impact construct and the approach taken to analyse it

Variable	Collection Method	Data Type	Analysis Method
Impact	Likert Scale	Ordinal	Wilcoxon test, Kruskal-Wallis test

The next chapter describes the findings from the study and the results from the data analysis.

5. Results

The results from the study are presented below. For most constructs, quantitative data comes first, with qualitative findings and observations following. For quantitative data types, I calculated descriptive statistics and present them here as bar graphs.

5.1. Usability

5.1.1. Effectiveness

I calculated the mean task scores (converted into %'s) for each task set (figure 12, first four sections). I also calculated an aggregated score across all tasks (figure 12, most right section). I ran a one-way between subjects ANOVA between mapping strategies on the aggregated score. There were no significant differences for aggregated task score between mapping strategies ($p > 0.1$)[5].

T2 Task Scores

I ran a Bartlett test to examine the homogeneity of T2 task scores between the three conditions. The test showed a violation of homogeneity of variances ($p < 0.0001$). I ran a Shapiro-Wilk test to test the normality of the data between mapping conditions. This test showed a bimodal distribution for T2 task scores ($p < 0.0001$). Since homogeneity and normality assumptions did not hold, I ran a non-parametric test (i.e. Kruskal Wallis) instead of a parametric test (i.e. ANOVA) for T2 task scores (figure 12, first section). A Kruskal Wallis test showed a significant effect of mapping strategy on T2 task scores ($\chi^2(2) = 9.02$, $p = 0.01$). Post hoc comparisons using a Mann-Whitney test with Bonferroni correction showed a significant difference between the metaphoric mapping condition and the isomorphic mapping condition ($p = 0.01$, $r = 0.45$). There was

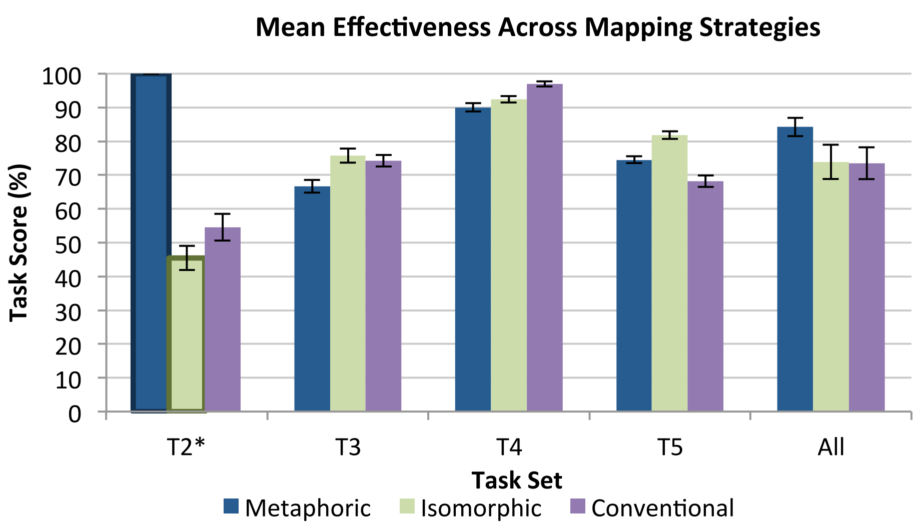
5 Exact results from all statistical tests are located in Appendix E

no significant difference between the conventional mapping condition and the other two mapping conditions.

T3 – T5 Task Scores

Bartlett tests did not show a violation of homogeneity between mapping conditions for T3 ($\chi^2(2) = 0.66$, $p = 0.72$), T4 ($\chi^2(2) = 1.44$, $p = 0.49$) and T5 ($\chi^2(2) = 3.34$, $p = 0.19$). Because this assumption held, I ran 3 one-way between subjects ANOVAs for each of these task sets (figure 12, second, third and fourth section). All tests showed no significant effect of mapping strategy on T3 ($p > 0.5$), T4 ($p > 0.5$) or T5 ($p > 0.1$) task scores.

Figure 12. ***Mean task completion scores across the different mapping strategies. Whiskers represent standard error.***



* Significant difference between metaphoric (blue bar) and isomorphic (green bar) mapping conditions on task score ($p = 0.01$)

5.1.2. *Efficiency*

I calculated the mean task completion times for each task set (figure 13, first four sections) and an aggregated task time for all tasks (figure 13, last section). I ran a one-way between subjects ANOVAs between mapping strategies on the aggregated task time. There was no significant effect of mapping strategy on aggregated task completion times ($p > 0.5$).

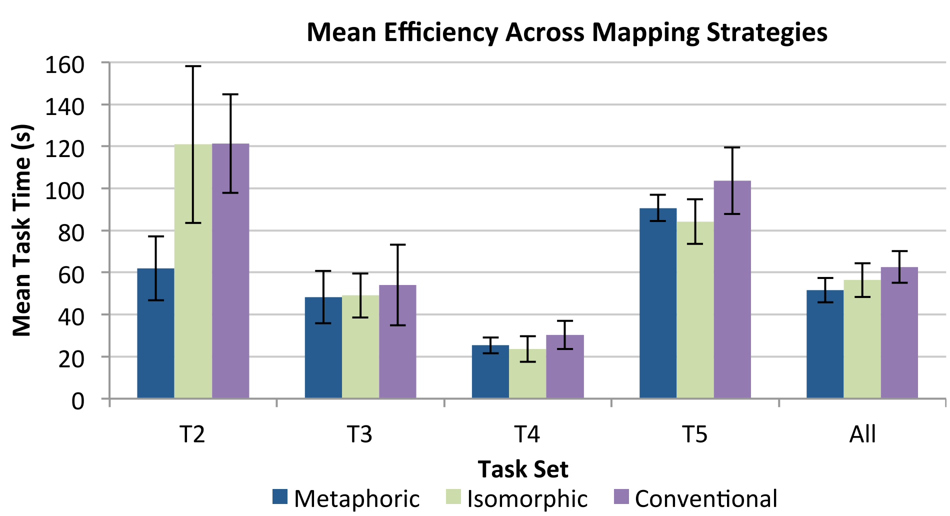
T2 and T5 Task Times

Bartlett and Shapiro-Wilk normalcy tests showed negatively skewed distributions for T2 (B: $p < 0.5$, SW: $p = 0.001$) and T5 (B: $p < 0.05$, SW: $p < 0.001$) task completion times. For this reason, I used non-parametric tests to find any significant differences between mapping conditions on T2 (figure 13, first section) and T5 (figure 13, fourth section) task completion times. Two Kruskal Wallis rank sum tests showed that mapping strategy had no significant effect on T2 ($p > 0.1$) or T5 ($p > 0.1$) task completion times.

T3 and T4 Task Times

Bartlett tests showed no violation of homogeneity between mapping conditions for T3 ($\chi^2(2) = 4.04$, $p = 0.13$) and T4 ($\chi^2(2) = 3.40$, $p = 0.18$) task completion times. As such, I ran two one-way between subjects ANOVAs to see if mapping strategy had a significant effect on T3 (figure 13, second section) or T4 (figure 13, third section) task times. These tests showed that mapping strategy had no significant effect on either T3 ($p > 0.5$) or T4 ($p > 0.5$) task times.

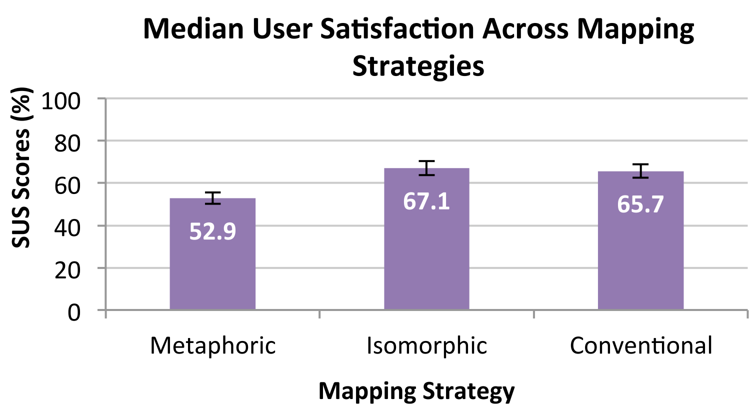
Figure 13. Mean task completion times across the different mapping strategies. Whiskers represent standard error.



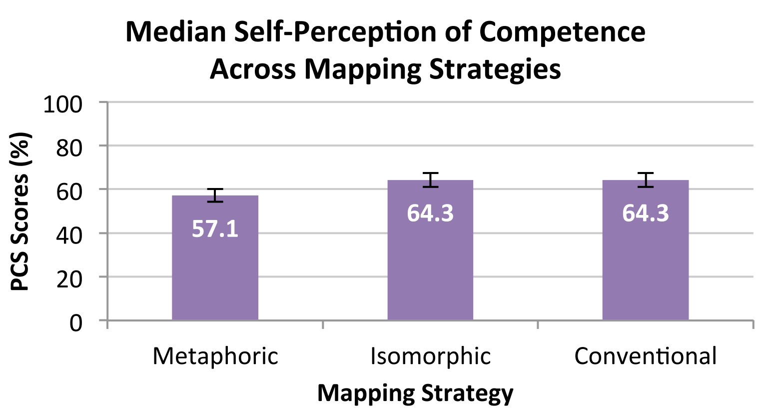
5.1.3. User Satisfaction and Perceived Competence

I calculated the median System Usability Scale (SUS – figure 14a) and Perceived Competence Scale (PCS – figure 14b) scores for the three mapping condition and converted them to percentages. Higher SUS and PCS scores represent participants who were more satisfied and confident using the system. Two Kruskal-Wallis tests showed no significant differences between mapping conditions on user satisfaction ($p > 0.1$) or self-perception of competence ($p > 0.1$). A Spearman's rank coefficient test showed a strong correlation between SUS and PCS scores (Spearman's $r = 0.80$, $p < 0.0001$). This suggests a positive relationship between user satisfaction and self-perception of competence (i.e. participants who feel more satisfied also feel more confident using the system).

Figure 14. ***Median SUS (a) and PCS (b) scores across the different mapping strategies. Whiskers represent percentage error***



a)



b)

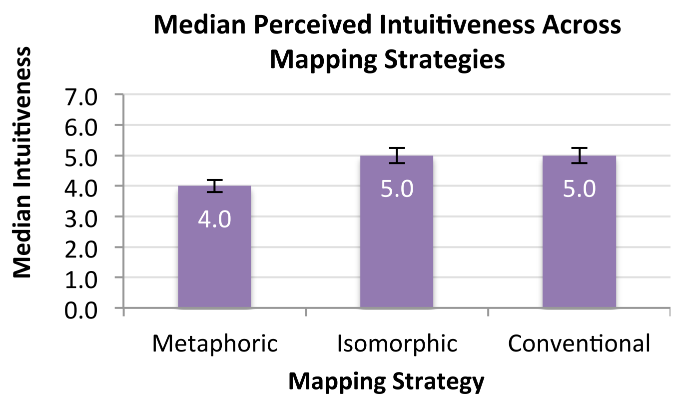
The SUS is a 10 item 7-point Likert scale and the PCS is a 6 item 7-point Likert scale. Ordinal values are non-parametric and are represented with medians rather than means. To calculate percentages, I divided the median scores by 70 (for SUS) and 42 (for PCS).

5.2. Intuitive Interaction

5.2.1. Perceived Intuitiveness

I calculated median intuitiveness ratings for all mapping conditions (figure 15). A Kruskal-Wallis test showed that mapping strategy had no significant effect on perceived intuitiveness ($p > 0.1$).

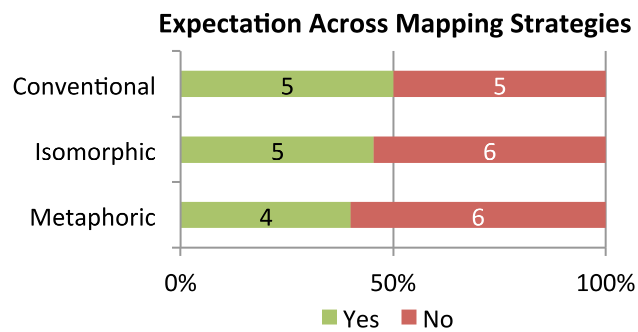
Figure 15. Median perceived intuitiveness ratings across the different mapping strategies. Whiskers represent percentage error.



5.2.2. Expectation

I calculated the distribution of participants' coded interview responses regarding their expectations with Springboard for all mapping conditions (figure 16). These numbers suggest an even distribution between people who felt the interface met their expectations and people who did not feel that the interface met their expectations. For this reason, I did not use inferential statistics to analyse the data. These numbers also show that approximately half of the participants had expectations that did not match the system.

Figure 16. Distribution of participants who (did not) feel that the interface design met their expectations



I analyzed the interview responses of participants who had unmet expectations for any recurring themes that occurred for multiple participants. The following themes were identified:

- Unhappiness with the controls of the system (1 metaphoric: U1[6], 1 isomorphic: U29, 2 conventional: U3, U9)
- A desire for more control (2 metaphoric: U7, U22, 3 isomorphic: U11, U20, U23, 1 conventional: U30)
- Difference between perceived and actual action-control mapping (2 metaphoric: U10, U13, 1 isomorphic: U8, 3 conventional: R1, U18, U24)

Unhappiness with the controls of the system

Four participants (12%) were unhappy with the controls of the systems. U1 (metaphoric) felt that the controls were inconsistent. Similarly, U9 (conventional) said that he sometimes had to repeat the movement for the system to respond properly. U3 (conventional) felt that the images changed too fast and the combination of changes in audio and visual cues presented a high cognitive load. U29 (isomorphic) initially thought the system was uncontrollable:

> "Not as easy to control as I had thought it would be. [At first] It seemed to have its own schedule." – U29, isomorphic

[6] This is the participant code

A desire for more control

Six participants (18.8%) wanted more control. U11, U23 (both isomorphic) and U30 (conventional) wanted the ability to stop the images. U30 stated that the lack of a pause or stop function made it difficult to recognize and understand the feedback:

> "It needs to be able to stop. There was no feedback or it was hard to spot because of the constant movement and constant change." – U30, conventional

U7 (metaphoric) wanted hard divisions between the different states. U20 (isomorphic) simply wanted more control over the system. U22 (metaphoric) expected to be able to control the images in smaller gestures and with his arms.

Difference between perceived and actual action-control mapping

Many participants had perceptions of the interaction model that did not meet the actual design. One common misconception many participants had was their ability to control the speed of the images. Many saw Springboard as a video stream (i.e. animation or slideshow), which could afford moving through the timeline of images and pausing it. U13 (metaphoric) initially wanted the rectangle floor marker to act as a scrubber, rewinding the images on the left side, fast-forwarding the images on the right. U13 described her expectations in a way that suggests a conventional model ("like a scrubber"). Similar to U13's scrubber model, U11 (isomorphic) and U12 (conventional) thought certain spots in the space would lead to faster or slower speeds. Three participants thought the speed of their own movement was mapped to the speed of the images (R1, U18, U22):

> "I didn't think it would be kind of like a spider thing I thought it was about how fast you moved. So that's kind of what I expected." – U18, conventional

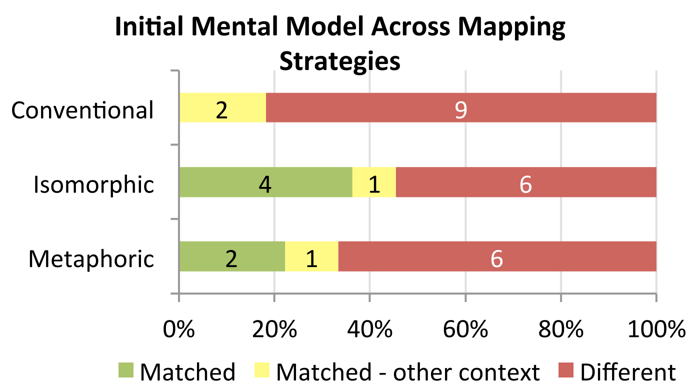
It is unclear what U18 meant by "spider thing". This may be her visual model of the circular system with the body of the spider being the centre and the different states as different legs spouting from the centre. R1 (conventional) and U22 (metaphoric) in particular thought the images themselves were random and the speed was mapped to their movement:

"I thought things were random and that I could only speed them up or slow them down" – U22, Metaphoric

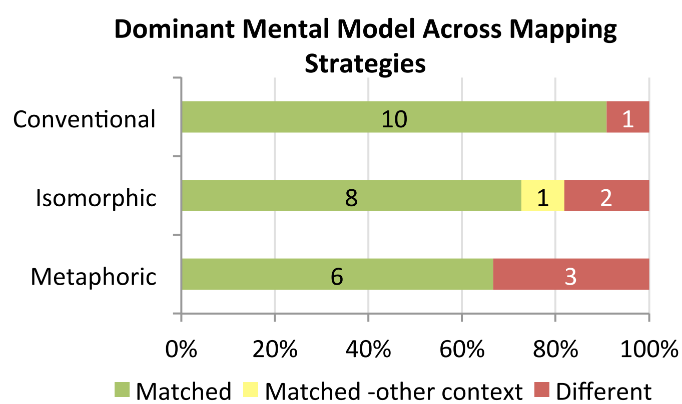
Video analysis of mental models

To supplement the interview responses, I reviewed the video data and inferred each participant's perceived action-control mapping during the beginning of the experiment (initial mental model – figure 17a), throughout the experiment (dominant mental model –figure 17b) and at the end of the experiment (final mental model – figure 17c). I coded these mental models as matching the system, matching the system but in a different context (i.e. metaphoric but physical vs. spatial balance), or different than the system (i.e. no model or a different mapping strategy). I examined the distribution behind these mental models for all mapping conditions (Figure 17).

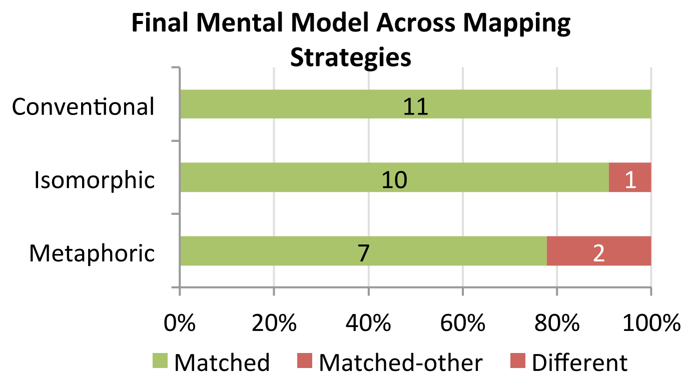
Figure 17. Initial (a), Dominant (b), and Final (c) inferred mental models across all mapping conditions



a)



b)



c)

In general, the majority of participants had initial mental models that did not match the actual UI design (figure 17a). However, participants did pick up on the mental model during the experiment (figure 17b) and the majority of participants had matched mental models at the end (figure 17c). While more participants had initial mental models that matched the actual input-control mappings in the metaphoric and isomorphic condition (figure 17a), more people in the conventional group had matched mental models throughout the experiment and at the end (figure 17b and c).

Hand Gestures

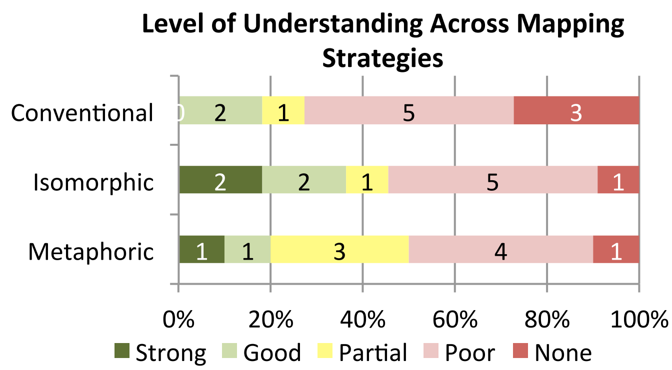
During the experiment, I noticed that various participants waved their hands in front of the screen. I inferred this as interacting with the system using hand gestures. I revisited the video data to see how many participants attempted hand gestures and during which task sets this occurred in. Eighteen participants (56%) attempted hand gestures during the experiment (3 metaphoric, 5 isomorphic, 7 conventional). While six participants (18.8%) only attempted them during the exploration phase, the remaining twelve (37.5%) tried them in other task sets as well. I analysed the hand gestures for recurring gestures across multiple participants. I discuss this further in chapter 6.

5.2.3. Conscious Attention

Level of Understanding

From the coded first interview responses, I calculated the distribution of the participants' level of understanding of the system controls and content for all mapping conditions (figure 18). Values suggest a fairly even distribution across mapping strategies. However, there are a slightly higher number of participants in the conventional condition who had no verbal understanding of the system and slightly higher number of participants in the isomorphic condition who had a strong or good level of understanding.

Figure 18. Distribution of participants and their level of understanding of the Springboard system



Out of the eight participants who demonstrated a strong or good verbal understanding of *Springboard*, four (1 metaphoric, 2 isomorphic, 1 conventional) had task scores 80% and higher. Three participants who demonstrated a good understanding had tasks scores between 68% and 78% (M= 73.2%). User U24 (conventional), who demonstrated a good understanding of the system, had a task score of 50% and is discussed further in chapter 6. Out of the 23 participants who had a partial, poor or no verbal understanding of the system, 11 had tasks scores of 80% or higher (6 metaphoric, 3 isomorphic, 2 conventional).

Rather than focus on just action-control mapping, I explored the use of action-meaning mappings as a mechanism for representing abstract concepts through the UI controls.[7] Twenty-one participants (65.6%) had a greater understanding of the abstract concept (i.e. food management) than UI controls (overall understanding: 5 good, 1

[7] Please refer to section 4.5.2, pg. 54 – 55 for more details on the questions and grading scheme used to measure level of understanding.

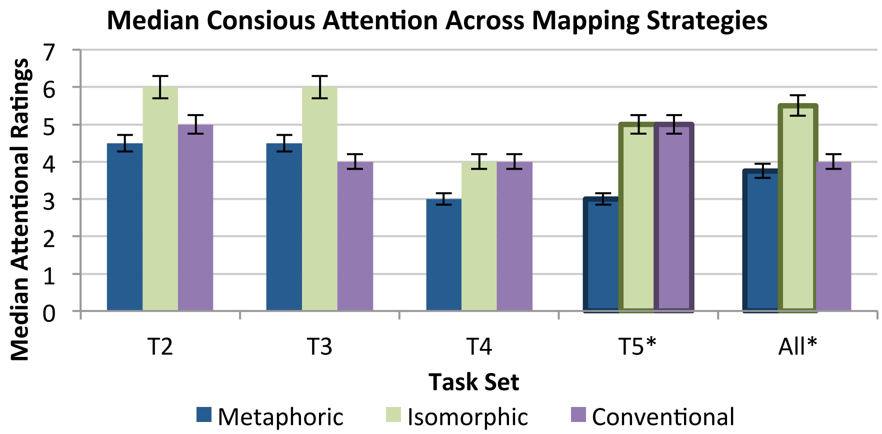
partial and 15 poor). The remaining eleven participants (34.4%) had equal understanding of abstract concept and UI controls (overall understanding: 3 strong, 3 partial and 5 none). These results suggest that the mapping strategies in this thesis study were more effective in conveying the abstract concepts than the UI controls in the beginning of the experiment.

There were no noticeable trends between mapping strategies and having an imbalanced or balanced understanding of the controls and abstract concept. Out of the twenty-one participants who had a better understanding of concept than control, six were from the metaphoric condition, eight were from the isomorphic condition and seven were from the conventional condition. Out of the eleven participants who had equal understanding of content and control four were from the metaphoric, three were from isomorphic, and four were from conventional.

Attentional Ratings

I calculated the median attentional ratings (1 = attention on movement, 7 = attention on solving the task) for each task set (figure 19, first four sections). I also aggregated ratings across all tasks (figure 19, last section). A Kruskal-Wallis test showed a significant effect of mapping strategy on aggregated rating ($\chi^2(2) = 9.33$, $p < 0.01$ – figure 19, last section). Post-hoc comparisons using a pairwise comparison Mann-Whitney test with Bonferroni correction show a significant difference between the attentional ratings of metaphoric (Med = 3.75) and isomorphic (Med = 5.5) mappings ($p = 0.01$). No significant differences were found between conventional mappings (Med = 4.0) and the other two mapping conditions.

Figure 19. Attentional focus ratings across the different mapping strategies. Whiskers represent percentage error.



* Mapping strategy had a significant effect on T5 ratings ($p < 0.01$) and overall ratings ($p < 0.01$)

I ran four Kruskal-Wallis tests to see if mapping strategy had a significant effect on any of the task sets (figure 19, first four sections). Mapping strategy had no significant effect on T2 ($p > 0.1$), T3 ($p > 0.1$) and T4 ($p > 0.05$) ratings. However, mapping strategy did have a significant effect on T5 ratings ($\chi^2(2) = 10.42$, $p < 0.01$). Post-hoc comparisons using a pairwise comparison Mann-Whitney test with Bonferroni correction show a significant difference between metaphoric mappings and the other two mapping conditions (isomorphic: $p = 0.02$, conventional: $p = 0.03$). There was no significant difference between isomorphic and conventional conditions.

I sorted participants into groups based on their understanding, task score and attentional rating (table 11) Depending on these factors, I classified groups as intuitive or learnable behaviour. Four participants demonstrated a strong or good understanding, had a high task score and spend most of their conscious attention on completing the task (table 11, top row). These results suggest that this group of participants spent minimal conscious attention on their movement and it is very likely that these users used intuitive interaction.

Table 11. Grouping of participants with high task scores to distinguish between learnable and intuitive behaviour

# of Participants	Understanding	Task Score	Attentional Ratings
Four (1 metaphoric, 2 isomorphic, 1 conventional)	Strong or good	High	Between 5.5 and 6.5
Six (4 metaphoric, 2 conventional)	Partial, poor or none	High	Below 5.0
Five (1 metaphoric, 3 isomorphic, 1 conventional) + U28 (metaphoric)	Parital, poor or none	High	5.0 or higher (U28: 4.5)

Six participants demonstrated partial, poor, or no verbal understanding, had a high task score, and reported attentional ratings lower than 5.0 (table 11, second row). This group of participants spent their conscious attention on using the system. They are classified as demonstrating learnable behaviour.

Five participants demonstrated partial, poor or no verbal understanding, had high tasks scores and reported attentional ratings of 5.0 or higher (table 11, bottom row). U28 (metaphoric) demonstrated partial understanding, had high task scores for each task set, and reported a median attention rating of 4.5. However, her final interview question suggests that she did not have a clear understanding of the system:

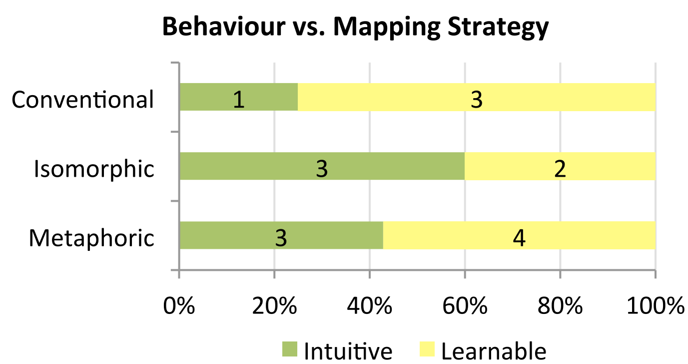
> "Umm yes, so how does this actually work?" – U28, metaphoric

She was grouped with these five participants. Because this group did not have a strong or good understanding, I analysed the tasks scores across the different task sets to see if their scores were consistently high (i.e. suggesting intuitive behaviour) or improved over time (i.e. suggesting learnable behaviour). U19 (metaphoric) had scores of 80% and higher for all tasks sets. I classified his behaviour as intuitive. U8 (isomorphic) and U28 (metaphoric) had tasks scores of 80% and higher for all task sets but T5. However, this is likely due to the increased difficulty of T5 and the higher cognitive load needed to perform it correctly. I classified both U8 and U28 as instances of intuitive interaction. U14 (isomorphic) and U21 (conventional) had high scores for all task sets except for T3. It is suspected that they may have gotten T2 correct out of luck and learned how to use the interface after T3. I classified their experiences as learnable. U17 (isomorphic) had a poor score for T2 but had high tasks scores for the rest of the task sets. I classified her experience as learnable as well.

Four participants (1 isomorphic, 3 conventional) demonstrated partial, poor or no understanding, had low task scores (<= 70%) and used a high degree of conscious attention on their movement. These participants demonstrated an un-intuitive and difficult to learn interface experience.

Using this analysis, I calculated the distribution on intuitive, and learnable experiences for all mapping conditions (figure 20). There is a fairly equal distribution between intuitive and learnable behaviour across all mapping conditions. However, the sample size may be too small to see any distinct differences.

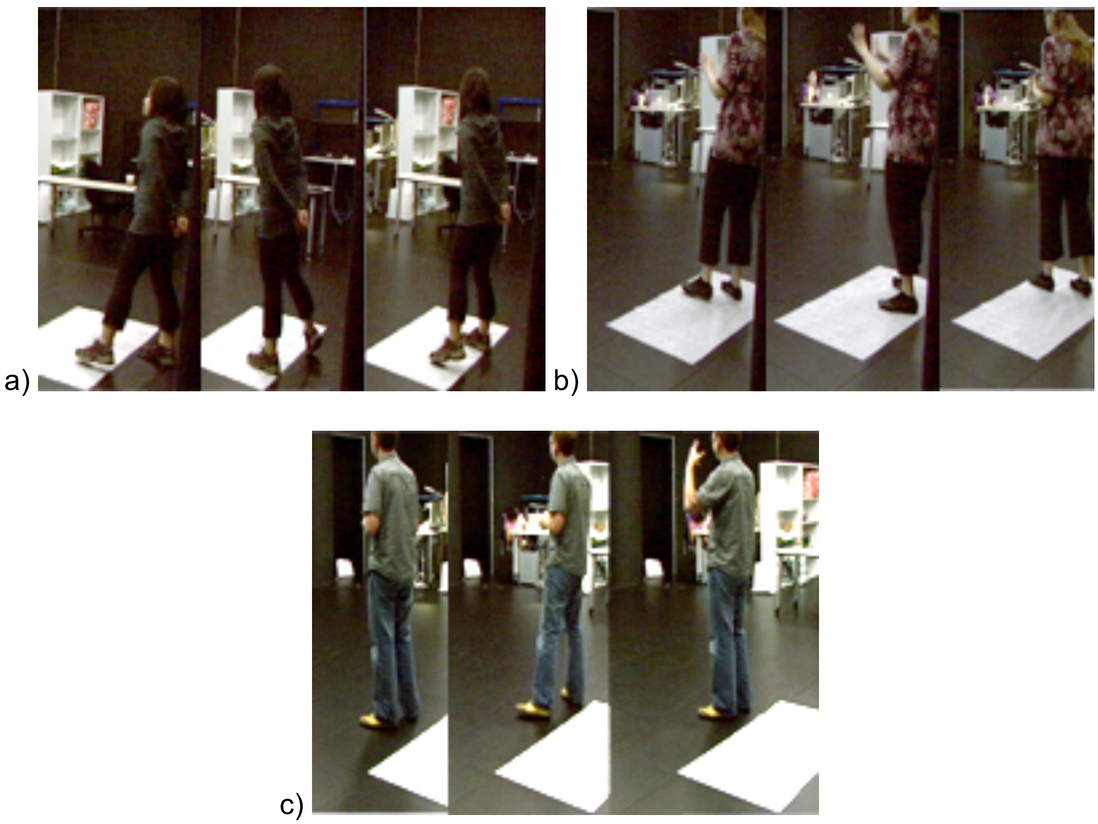
Figure 20. Distribution of intuitive and learnable behaviour across all mapping conditions for participants who achieved high task scores



5.2.4. Subconscious Action

In general, the majority of participants did not exhibit subconscious actions during the two interviews. Three participants did display subconscious actions during one of the two interviews. During the first interview, while describing what the images represented, U13 leaned to the left side while discussing pristine nature (figure 21a). Similarly, U19 moved towards the right side when describing how some of the images symbolized food waste (figure 21c). These two instances are interesting because environmental preservation was assigned to the left image and food production was assigned to the right image. U13's actions suggest an enactment of physical balance with excess force on the left side (i.e. excess environmental preservation. U19’s actions suggest a similar enactment but with excess force on the right side (i.e. excess food production). During the second interview, while discussing her expectations U16 moved in a motion that mimicked the way she moved while using the interface (figure 21b). All three participants were assigned the metaphoric mapping condition.

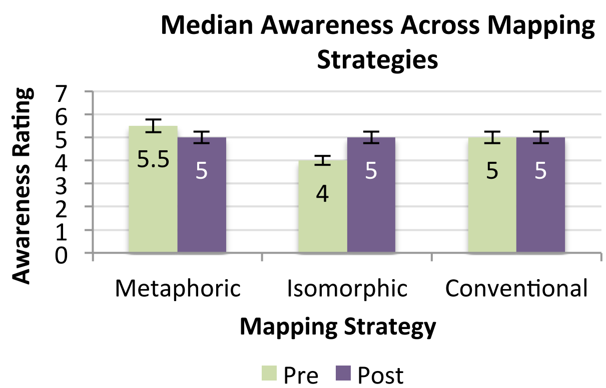
Figure 21. ***Instances of subconscious action: (a) and (c) enacted physical balance. (b) enacted motions used during experiment.***



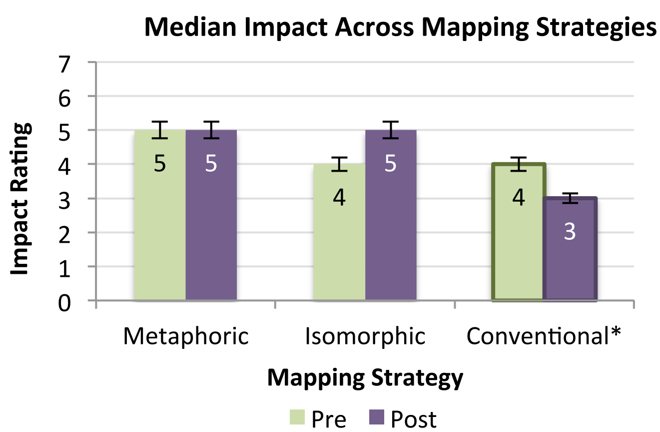
5.3. Awareness and Impact

I calculated the medians of the pre and post ratings of awareness (figure 22a) and impact (figure 22b) for all mapping conditions. I ran six Wilcoxon Signed-rank tests (3 for awareness, 3 for impact) to compare the pre and post ratings for each mapping condition. These tests showed no significant changes between pre and post awareness ratings for all conditions (metaphoric: $p = 1$, isomorphic: $p > 0.5$, conventional: $p > 0.1$). There were also no significant changes between pre and post impact ratings for the metaphoric ($p > 0.5$) and isomorphic ($p = 1$) condition. However, there was a significant change between pre and post impact ratings for the conventional condition ($W = 47.5$, $p < 0.05$, $r = 4.75$). Kruskal-Wallis tests showed no significant effect of mapping strategies on post-awareness ($p > 0.5$) or post-impact ($p > 0.5$) ratings.

Figure 22. ***Median pre and post awareness (a) and impact (b) ratings across mapping strategies***



a)



b)

*Significant difference between pre and post impact ratings ($p = 0.044$)

During the post-task interview one participant stated that the embodied nature of the interaction made him feel more engaged to the material. He continued to state that because his movement matched the model of the concepts being explored, it was more effective in portraying a message than having someone say it to him.

> “The connection between body movement and the themes made a stronger impression [...] If you consider politics or something, you get left/right associations with things. Having an interface where your body is engaged to pre-set associations to movement is more impressionable and memorable.” --- U9, conventional

Whole body systems in general may be a good medium for action-meaning mappings.

6. Discussion

In this chapter, I discuss the implications of the results presented in chapter 5. I revisit the research questions and compare the insights from the findings to related work. Each mapping strategy is revisited and reflected upon. I discuss limitations from the study and provide an initial set of design implications based on the results and insights.

6.1. Usability

Based on the inferential statistical analysis results, there appears to be no significant difference between overall usability and the different mapping strategies. However, there are significant differences between the mapping conditions for individual variables. For this reason, I revisit the results for each variable. Variables that had significant differences or noticeable trends are followed by possible reasons behind the difference or trend. An overall insights section, which triangulates the findings from the separate variables, follows the individual variable analysis.

6.1.1. Effectiveness

Mapping strategy had a significant effect on T2 task scores ($p = 0.01$). All participants assigned to the metaphoric mapping got T2 correct. This is significantly different from the 7 participants (45%) who got it correct in the isomorphic condition. Taking a further look at the ten participants in the metaphoric condition, seven had good task scores throughout, leaving only three participants getting this task correct by chance. Though not significant, there was a trend between mapping strategies for the aggregated task scores (metaphoric: 84%, isomorphic: 74%, conventional: 73% - see pg. 60, figure 12: last section). Furthermore, out of the seventeen participants (53%) who achieved task scores 80% or higher, seven of those participants (41%) were assigned the metaphoric mapping condition. These findings suggest that the metaphoric mapping condition may allow users to more effectively complete tasks than the other conditions.

However these are not significant differences. Thus while metaphoric mappings are effective for T2, these mappings seem less effective for other task sets.

The spatial position that mapped to balanced food management (i.e. T2) may have been more obvious in the metaphoric condition than the other two conditions. In the metaphoric condition, participants had to stand in the middle of the rectangular input space to get balanced food management[8]. In the isomorphic condition, participants had to stand closest to the triangle segments that had equal area[9]. In the conventional condition, participants had to stand at 6 o'clock on the circular path[10]. Associating balance with a centre position (i.e. metaphoric condition) may have been more obvious than associating balance with equal triangle areas (i.e. isomorphic) or associating balance with the lower midpoint on a circular path (i.e. conventional). Future work needs to test these mapping strategies in systems where tasks are equally represented across UI designs.

6.1.2. Efficiency

As with effectiveness, mean T2 task completion times are noticeably shorter for participants assigned to the metaphoric mapping condition (62.0 s) compared to participants in the isomorphic (120.9 s) or conventional (121.3 s) conditions (pg. 61, figure 13: second section). These results combined with the results from the effectiveness construct suggest that participants in the metaphoric condition completed T2 task, the first task after the exploration phase, quickly and effectively – traits associated with intuitive interaction. However, unlike effectiveness, these differences were not significant. This could be due to the high standard error associated with this particular data (15.2 – 37.4 s).

On average, participants assigned to the conventional mapping (62.7 s) condition took approximately ten more seconds to complete a task (from any task set) than participants in the metaphoric (54.3 s) or isomorphic (51.3 s) conditions (pg. 61, figure

[8] See pg. 37-38, figure 7 to review metaphoric input space
[9] See pg. 39-40, figure 9 to review isomorphic input space
[10] See pg. 41-42, figure 11 to review conventional input space

13: last section). One possible reason behind the longer aggregated task times is the instances of learning and reflection that occurred more often in the conventional condition. Eight participants (73%) in this condition had poor or no understanding of the system controls or content after T2 (pg. 68, figure 18). This differs from the six participants (54% - isomorphic) or five participants (50% - metaphoric) who had poor or no understanding in the other conditions. Furthermore, out of the four participants (36%) in the conventional condition who got a total task score of 80% or higher, three of these participants exhibited learnable rather than intuitive behaviour (pg. 72, figure 20). These results suggest that participants in the conventional mapping condition needed to spend more time to learn the system and reflect on their actions in order to complete the tasks. These results also suggest a possible relationship between conventional mappings and learnability. This relationship is further explored later in this chapter.

Participants spent less time completing tasks in T4 for all mapping conditions in comparison to the other task sets (pg. 61, figure 13: third section). This task set may have given clues on the nature of the interaction model. By asking participants to stand in a spot, participants understood that that spot was important to the system. Using this knowledge with the previous knowledge gained from the previous task sets, many participants had a good or strong understanding of the system controls by the first task for T4. These results suggest that the nature of a task can also act as a clue on the interaction model.

6.1.3. User Satisfaction

In general, mean SUS scores were fairly low and ranged from 37 (53%) to 47 (67% - pg. 62, figure 14a). This dissatisfaction could be closely related to a user's expectation with the system. Based on the second interview responses, approximately 53% of participants did not have their expectations met (pg. 64, figure 16). Participants from the metaphoric condition gave SUS score that were approximately 10% lower than participants assigned to the other conditions (figure 14a). Yet, there was a fairly equal distribution between mapping conditions in participants who did and did not have their expectations met. Therefore, while expectation may be a major contributor towards a user's satisfaction with the system, it was not the main factor behind the trend of the median SUS scores across mapping conditions.

The theory behind each mapping strategy is likely the reason behind the trends in user satisfaction. Metaphoric mappings rely on the subconscious application of previous knowledge, which is not the case for isomorphic or conventional mappings. Because of this, participants most often were unaware that they knew how to use the system. This can be seen by a participant's response when asked how well Springboard met their expectations in the post task interview:

> "No it did not, I expected left is more nature, right is more waste." – U7, metaphoric condition

This quote is interesting because this metaphorical model is correct yet the participant consciously felt that this was not how the system worked. When asked how she thought the system worked during the first interview, this participant only showed partial understanding of the content and controls. However, her effectiveness scores for task sets following the first interview increased from T3 (50%), to T4 (66%) and finally T5 (70%). Based on her increasing task score and final interview response, it is clear that she had a better grasp of the model by the end of the experiment. However, this fact was not obvious to her until it was explicitly pointed out that her expectations were correct. Antle et al. found similar findings: participants in these studies had less satisfying and enjoyable experiences in the metaphoric condition but performed reasonably well (Antle et al., 2011; Antle, Corness, & Droumeva, 2009b).

6.1.4. Perceived Competence

Similar to the SUS scores, median PCS scores were also quite low and ranged from 24 (57%) to 27 (64% - pg. 62, figure 14b). This is similar to findings found in previous Springboard studies (Antle et al., 2013). Participants assigned to the whole body condition felt less competent than participants assigned to the controller condition (Antle et al., 2013). These findings suggest that participants may not feel competent using whole body systems in general. Future work should look at making whole body systems that leave users feeling competent during use.

The strong correlation between User Satisfaction and Perceived Competence suggests a strong positive relationship between feeling competent with using a system and feeling satisfied about the experience. There were no noticeable trends or significant differences between PCS scores and the different mapping strategies. This suggests that each mapping strategy gave users similar feelings of competence in their ability to effectively use the system. The median PCS score for the metaphoric mapping condition (24 – 57.1%) was slightly lower than the isomorphic and conventional mapping conditions (both 27 – 64.3%). This agrees with the slight differences found from the SUS scores. However, this difference is less noticeable than the SUS scores and is most probably caused by natural differences between participants.

6.1.5. Insights for Design

Metaphoric mappings resulted in significantly higher task scores for the T2 task set and noticeably higher measures in the aggregated scores and times. These results are similar to Antle et al.'s comparative study on a metaphoric and non-metaphoric interface design of Sound Maker. In Antle et al.'s experiment, adults assigned to the metaphoric condition had better accuracy and completion times then the adult participants in the non-metaphoric condition (Antle, Corness, & Droumeva, 2009b).

While effectiveness and efficiency in this thesis study were generally good for the metaphoric condition, users were feeling unsatisfied and incompetent with their experience using the system. Furthermore, while participants assigned to the conventional mapping condition demonstrated lower efficiency, they were still fairly satisfied with their performance.

This relates back to the nature of metaphoric and conventional mappings. Metaphoric relationships based on CMT and used in metaphoric mappings are processed subconsciously and use knowledge subconsciously gained and used. Conventional mappings on the other hand are understood through reflection, learning or salient feedback and use knowledge consciously gained and used. With metaphoric mappings, many who had high task scores still lacked an explicit understanding of how the system worked and felt frustrated or incompetent while using it. However, those who used the conventional mapping design demonstrated more instances of learning how the system worked as the study progressed, even if their task scores were poor throughout. Participants were consciously aware of their increased understanding as the study progressed. This in turn gave them encouragement and increased their feelings of satisfaction while using the system.

These findings suggest two key concepts. The first is the importance of discoverability of the interaction model. Discoverability refers to the likelihood of a user discovering a system function or feature by chance (Antle, Corness, & Droumeva, 2009a). This is consistent with previous work that suggests that discoverable mappings are needed to support intuitive interaction (Antle, Corness, & Droumeva, 2009a; O'Brien et al., 2008). Furthermore, discoverable mappings help users understand what they can and cannot do within a system – which is especially important if the system lacks affordances to give this type of information (Hornecker, 2012). To make mappings more discoverable, designers should create UI designs where it is likely that the user will enact the correct input action. This could be done by restricting the type of actions a user can do within a system or by using feed-forward methods to provide the user with clues of the potential functions the system supports (O'Brien et al., 2008). Designers should also create systems that provide salient feedback so users can understand that they have enacted the correct action for a supported UI control (Antle, Corness, & Droumeva, 2009a).

The second concept these findings suggest is the relationship between understanding the interaction model of a system explicitly and having a satisfying user experience. Users who can understand the interaction model will find the design behind the system clear, the functions better integrated and feel more competent about being able to use the system successfully. All these traits refer back to high user satisfaction (Brooke, 1996) and perceived competence (Deci & Ryan, 1985). To ensure a satisfying user experience, designers should create mappings that are literal or isomorphic (Smith, 1987) or leverage the user's knowledge of previous systems that have similar function – i.e. use established conventions (Norman & Nielsen, 2010). However, pairing metaphoric mappings with salient feedback could also result in higher user satisfaction and warrants further investigation. Furthermore, it would be interesting to see how these mapping strategies affect satisfaction over long-term use.

6.2. Intuitive Interaction

Based on the quantitative analysis, participants in the isomorphic condition used significantly more conscious attention on completing tasks than on using the system. On the other hand, there were no differences between mapping strategies on participants' perceived intuitiveness or expectations. From the qualitative analysis, I found concurrent themes that explain unmet expectations across multiple participants and discuss them below. Furthermore, the detailed analysis of a participant's use of conscious attention suggests differences between mapping strategies on understanding controls and abstract concepts, intuitiveness and learnability. Similar to section 6.1, each variable is revisited with potential reasons behind their results. This is followed by an insights section, which triangulates the findings into overall concepts and relates these concepts to previous research.

6.2.1. Perceived Intuitiveness

Based on the results from the inferential statistical analysis, the three mapping strategies were similar in how intuitive they felt to the user and in their ability to foster an explicit understanding of the system (pg. 63 – figure 15). This lack of difference suggests that each mapping strategy has the potential to foster intuitive experiences. This agrees with previous work, which presents metaphoric (Antle, Corness, & Droumeva, 2009a; Hurtienne et al., 2008), isomorphic (Smith, 1987) and conventional (Blackler et al., 2005) mappings as a way of fostering intuitive interaction.

6.2.2. Expectation

While the three mapping conditions resulted in similar distributions of met expectations, the qualitative analysis provide interesting themes behind the unmet expectations of about half of the participants, as well as differences between the mapping strategies and a participant's initial, dominant and final mental model. The themes outlined behind mismatched expectations are further explored below. This is followed by a critique on the different mapping strategies and how they affect a user's mental model of the system over time.

Unhappiness with controls of the system

Four participants (12%) were unhappy with the controls of the system. Two of these participants (U1 and U9) felt that the controls were inconsistent. Another participant (U3) felt that the images moved too fast. The buffer time used to transition between balance states (0.8 s) and image pairs within the same state (3 s) could be the reason behind these participants' unmet expectations. The buffer time was there to help the system differentiate between a deliberate change in state and movements between states. However, in the beginning of the experiment, some participants used playful and quick movements rather than slow and reflective movements and made this distinction difficult for the system. As a result, participants who used playful and quick movements would often not recognize changes in balance states. When the system registered their spatial position and displayed the corresponding balance state, the participant would already be moving towards a new position and miss this change. For U3, the exact buffer time could be a personal preference and may have been too fast for him to learn the interface effectively. One participant (U29) simply thought that the changes were random. She may have had an incomplete understanding of the system controls. Also, having multiple images for a single state could give a sense of no control if a user did not understand the state the images were portraying.

A desire for more control

Earlier in this chapter, I introduced the use salient feedback as a means to bridge effectiveness and user satisfaction. U11, U23 and U30 wanted to be able to stop the images. Having a stop state or salient null state could help create clearer cause-and-effect relationships and provide more recognizable and understandable feedback. U7, U20 and U22 wanted more control over the system. It is not clear why these participants wanted more control. One possible origin for these expectations is the amount of control they had over other streaming media systems such as DVD players or cameras, which they expected to find in Springboard. This warrants further investigation.

Difference between perceived and actual input-control mappings

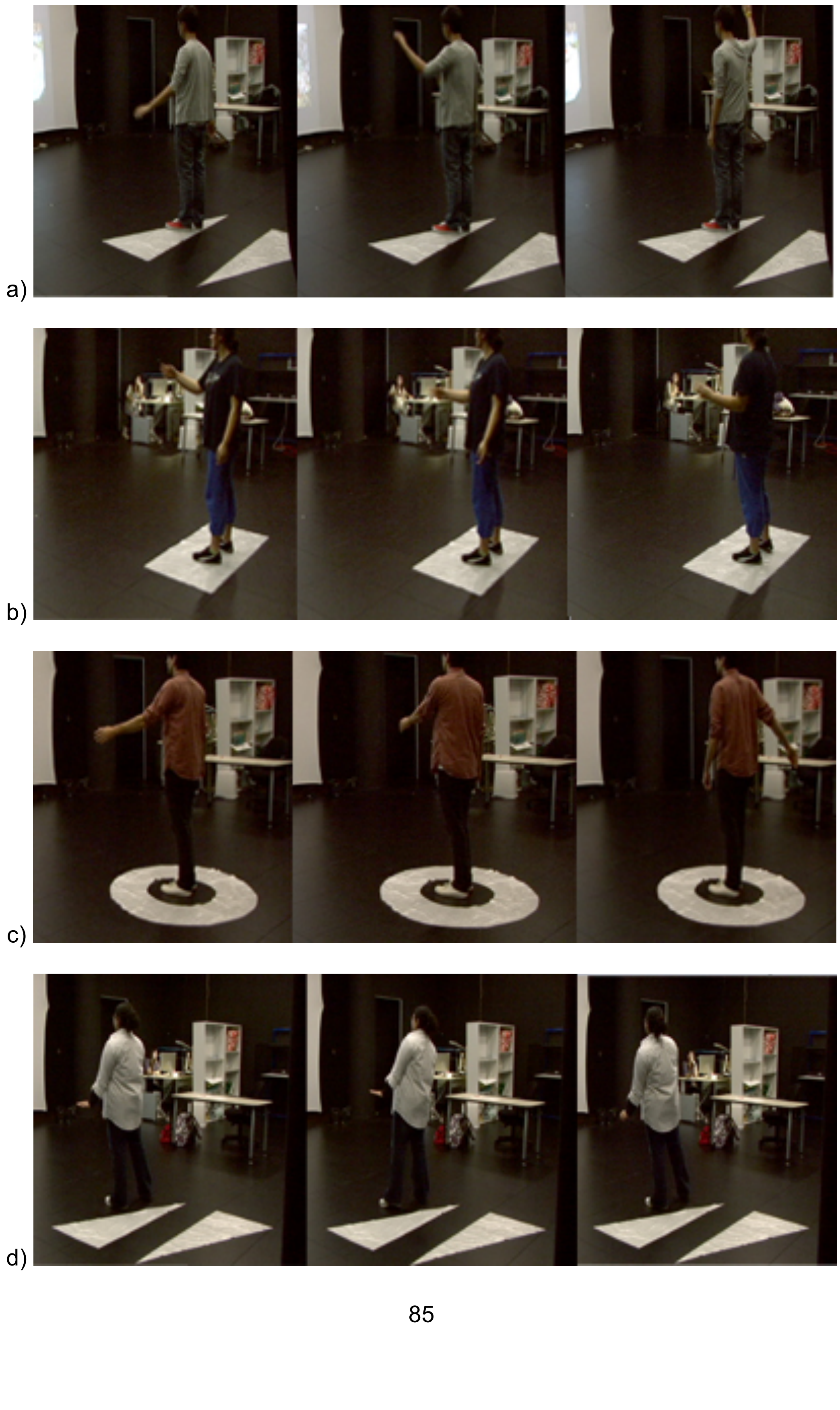
Two participants (6%) associated areas in the physical space with faster and slower speeds. Both associated the left side of the space with faster images, middle to normal speed and right side to slower images. This is a metaphoric mapping between spatial position and image speeds (i.e. LEFT IS FAST, RIGHT IS SLOW). The reasoning behind associating the left side of the room with faster image speeds was unclear. The speed during states and the speed in-between states was consistent across all states. This metaphor was not used because it did not reflect the abstract concepts embedded in the UI. Like Hurtienne et al. (2009), Antle et al. (2011) and Macaranas et al. (2012a), one focus of this study was to explore the effectiveness of the mapping strategies in representing abstract concepts, rather than solely focusing on control.

Three participants mapped the speed of their movement to the speed of the image change. This relationship between body movement speed and image speed is an isomorphic relation. A similar relationship can be seen in Antle et al.'s (2009a) Sound Maker system. In Sound Maker, this isomorphic mapping was easy to understand and as a result, easily accessible to the participants (Antle et al., 2009a).

Another common trend found across participants was the use of hand gestures. 56% of users attempted hand gestures during the experiment, with 37.5% having used it in multiple task sets. From the video analysis, I identified a set of very common hand gestures (figure 23):

- Isomorphic model #1: each hand assigned to a picture, raise and lower to change image
- Isomorphic model #2: hands swipe together or separately to flip through the images
- Conventional model: arms spin around body like the hands of a clock to browse the different states.
- Metaphoric model: arms stretched outwards like a scale or teeter-totter and tilt up and down to change the different states (i.e. physical balance).

Figure 23. Recurring hand gestures: isomorphic model #1 (a), isomorphic model #2 (b), conventional model (c) and metaphoric model (d)



Some participants had hand gesture models that complimented their mapping condition (figure 23a, figure 23c). Other participants had hand models that contradicted their assigned mapping condition (figure 23b, figure 23d). For some participants, the floor markers may have given hints to possible hand gestures (figure 23c). For others, the floor markers may have been completely ignored (figure 23d). These results suggest that clearer affordances are needed to inform users which interaction is supported by the system. In this case, it wasn't initially clear to 56% of participants that hand gestures were not the supported by the system.

While 18 participants were observed using hand gestures, only 3 participants explicitly stated this during the interview sessions. One user in particular was U24. The visual cue of the floor marker triggered the system to be similar to an iPod wheel (which is correct). However, rather than moving around the circle with his body, he opted to move around the circle with his hands:

> "When I saw the circle, I saw it as a cue and started doing arm gestures. I thought it was like scrolling on an iPod." – U24, conventional

When asked why he used his hands, U24 offered the following response:

> "It seemed natural for some reason. It's probably because I've seen it in movies. On the other hand, your hands seem like the natural place to go to start manipulating things" – U24, conventional

U24 raises an interesting point about the use of whole body systems and spatial position as the source of input action. Various researchers have looked at gestural analysis for whole body systems (Höysniemi & Perttu Hämäläinen, 2004; Huang & Pavlovic, 1995; Quek, 1994; Slater & Usoh, 1994). Additionally, popular systems like the Kinect and Wii use a variety of arm gestures for menu selection or gameplay. Some participants thought controlling Springboard would be similar to using the Kinect. Though no participants explicitly stated this in the pre experiment questionnaire, some participants like U20 (isomorphic) and U21 (conventional) commented on this during the experiment. Other participants may also have experience with the Kinect and used conventions within that system to understand Springboard. These systems have only been out for a few years (Wii: 6 years, Kinect: 2 years). However, this may have been enough time to make hand gestures an established convention for whole body systems. Media depictions of futuristic systems using hand gestures as control reinforce this view.

Other researchers have used body movement as a source of input for previous whole body systems with success (Antle et al., 2009a; Holland, 2010). However, the majority of these systems use body movement for sound manipulation. The Springboard redesign may have not suggested body movement as the method of input. The previous design utilized a spring-enabled platform, which gave greater cues in the use of body movement. This warrants further work on the suitability of body movement as system input for whole body systems in other contexts, and on design features that suggest body movement as input.

Many participants in the conventional condition had an initial mental model that did not match the actual UI design (pg. 66 – figure 17a). However, these participants had mental models that matched the UI design by the end of the experiment (pg. 67 – figure 17c). The transition from mismatched to matched expectations suggests a high learnability with the conventional UI used in this study. This may be due to the fact that new conventions leveraged from other domains (i.e. analogue controller) require time to recognize and transfer properly onto the new domain (i.e. whole body). Some participants did not initially recognize the convention used in this study (i.e. rotating dial). Other participants may have recognized the convention but tried a different input action (i.e. hand gestures). Nevertheless, all participants in the conventional condition recognized the relation between the circular floor marker and older dial devices by T4 and used the system properly for the majority of the experiment.

Three participants in the metaphoric condition did not understand the system model for most of the experiment (pg. 66 – figure 17b). Two of these participants completed the experiment without demonstrating any understanding of the system (figure 17c). On the other hand, the isomorphic condition had the most participants who had initial mental models that matched the system (figure 17a). These findings support Blackler et al.'s proposed approach towards using conventions and metaphors in interface design. Blackler et al. state that designers should use conventions if they exist and metaphors if they do not, claiming metaphors to be the most complex in design tools that can facilitate intuitive interaction (Blackler et al., 2005). They state this is because metaphors must relate two unrelated domains together while conventions rely on similar domains or models (Blackler & Hurtienne, 2007; Blackler et al., 2005). They place isomorphic mappings in the highest level of the continuum, calling them body reflectors and stating that they are the simplest tools in facilitating intuitive interaction (Blackler & Hurtienne, 2007).

It is important to remember that half of the participants did have their expectations met. There were participants who did illustrate a clear understanding of the mapping strategy used. U2 (isomorphic) was able to successfully associate the left image with the top triangle and the right image with the bottom triangle. U4 (metaphoric) made the association of imbalance towards the left as “less” food but a “more” pristine world. R1 (conventional) shared the analogy of a clock during the second task of T4. Thus while not ideal, these mappings did show some success in being accessible to the user. Slight modification to the current UIs may be enough to increase user expectation.

6.2.3. Conscious Attention

Each mapping condition had similar levels of understanding (pg. 68 – figure 18). However, the conventional condition had a slightly higher number of participants who demonstrated no level of verbal understanding after T2. The isomorphic condition had a slightly higher number of participants who demonstrated a strong or good level of verbal understanding after T2. These results match our knowledge of conventional and isomorphic interfaces. New conventions take time to learn and ones that leverage from older domains take time and conscious effort to recognize and translate over to the new domain. For example, when navigational touchpad wheels on older MP3 players were first introduced, users would have to first recognize that it’s leveraging conventions from a physical dial and then translate physical rotation of the dial to a circular motion with their finger. Isomorphic mappings on the other hand are literal relations and should be immediate and obvious. Smith states that isomorphic (or literal) mappings are very easy to learn and are what novice users expect when interacting with a new system (Smith, 1987). These results agree with Smith’s observations. Based on these findings and previous literature, conventional mappings should be used in systems that allow low-risk exploration because participants need time to learn and understand the convention being used. Isomorphic mappings should be used for systems that require immediate understanding or require minimal instruction and supervision.

Over half of the participants who had partial, poor or no verbal understanding and had a high task score were in the metaphoric condition. This contradiction between a high task score and poor verbal understanding can also be seen in Antle et al.'s previous work on Springboard and Sound Maker (Antle et al., 2011; Antle, Corness, & Droumeva, 2009b). Participants in Antle et al.'s study had difficulty verbally describing the interaction model (i.e. had a poor verbal understanding of the system) but were able to perform the tasks correctly (Antle et al., 2011). Antle et al.'s findings and the findings from this study illustrate the tacit understanding associated with metaphoric mappings. A possible application for metaphoric mappings is systems that require automated body movements and minimal thinking.

Approximately two thirds of participants had a better understanding of the content of the system than the controls after T2. There were no trends with mapping strategy and having a dominant content understanding or equal content and control understanding. This may be due to the content being displayed in the same way visually in all three conditions. Or, action-meaning mappings may be more accessible than action-control mappings after a short period of system use. No participants had a better understanding of the controls than the content. This may be due to the previous validation of the image sets in previous Springboard studies. The interface designs for this study are new and being used for the first time. The balance between content understanding and control understanding warrants further research in other systems and context.

Participants in the isomorphic condition placed more attention on performing the task and less on their body movement in comparison to participants in the metaphoric or conventional condition (pg. 70 – figure 19: fifth section). This suggests that the participants in the isomorphic condition knew how to use the system and did not need to consciously focus on how to use it. There are a few possible reasons behind the lower aggregated attentional ratings in the metaphoric and conventional conditions. In these conditions, participants were unclear on the interaction model and spent more time trying to relate their movement to the system effects. They spent a lot of time trying to learn the action-control mappings and to reflect on their observations from the previous tasks.

Participants in the metaphoric condition spent significantly more attention on using the system than participants in the isomorphic and conventional condition during T5 (figure 19: fourth section). Participants in the conventional condition, who were spending a lot of attention on using the system in previous task sets, may have understood the system controls by T5 and shifted their attention to doing the task. Likewise, complex tasks such as making sequences may be difficult for participants in the metaphoric condition, who may have a tacit understanding of the system.

These results suggest the effective use of literal or isomorphic mappings in maintaining the user's attention on completing the task. While there are times when body focus is important (i.e. dance, surgery), the execution of movement should still fall in a semi-conscious state (i.e. automatic). Hornecker also discusses instances when intuitive interaction may not be desired and that designers may want users to reflect and learn the controls of the system (Hornecker, 2012). An example of a system when learning the controls is important and the user should be consciously alert is an aircraft pilot system. Knowing when systems should rely on automatic movement or when they should illicit conscious use is an area that needs further research.

There were no distinct differences between intuitive or learnable behaviours and high task scores across the mapping conditions. However, as stated previously, the sample size of participants may have been too small to see distinct differences. Future work should explore the distinction between learnable and intuitive behaviour and its relationship to the mapping strategies.

6.2.4. Subconscious Actions

Three participants exhibited subconscious actions during the interview sessions. These actions were classified as subconscious because the participants did not explicitly refer to their movement during the conversation nor were they using it to demonstrate a point. These instances of intuitive interaction occurred for participants assigned to the metaphoric condition. These findings match findings from previous studies that had participants subconsciously mimic the interface in the metaphoric condition (Antle et al., 2011). These instances of subconscious action further illustrate the subconscious and tacit understanding associated with the use of metaphoric mappings. This matches previous studies that used a whole body system with metaphoric mappings to elicit an tacit understanding of tonal harmony (Holland, 2010). Metaphoric mappings may be beneficial for systems that deal with concepts that are easier to understand with our bodies than our minds alone. Some examples of these concepts are politics (i.e. left/right associations with liberalism/conservatism) and affect (i.e. understanding anger or fear with body movement and orientation).

6.2.5. Insights for Design

Each mapping strategy has the potential to foster intuitive interaction. This can be seen by the similar values of perceived intuitiveness ratings, expectation responses and intuitive/learnable behaviour distributions across the three mapping strategies. This resonates with previous work that presents metaphoric (Antle et al., 2009a; Hurtienne et al., 2008), isomorphic (Smith, 1987) and conventional (Blackler et al., 2005) mappings as a possible way for supporting intuitive interaction.

Approximately half of the participants had expectations that did not match the actual system design. In particular, various participants mapped the space or their bodies to changes in speed or attempted hand gestures to control the images. This mismatch in expectations matches findings from previous studies (Hornecker, 2012). It is almost impossible to predict what a user will try and in most cases, there are more attempted actions than corresponding system effects (Hornecker, 2012). In this particular case, users were basing their expectations on previous systems (scrubbers, DVD players), literal mappings between their body and the system, and their previous everyday experiences with manipulating objects and physical balance. Many of these can be categorized into conventional (scrubber, DVD player), isomorphic (literal mappings), and metaphor (BALANCE schema). Thus the three mapping strategies outlined and explored in this thesis seem like a good starting point for designing mappings that most correspond to a user’s expectations. However, it is also important to take into account how a user would normally do a task of a similar nature (i.e. manipulation of images) in the physical world and create interactions that match. In this case, using body movement for manipulation did not match the way we manipulate things in the physical world and led to various users using hand gestures.

The results from the conscious attention variable illustrate an ordering of UI designs that require less conscious attention to use (i.e. isomorphic) to designs that require more attention to use (i.e. metaphoric). This ordering matches previous work that orders strategies from most innate to most complex (Blackler & Hurtienne, 2007). Isomorphic mappings were the most easy to use: there were more participants with a strong or good understanding of the system near the beginning of the experiment and overall, the majority of participants placed their attention on solving the task versus using the system. For this reason, isomorphic mappings may be most suitable for systems that use a walk up and play interaction model (i.e. art installation, museum exhibit).

The conventional condition had the most participants with no understanding and mismatched mental models in the beginning. However, the UI in this condition was also the most learnable, having all participants understand the interaction model by T4. Systems that require conscious attention to use and are difficult to learn (i.e. airplane pilot, nuclear operations) should use conventional mappings but allow low-risk exploration that forgives a user for their initial mistakes as they begin to learn how to use the system.

Metaphoric mappings had better levels of understanding than conventional mappings. However, there were still participants who did not understand the interface model by the end of the experiment. Furthermore, participants in this mapping condition had to spend the majority of their conscious attention on using the system during the most difficult task set. Metaphoric mappings may not be as effective as the other mapping strategies in placing a user's conscious attention on the task as opposed to system use. This needs further exploration in future work and on systems that deal with other functions and concepts.

While Blackler et al.'s ordering is true for conscious attention; this was not the case for the other three constructs (perceived intuitiveness, expectation or subconscious action). Rather than a gradient of design strategies that most support to least support intuitive interaction, I suggest Blackler's continuum as an ordering from least conscious attention needed to effectively use and understand the interface to most conscious attention needed. Designers should consider the degree of conscious attention desired for effectively using and consciously understanding a system and use that as one of many factors when choosing a mapping strategy.

The instances of subconscious action found in this study and Antle et al.'s study suggest an embodied understanding of the whole body system and content portrayed within. However, this understanding lies on the subconscious level and the context of when this would be desired is not clear. When would a subconscious demonstration of the controls be useful? This could be an interesting design space when exploring metaphors for rote learning (the repetitive action of a task to make it automatic) or for transitioning users from a subconscious to conscious state of understanding.

When comparing the Usability measures to Intuitive Interaction, there appears to be a difference between knowing how to use the system (i.e. effectiveness and conscious attention) and knowing that you have used it successfully (i.e. satisfaction, expectations). Participants who were unaware of their successful performance subconsciously knew how to use the system but were consciously unaware of it. This correlates to previous work that had similar findings with a system using metaphoric mappings (Antle et al., 2011). Instances of unsuccessful interaction illustrate mismatched expectations and minimal understanding of how the system works. Having a conscious understanding of both the system and instances of successful interaction are important when meeting user expectations and raising user satisfaction. Designers need to make the interaction model easily understood by the user and provide clearer feedback on actions that are supported by the system.

6.3. Awareness and Impact

There was a significant difference between pre and post impact ratings for the conventional condition (pg. 74, figure 22b: last section). After using Springboard, participants in the conventional condition felt less inclined to do a co-op term with a company that advocated issues on food management. It is not clear why impact ratings decreased. Some participants stated that they liked the concepts of the system but felt that the social justice questions were out of place and felt more like propaganda. Conventions used for contexts that differ from previous systems may have an inverse effect on engaging users. In this particular case, circular navigation wheels were previously associated with navigating music and other media – not different perspectives of social justice. Using conventional mappings for abstract-meaning mappings had less impact on the participants. Conventional mappings need to be explored in whole body systems that explore other abstract concepts.

There were no significant differences between pre and post impact ratings for the other mapping strategies or pre and post awareness ratings for all mapping strategies. Furthermore, mapping strategy did not have a significant effect on post awareness or impact ratings. This contradicts with a previous Springboard study that showed a significant difference for both measures for a metaphoric design (Antle et al., 2013). One key difference between this thesis study and Antle et al.'s study is that they compared a whole body metaphoric system (i.e. spring-enabled platform using body balance) with a non-metaphoric controller-based system (i.e. analog slider and dials). The factor that affected a participant's awareness and impact on issues of social justice in Antle et al.'s study may not have been the metaphoric but the whole body aspect of the system. Antle et al.'s study also used the original Springboard, which had 3 different image sets, not just food management. Seeing different aspects of social justice may have increased awareness or impact amongst users. Participants in the thesis study also used the system for a short time period. Pro-longed uses with the system or moving it out of an experiment context could have increased these values. The interface designs may have also been too similar to each other. This is further explored in section 6.6.

One user in particular (U9) found value in the connection between his body movement and the themes. It's interesting to note that he was in the conventional condition but originally tried physical balance to change the states. His body exploration which comes from trying to attach a metaphorical connection in tandem with his conscious reasoning from being wrong and correcting his view could have also added to his engagement with abstract concepts. This observation extends Antle et al. (2011), Macaranas et al. (2012a), and Hurtienne et al.'s (2009) work on abstract-meaning mappings. Designers should explore the use of body movement and conscious reasoning for engagement with abstract concepts and see if this connection occurs in other contexts.

6.4. Benefits and Setbacks of Each Mapping Strategy

6.4.1. Metaphoric Mappings

From the inferential statistics, metaphoric mappings did not vary much from the other mappings in usability. Metaphoric mappings did have a significant effect on T2 task scores and a similar but insignificant trend on T2 task times. From looking at the descriptive statistics, users of the metaphoric UI had higher task scores (i.e. better effectiveness) but lower SUS and PCS scores than users of the isomorphic and conventional UI.

In terms of perceived intuitiveness and expectation, metaphoric mappings performed similarly to the other two mapping conditions. However, when analysing a user's initial, dominant and final mental models, metaphoric mappings performed worse than the other two conditions for eliciting learning. This could be primarily due to a conceptual metaphor's subconscious nature. Users of the metaphoric UI were less successful than users of the isomorphic UI, but better than users of the conventional UI in understanding the system controls and content near the beginning of the experiment. The metaphoric mapping condition was the only condition that had participants who demonstrated subconscious actions during the interview sessions.

Metaphoric mappings have the potential to have high usability, but salient feedback is required with these mappings to ensure a satisfying user experience. Metaphoric mappings may also prove to be useful for learning applications where actions fall to a subconscious level and a conscious understanding is not needed.. One possible application is a sports or performance related system where body movements are practiced to a point of automation. Previous work on children and learning simple math has shown gestures to have a positive effect on retaining knowledge (Cook, Mitchell, & Goldin-Meadow, 2008). Metaphoric mappings, which can help users develop an embodied understanding of a concept, may also help users retain this knowledge. This warrants further exploration.

6.4.2. *Isomorphic Mappings*

From the descriptive statistics, isomorphic mappings had good efficiency, user satisfaction and perceived competence measures. Furthermore, Many of the observed mental models and attempted hand gestures were isomorphic. Though not as distinct as the conventional condition, participants assigned to the isomorphic mapping condition demonstrated instances of learning from the initial mental model to the final mental model. Participants using this mapping also elicited more instances of strong and good levels of understanding than the metaphoric and conventional condition. They spent the majority of their conscious attention on solving the problem rather than controlling the interface.

While isomorphic mappings have shown to be great for designing controls, there may be cases when a literal and suitable isomorphic mapping is not available or situations when isomorphic mappings are not ideal. For example, isomorphic mappings may not clearly represent meanings as well as metaphors or analogies. Physical isomorphic[11] mappings are restricted to mapping left input motions to left motions within the system. Metaphors and conventions can connect left movement to liberalism, less content, backwards, undo and rewind. Physical-abstract isomorphic mappings can create this connection but they are less straightforward to design than physical isomorphic mappings. The isomorphic mapping used in this study was a physical-abstract mapping between spatial area and states of food management. The abstractness of this mapping may have caused participants in this condition to have lower effectiveness scores than participants in the metaphoric condition. Creating effective physical-abstract mappings requires further research.

Isomorphic mappings have the potential for great usability, can support immediate learning and allow users to focus on the task, rather than learning how to use the system. This is ideal for situations where instructions are not desired. One possible application is walk up and use systems in art galleries and museums. However, there are cases when isomorphic mappings are not available and cases when isomorphic

[11] See pg. 38-39, section 3.5.2 for a recap on physical and physical-abstract isomorphic mappings.

mappings are less effective in conveying abstract meanings. In these cases, metaphoric and conventional mappings should be considered.

6.4.3. Conventional Mappings

Based on the descriptive statistics, participants assigned to the conventional condition had similar effectiveness measures to participants in the isomorphic condition and were not as good as participants in the metaphoric condition. Participants in this condition had the longest task completion times but had high user satisfaction and perceived competence. While participants in the conventional condition had the worse levels of understanding after the exploration phase and first task, they also demonstrated the highest level of learning – having all participants' mental models match the system design by the end of the experiment.

Conventional mappings can sometimes take the form of a simile or an analogy (i.e. "like an ipod" or "like a scrubber"). Similar to a metaphor, analogies connect two different things together and can speed up the learning process by relating new things to more familiar things. However, analogies make this relationship more explicit and obvious than metaphors. Participants may have felt satisfied and competent using conventional mappings because it was familiar to systems they have interacted with before and they had an explicit understanding of the simile or analogy.

Conventional mappings seem suitable for learning applications where low risk exploration is allowed and the system can create analogies from older domains. This can be especially useful for really complex systems like an aircraft control pilot system. Pilots can use their experiences using other vehicles (e.g. cars, boats), other aircraft (e.g. helicopters), or older versions of the same aircraft to make sense of the controls. For these systems, introducing controls that go against controls from similar systems may make the system less learnable.

There may be cases when there are multiple conventions available. For example, in this study, I could have used a scrubber analogy or the circular dial. I chose to use the circular dial because it had been around longer, successfully transferred over from multiple domains and was very familiar with many participants. Guidelines of when to use certain conventions over others could be an interesting space to explore in future work. For example, would it be better to use the most recent or the most familiar convention?

6.5. Limitations

Due to low sample size and a between-subjects design, I make the above claims cautiously. Some of the variables themselves were difficult to measure simply because of their cognitive nature. Intuitive interaction in particular is the subconscious application of prior knowledge. Identifying mental models or classifying actions or understanding as conscious or subconscious can only be done through inferences based on observations from actions and verbal responses. A user's behaviour may suggest these instances, but it is difficult to know for sure if these were indeed subconscious.

Due to limited time and resources, I executed the video coding and qualitative analysis alone. There may be an unintentional bias in the coding. In future work, independent naïve coders should be used to assess the video data.

Participants had different levels of familiarity with technology. While most used a computer on a daily basis, not all owned smart phones and few used tablets on a regular basis. Previous work has shown that technology familiarity affects intuitive interaction (Blackler et al., 2002). Though this was not explored explicitly, some participants who were more familiar with motion tracking systems did perform better than participants who were using them for the first time. Even distribution of familiarity across participants or having a singular familiarity level for all participants would have made this study more balanced. Furthermore, 72% of participants were students. This limits the generalizability of the findings from this study.

T2 (perfect balance) had an abnormal distribution for both task scores and times. As such, the nature of this task may not have been balanced across all conditions. Findings from this task should be taken cautiously.

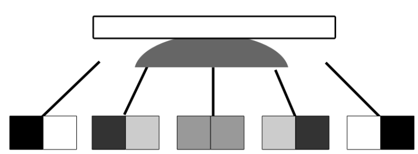
Before the findings from this experiment can be generalized to other whole body systems, more studies are needed to test these mappings in different contexts, systems and with a greater sample size. Springboard should also be tested in a public space such as a science museum to see if the findings from this study are ecologically valid.

6.6. Potential Redesigns

To balance the three mapping conditions, interface designs were very similar and may not leverage the best aspect of a certain mapping strategy. Had the perfect conventional, isomorphic or metaphoric examples been used, the differences between the interface designs may have been increased and lead to more significant results. A possible redesign for each condition is outlined below.

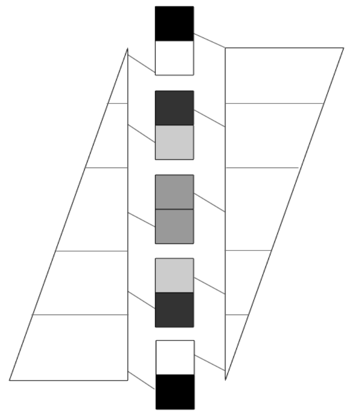
One redesign for an ideal metaphoric mapping could utilize a person's physical balance to change the states of food management. Visually, it will illustrate the concept of balance and be similar to a teeter-totter (i.e. a plank on a fulcrum), but shorter in length (figure 24). An iconic symbol for justice is the twin-pan scale. This design uses the metaphor of PHYSICAL BALANCE IS FOOD MANAGEMENT BALANCE. This was not used in the study because users may be too focused on staying balanced on the platform in fear of falling off. The new design needs to illustrate aspects of a teeter-totter, but be in a low enough elevation and a wide platform area to avoid this fear.

Figure 24. Front view of an ideal metaphoric mapping



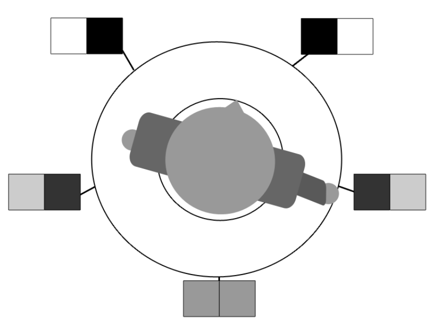
An alternative isomorphic mapping could use the triangles but create hard divisions between the states. The triangles would be rotated 90 degrees so that the triangle mapped to the left image would fall under the person's left foot and the triangle mapped to the right image would fall under the person's right food (figure 25). Rather than moving left and right, the user would move forward and backward, so that they would have to step on the related triangle regions to illicit that state.

Figure 25. Top view of an ideal isomorphic mapping



A possible redesign for the conventional mapping would keep the iPod wheel but use the participant's arm swings to change the states of food management (figure 26). This change in interaction makes it closer to previous systems and conventions for two reasons. Firstly, arm gestures are the conventional way of manipulating objects in the physical world and other whole body systems. Secondly, swinging the arms introduce minor clockwise and counter-clockwise torso rotations making this more similar to the rotations needed in analog dials. While a scrubber model is another example of a potential conventional mapping redesign that uses more whole body movement, the redesigns suggested in this section aim to be close to the previous designs, while better representing their mapping strategy.

Figure 26. Top view of ideal conventional mapping with a user using his right hand to illustrate an example input state.



However, these redesigns would introduce confounds to the study design. They should be used in a less formal experiment or in an informal public space.

6.7. Design Implications

I provide the following design implications based on the findings from this study and context from prior research. These are preliminary and will need further exploration in future studies before they become established guidelines.

1. Use interaction models that are literal if possible or leverage from previous systems and everyday experiences.
2. Leverage conventions from similar domains or different domains that involve similar tasks. If there are no previous conventions available that match the task, include instructions or salient feedback.
3. Pair metaphoric mappings with salient feedback and affordances when possible to make instances of successful interaction clear, raising user satisfaction.
4. Use metaphoric mappings if input-actions need to be initially automatic.
5. Use isomorphic mappings to match a user's initial expectations or perceived mental model.
6. Use isomorphic mappings if a user's attention should be focused on the task rather than their movement.
7. Use conventional mappings if learnability is important and low risk exploration is allowed.
8. Use conventional mappings if controls are not obvious (i.e. isomorphic) and the relationship between input action and control or meaning needs to be explicit (i.e. not metaphoric). Examples of such systems are health monitor machines and aircraft pilot controls.

7. Conclusion

7.1. Summary

This thesis describes a mixed-methods experiment that explored usability, intuitive interaction, awareness and impact for three different mapping designs of a whole body system. While mapping strategy had a significant effect on usability and impact for certain task sets (i.e. T2 and T5), overall, there were no statistical differences between the different mapping strategies and usability, awareness and impact.

Despite this, there were other observations that provided insights on the relationship between effectiveness and user satisfaction, as well as the relationship between body movement and content engagement. From the quantitative analysis, there was a significant difference between the mapping strategies and where participants placed their attention during the whole experiment. In particular, participants in the isomorphic condition gave attentional ratings that indicated more attention on completing the task then on using the system. Using less conscious attention on using a system is a trait that is commonly associated with intuitive interaction (Macaranas, Antle, & Riecke, 2012b).

From the in-depth qualitative analysis, there were various insights derived from expectation, conscious attention and subconscious action. Approximately half of the participants did not have their expectation met. The video analysis revealed recurrent themes that explained the mismatched expectations. Some findings include: perceived mental models that mapped speed to the system controls or that used hand gestures as a source of input. The qualitative analysis for conscious attention revealed some key differences in learnability and the different mapping strategies. Participants in the isomorphic condition demonstrated immediate and conscious learning while participants in the conventional condition demonstrated the most overall learning from the beginning of the experiment to the end. Participants assigned to the metaphoric condition were the only ones who subconsciously mimicked the system controls during the interview sessions.

By triangulating the results from the different research constructs, I was able to derive potential benefits, setbacks and uses for each mapping condition. Metaphoric mappings have the greatest potential to support automated learning of movement and subconscious learning of controls. Isomorphic mappings seem most suitable for walk up and play applications, which desire immediate use and minimal instruction. Conventional mappings demonstrated the greatest potential for learning applications, which have no literal mappings but can use analogies to create an explicit understanding of the action-control or action-meaning mapping. By combining the thesis findings with prior work, I introduce a set of design guidelines, which should be explored in future studies.

7.2. Future Work

The three mapping strategies were defined to be mutually exclusive in this study to allow a rigorous between-subjects experiment design. In normal context, these strategies can intertwine. Metaphoric mappings such as a slider for volume control can become an established convention. Isomorphic mappings could also become an established convention as well. However metaphoric mappings cannot be isomorphic or vice-versa. The non-exclusive nature of mapping strategies may be an interesting space to explore when making system controls that have multiple input actions. Previous studies have shown the success of conceptual blends (Imaz & Benyon, 2007) and multiple conceptual metaphors (Bakker et al., 2011). A system could use hybrid conventions, strict conventions, metaphoric, and isomorphic mappings as strategies for creating UI controls. Having controls that use some of these strategies and some that use others could make interesting user mental models.

The current Springboard redesign can also be tested in a public space, such as a science museum. This can be done in two phases: one with the current mappings and one with the suggested mappings in section 6.6. Another potential area to explore is the inclusion of instructions. It would be interesting to see how much instruction each design needed and how that would affect the intuitiveness or usability of the system. For example, metaphoric mappings may be more discoverable and satisfying if there were instructions describing the metaphor. However, this may conflict with the subconscious nature of intuitive interaction. Instructions may be added for more studies on usability but may not be suitable for future work on intuitive interaction.

When choosing an approach to extend this work, researchers need to understand the pros and cons between a formal, comparative experiment in a lab setting and an informal, exploratory study in a public space. Both can contribute to the work but each requires a different level of comparability between the three mapping UIs. Researchers also need to understand the qualitative nature of intuitive interaction and the limited power of making inferences on subconscious thoughts and actions.

7.3. Contribution

This thesis study replicates and expands on previous work in HCI, specifically works in tangible and embodied interaction. The findings in usability and expectation replicate findings from Hornecker (2012). Each mapping strategies' potential to facilitate intuitive interaction agree with researchers who advocate each as a approach to support intuitive interaction (Antle, Corness, & Droumeva, 2009a; Blackler et al., 2005; Smith, 1987). Observations made on conscious attention replicate and validate insights made by Smith (1987). Instances of subconscious action replicate findings from previous studies done by Antle et al. (2011) and Holland (2010) and extend the work of Hurtienne et al. (2009) and Macaranas et al. (2012a).

While this study contributes to the overall literature on whole body systems and intuitive interaction, it also presented some challenges on measuring intuitive interaction and empirically comparing mapping designs. It is difficult to measure subconscious behaviour and understanding without making educated guesses. Furthermore, while the different constructs of intuitive interaction gave valuable insights on how to support those specific aspects, minimal insights were given on an overall "intuitive" and "unintuitive" mapping design. The mapping designs were created to be empirically comparable in a lab setting. For this reason, each design may not have taken advantage of the characteristics an ideal mapping design would have provided. Finding a balance between empirical validity and truly representative designs is one that should be discussed and further explored. The UI designs and the limited power from the small sample size are seen as the biggest setbacks of this study.

Despite these setbacks, this thesis study provides many contributions to the HCI community from the various stages of the research and design process. It provides an operational definition of intuitive interaction, the distinction of three mapping strategies, grounded in literature and with the potential to support intuitive interaction, a methodology for measuring usability and intuitive interaction, and empirically and theoretically grounded design guidelines that can help shape future designs of whole body systems and NUIs.

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Appendices

Appendix A.

Games Analysis

Game	Input Actions	Output	Interaction Type	Role of Balance	Cognitive Dominance
Soccer Heading (WF+) Goal: Make avatar lean towards incoming soccer ball. Need a specific accuracy range to match the incoming soccer ball and to avoid non-soccer balls.	Shift weight left and right	Avatar moves similar to body shift.	Isomorphic	Equilibrium isn't goal but different shifts of weight to meet momentary accuracy needs. Balance is needed to hit target.	Seemed to be fairly equal in body and the game. Sometimes the game was going too fast so that I just gave up and focused on my body.
Ski Slalom (WF+) Goal: Avatar is moving downwards and needs to be in between two targets (range bigger than soccer)	Shift weight left and right	Avatar turns according to body emphasis	World convention	Equilibrium is not the goal. Balance is needed to meet target.	More on the game. Just like in real skiing, I was more focused on what was ahead of me.
Ski Jump (WF+) Goal: If the avatar jumps at the right time, the height and distance will be greater. If the avatar jumps too late, they will roll into a snowball. If too soon, height distance not as much.	Bend and unbend knees	Avatar bends their knees. Jumps when knees are unbent.	World convention	Not sure if it's really dominant here.	Focused on the game to see when the red line comes up then focused on my knees to go up fast enough, then back to the game to see how I did.

Table Tilt (WF+) Goal: Get balls into holes on by a set time. Table tilting activates balls to move according to gravity. If balls fall off table, table is flips and balls start at default.	Lean body left, right, forward and back.	Table tilts same way body is leaning	Isomorphic	Balance is needed to keep balls on the table.	My attention would go to the game to see tilt needed - then to my body to shift the right amount, then back on the game to see if I did right and what I need to do next.
Tightrope Walk (WF+) Goal: Cross the tightrope.	Walk on the spot. Lean left or right. Bend knees and unbend to jump.	Avatar moves forward. Go back to balance. Avoid obstacles	World convention	Equilibrium is desired. Balance is needed to keep avatar on the rope.	First on game. If avatar shows imbalance, then focus goes to body, then back to game unless obstacle calls attention to focus on body
Balance Bubble (WF+) Goal: Navigate bubble along stream of water. The stream will move bubble back. Avoid the edges of the river.	Lean body left, right, forward and backwards	Move bubble in direction of body weight.	Isomorphic	Balance is needed to avoid hitting the walls. Slight tilts left and right are needed to match the current shape of the path and to avoid bursting the bubble.	As with previous games, first attention goes to game then body orientation then game again. More focus goes to body orientation when game is not going well.
Penguin Slide (WF+) Goal: Move penguin along island and catch incoming fish	Shift body weight left and right	Penguin moves and tilts iceberg.	Isomorphic	Shifting balance is needed to catch the fish. Quick shifts in balance are needed to catch the big fish. Lack of balance will result in the penguin falling off the iceberg.	More on the game. I fell of the island many times but since I always came back on, consequence of lack of body focus was not great enough. More body focus = higher score. More fish = less body focus.
Snowboard Slalom (WF+) Goal: Go down hill fast and steer towards targets.	Shift weight forward and backward	Avatar moves left when you lean back and right when you lean forward	World convention	Control of balance needed to hit targets but shifts off-balance required to navigate towards targets.	Balanced: needed to be mindful of the body as well as target in game to be successful.

Lotus Focus (WF+) Goal: Keep candle lit as long as possible	Sit cross legged, back straight and stay perfectly still	Candle stays lit according to stillness.	Video game convention. Metaphor: you are the wind.	Absolute balance = still wind (though I wonder if movement > balance)	Was more focused on my body since any distractions from the screen would make me lose the game. Plus graphics were simple and encouraged more body focus.
Perfect 10 (WF+) Goal: Add up to desired sum by bursting the right numbered bubbles	Move hips left, right, back and front.	Avatar copies movement and bursts bubble in correspondin g direction.	Isomorphic	Different shifts of weight are needed to meet game requirements	Alternate dominance - think of sum, do body action.
Segway Circuit (WF+) Goal: Burst as many beach balls in given time limit	Shift weight forward, tilt wiimote left and right	Accelerate depending on time you lean forward. Turn based on wiimote.	Isomorphic	Balance is needed to gain speed and have enough force to pop the ball.	Mainly on the game. Too many navigational tasks to monitor. Body took a secondary role.
Bird's Eye Bull's Eye (WF+) Goal: Fly bird to target areas to increase time limit and score	Shift weight forward, left and right. Flap arms.	Bird glides according to weight shift. Bird height according to flap.	World convention	Equilibrium isn't goal but at times needed when the right direction is found and a straight motion is required to hit target	Seemed to be fairly equal in body and the game. As I got closer to the targets, attention became more focused on body so as not to screw up.

Appendix B.

Experiment Script

Part A: Briefing and pre-task questionnaire

Hello, you are here because you have agreed to participate in a study that explores different strategies for mapping body actions to system control for whole body systems. This experiment will take approximately sixty minutes. There are no known risks. You are free to back out of the experiment if you feel uncomfortable at any time. You will be rewarded for your participation with a $10 Blenz gift card, course credit or equivalent compensation.

Please take the time to read the following page for further details on the study. If you have any questions regarding the conditions, please do not hesitate to ask me. If you agree to these conditions, please sign at the end of the document and fill out the following questionnaire.

Part B: Exploration

This is the system that you will be using to complete tasks on in this experiment. Your task in the next five minutes is to figure out how the system works through exploration and experimentation. For the purposes of this experiment, I cannot answer any questions regarding the system. Once you feel that you understand the system and feel fairly confident in completing tasks, let me know and we will start the experiment. Otherwise, I will let you know when five minutes is up.

Part C: Task & Interview

For each task, I will state what you will need to do. If you understand the task and are ready to begin say, “OK”. If you want me to repeat the question, say “REPEAT”. When you feel that you have completed the task, say, “DONE”. After the first task, you will be asked a few questions which you will answer verbally. After every task, you will fill out this sheet. Are there any questions?

<u>Task 1: Perfect Balance</u>

1. Please make the picture on the left and the picture on the right show equal states in Food Management.

<u>Rate 1: Perfect Balance</u>

Please fill out this form before we proceed. **Hand participant rating sheet**

<u>Interview 1: System description</u>

Now I will be asking you a couple questions before we proceed with the next task.

- If you were going to teach someone how to use this interface, what would you say?
- What do the images represent?

<u>Task 2: Specific States</u>

In this next task, you will be asked to show specific images on the screen. I will read out what you will need to show. When you are ready to begin say, “OK”, if you want me to repeat the question say, “REPEAT”. When you feel that you have completed the task say, “DONE”.

1. Please show an excessive amount of environmental preservation and minimal food production.

2. Please show an above average amount of environmental preservation and below average food production.
3. Please show a below average amount of environmental preservation and above average food production.
4. Please show a minimal amount of environmental preservation and excessive food production.

Rate 2: Specific States

Please fill out this form before we proceed. **Hand participant rating sheet**

Task 3: Relative Change

For the following task, I will ask you to go to specific positions in the space. From that location, I will ask you to increase or decrease the value represented by the left or right image. When you are ready say, “OK”. If you would like me to repeat say, “REPEAT”. When you feel that you are complete say, “DONE”.

1. From your current position, please increase the level of environmental preservation.
2. From your current position, please decrease the level of environmental preservation.
3. From your current position, please increase the level of food production.
4. From your current position, please decrease the level of food production.

Rate 3: Relative Change

Please fill out this form before we proceed. **Hand participant rating sheet**

Task 4: Sequential Change

For this task, you will be asked to display different sequences of images. After I read the sequence say, “OK”. If you would like me to repeat say, “REPEAT”. When you feel that you have completed the task say “DONE”.

1. Please show us minimal environmental preservation, balanced food management, minimal environmental preservation, moderately high environmental preservation.
2. Please show us minimal food production, balanced food management, minimal food production, moderately high food production.
3. Please show us excess environmental preservation, balanced food management, excess environmental preservation, and moderately low environmental preservation.
4. Please show us excess food production, balanced food management, excess food production, and moderately low food production .
5. Please show moderately low environmental preservation, excess food production, balanced food management, and moderately low environmental preservation.
6. Please show moderately low food production, excess environmental preservation, balanced food management, and moderately low food production.
7. Please show moderately high environmental preservation, minimal food production, balanced food management, and moderately high environmental preservation.
8. Please show moderately high food production, minimal environmental preservation, balanced food management, and moderately high food production.

Rate 4: Sequential Change

Please fill out this form before we proceed. **Hand participant rating sheet**

Interview 2: System evaluation

That concludes the task portion of this study. The final parts remaining is another short interview and questionnaire.

- Did the interface behave as you expected it to? If not, what did you expect it do?
- Do you have anything else you would like to say or ask regarding your experience using Springboard or this study?

Part D: Post Task Questionnaire

The last part of this study is this short questionnaire. Let me know if you have any questions.

Thank you for participating in this study! Here is your reward for your participation. Please sign this form indicating that you have been compensated.

Appendix C.

Questionnaires

PRE TASK QUESTIONNAIRE

SECTION A: *To be filled out by experimenter*

DATE: _____________ PARTICIPANT #: ______ Condition: SCH / ISO / CON

SECTION B: *To be filled out by participant*

1. Gender M: _______ F: _________

2. Date of birth (MM/DD/YYYY): ______________________

3. Education Level:

a) High School or Under □ b) College or University in progress □
c) Diploma or Bachelor Degree complete □ d) Graduate or Post-Graduate in progress □
e) Graduate or Post-Graduate Degree complete □

4. Technology use: please list the types of technology (computer, smart phones, tablets, video games, etc) that you use on:

a) Very Frequently (Every day)

b) Occasionally (Weekly or Bi-Weekly)

c) Rarely (Monthly or less)

5. How aware are you of issues in social justice?

Not aware at all — Very Aware

6. If given the opportunity to do a coop work term working for The Fair Distribution of Food Organization how willing would you be to take this job?

Not likely at all — Very likely

POST TASK QUESTIONNAIRE

SECTION A: *To be filled out by experimenter*

DATE: _____________ PARTICIPANT #: ______ Condition: SCH / ISO / CON

SECTION B: *To be filled out by participant*

Statement	Strongly Disagree						Strongly Agree
1. I think that I would like to use the system frequently.							
2. I found the system unnecessarily complex.							
3. I thought the system was easy to use.							
4. I think that I would need the support of a technical person to be able to use the system.							
5. I found the various functions in the system were well integrated.							
6. I thought there was too much inconsistency in the system.							
7. I would imagine that most people would learn to use the system very quickly.							
8. I found the system very cumbersome to use.							
9. I felt very confident using the system.							

10. I needed to learn a lot of things before I could get going with this system.							
	Strongly Disagree						Strongly Agree
11. I think I am pretty good at using Springboard.							
	Strongly Disagree						Strongly Agree
12. I think I did pretty well at using Springboard, compared to other participants.							
	Strongly Disagree						Strongly Agree
13. After working with Springboard for a while, I felt pretty competent.							
	Strongly Disagree						Strongly Agree
14. I am satisfied with my performance in completing the tasks using Springboard.							
	Strongly Disagree						Strongly Agree
15. I was pretty skilled at using Springboard.							
	Strongly Disagree						Strongly Agree
16. Using Springboard was an activity that I couldn't do very well.							
	Strongly Disagree						Strongly Agree
17. How intuitive did you find the system to use?							
	Not intuitive At All						Very Intuitive
18. How aware are you of issues in social justice?							
	Not Aware At All						Very Aware
19. If given the opportunity to do a coop work term working for The Fair Distribution of Food Organization how willing would you be to take this job?							
	Not likely At All						Very Likely

Appendix D.

Experiment Data

Effectivness

	Perfect Balance	Specific States	Relative Change	Sequential Change	Overall
Metaphoric	100	66.66666667	90	74.50757576	84.21875
Isomorphic	45.45454545	75.75757576	92.42424242	81.81818182	73.86363636
Conventional	54.54545455	74.24242424	96.96969697	68.18181818	73.48484848
STD MET	0	1.868558895	1.272937693	0.961780485	2.701926628
STD ISO	3.557380873	2.147764016	1.030414432	1.123865934	5.03539505
STD CON	3.936479108	1.786738851	0.757575758	1.691474505	4.690368727

P#	Cond	T1	T2	T3	T4	Total
P6	CON	0	20.83333333	25	6.25	52.08333333
U3	CON	25	8.333333333	16.66666667	14.0625	64.0625
R1	CON	0	25	25	21.875	71.875
U9	CON	0	25	25	17.1875	67.1875
U12	CON	25	12.5	25	12.5	75
U15	CON	25	16.66666667	25	20.3125	86.97916667
U18	CON	0	20.83333333	25	20.3125	66.14583333
U21	CON	25	12.5	25	21.875	84.375
U24	CON	0	14.58333333	25	10.9375	50.52083333
U27	CON	25	22.91666667	25	25	97.91666667
U30	CON	25	25	25	17.1875	92.1875
P5	ISO	25	25	16.66666667	18.75	85.41666667
U2	ISO	25	25	25	23.4375	98.4375
R2	ISO	12.5	14.58333333	20.83333333	20.3125	68.22916667
U8	ISO	25	20.83333333	25	17.1875	88.02083333
U11	ISO	0	25	25	17.1875	67.1875
U14	ISO	25	12.5	25	25	87.5
U17	ISO	12.5	25	25	23.4375	85.9375
U20	ISO	0	25	25	23.4375	73.4375
U23	ISO	0	18.75	25	15.625	59.375
U26	ISO	0	4.166666667	25	25	54.16666667
U29	ISO	0	12.5	16.66666667	15.625	44.79166667
U1	MET	25	20.83333333	16.66666667	20.3125	82.8125
U4	MET	25	20.83333333	25	20.3125	91.14583333
U7	MET	25	12.5	16.66666667	17.1875	71.35416667
U10	MET	25	4.166666667	25	17.1875	71.35416667

U13	MET	25	12.5	25	15.625	78.125
U16	MET	25	20.83333333	25	15.625	86.45833333
U19	MET	25	20.83333333	25	21.875	92.70833333
U22	MET	25	22.91666667	25	23.4375	96.35416667
U25	MET	25	18.75	16.66666667	23.4375	83.85416667
U28	MET	25	20.83333333	25	17.1875	88.02083333
		16.40625	18.359375	23.30729167	18.89648438	76.96940104

Efficiency

	Perfect Balance	Specific States	Relative Change	Sequential Change	Overall
Metaphoric	61.9608	48.3873	25.39593333	90.73325	51.64188889
Isomorphic	120.9196364	49.10257576	23.50412121	84.26686364	56.36371717
Conventional	121.349	54.094	30.369	103.645	62.731
STD MET	15.15313921	12.50312425	3.792888777	6.351521582	5.906220476
STD ISO	37.36230648	10.48912461	6.108915591	10.63671238	7.987132414
STD CON	23.53174202	19.18923978	6.755438225	15.89778451	7.604703293

P#	Cond	T1	T2	T3	T4	Total
P6	CON	69.987	24.023	41.002	139.702	60.496
U3	CON	110.830	73.955	56.059	204.751	101.1525556
R1	CON	81.973	64.15766667	16.604	76.668	53.066
U9	CON	39.18	34.33966667	11.701	93.075	40.38355556
U12	CON	270.59	33.061	65.297	78.4385	80.28233333
U15	CON	69.408	39.701	18.36466667	45.2595	31.90633333
U18	CON	214.341	29.693	14.404	76.025	55.40911111
U21	CON	61.562	236.8845	16.30066667	75.352	91.867125
U24	CON	182.756	37.76533333	13.79166667	96.544	58.94611111
U27	CON	50.545	6.910666667	13.61166667	61.275	26.07355556
U30	CON	183.671	14.54033333	66.927	193.01	90.45477778
P5	ISO	27.991	26.018	12.53433333	69.251	31.35
U2	ISO	16.396	29.79233333	9.949333333	66.275	29.79677778
R2	ISO	100.107	117.4036667	78.53533333	147.1555	109.1372222
U8	ISO	1.67	97.512	40.94366667	95.6925	67.60244444
U11	ISO	160.844	73.80833333	20.526	91.037	69.54677778
U14	ISO	58.779	38.356	11.023	42.4375	32.42122222
U17	ISO	15.571	16.65733333	11.66266667	66.507	25.94944444
U20	ISO	378.145	22.24233333	16.207	61.515	68.50255556
U23	ISO	278.676	25.32733333	18.08633333	152.1995	79.25733333
U26	ISO	218.351	70.05666667	14.563	67.904	67.55755556
U29	ISO	73.586	22.95433333	24.51466667	66.9615	38.87955556
U1	MET	95.537	47.794	25.43166667	114.1825	60.39766667
U4	MET	27.145	14.88033333	12.081	107.5925	35.91266667

U7	MET	107	15.26	13.03666667	84.045	39.99777778
U10	MET	129.348	146.1616667	27.30366667	107.5165	96.08633333
U13	MET	39.517	71.53	14.474	105.9135	56.59511111
U16	MET	37.762	58.41233333	30.58633333	79.244	51.47177778
U19	MET	11.923	15.40933333	21.95733333	54.77	25.95144444
U22	MET	36.5	49.14866667	50.18233333	69.2355	52.55155556
U25	MET	128.492	26.767	20.62933333	79.2515	47.68711111
U28	MET	6.384	38.50966667	38.277	105.5815	49.76744444

PCS / SUS scores and Perceived Intuition Ratings

P#	Cond.	SUS	PCS	IR
P6	CON	53	27	5
U3	CON	40	21	5
R1	CON	25	17	2
U9	CON	58	32	7
U12	CON	46	30	5
U15	CON	55	36	7
U18	CON	46	27	5
U21	CON	43	22	5
U24	CON	31	16	3
U27	CON	57	38	5
U30	CON	24	17	2
P5	ISO	63	40	7
U2	ISO	49	28	4
R2	ISO	63	34	5
U8	ISO	34	15	4
U11	ISO	32	21	6
U14	ISO	56	42	5
U17	ISO	62	34	6
U20	ISO	43	16	3
U23	ISO	47	26	6
U26	ISO	40	25	2
U29	ISO	42	27	4
U1	MET	26	22	2
U4	MET	64	34	6
U7	MET	25	7	3
U10	MET	43	13	4
U13	MET	34	26	3
U16	MET	40	21	4
U19	MET	51	29	6
U22	MET	40	27	1
U25	MET	28	27	5
U28	MET	33	15	4

Hand Gestures and Mental Models

User	Condition	Hand Gesture	When	Initial	Dominant	Final
P5	Isomorphic	No	0	Isomorphic	Isomorphic	Isomorphic
P6	Conventional	No	0	None	Conventional	Conventional
U1	Metaphoric	No	0	None	Metaphoric	Metaphoric
U2	Isomorphic	No	0	Isomorphic	Isomorphic	Isomorphic
U3	Conventional	Yes	20	None	Conventional	Conventional
U4	Metaphoric	No	0	Metaphoric	Metaphoric	Metaphoric
R1	Conventional	Yes	27	None	Conventional	Conventional
R2	Isomorphic	No	0	*Isomorphic*	Isomorphic/Metaphoric	Isomorphic
U7	Metaphoric	No	0	Metaphoric	Metaphoric	Metaphoric
U8	Isomorphic	Yes	20	Metaphoric	Metaphoric	Metaphoric
U9	Conventional	Yes	40	Metaphoric	Conventional	Conventional
U10	Metaphoric	Yes	80	Isomorphic	Isomorphic	Isomorphic
U11	isomorphic	No	0	Metaphoric	Isomorphic	Isomorphic
U12	Conventional	Yes	20	Isomorphic	Conventional	Conventional
U13	Metaphoric	No	0	Conventional	Metaphoric	Metaphoric
U14	isomorphic	Yes	10	Isomorphic	Isomorphic	Isomorphic
U15	Conventional	Yes	10	None	Conventional	Convention
U16	Metaphoric	Yes	10	None	Metaphoric	Metaphoric
U17	isomorphic	No	0	None	Isomorphic	Isomorphic
U18	Conventional	No	0	Isomorphic	Conventional	Conventional
U19	Metaphoric	Yes	20	Metaphoric	Metaphoric	Metaphoric
U20	isomorphic	Yes	20	Metaphoric	Isomorphic	Isomorphic
U21	Conventional	Yes	60	Conventional	Conventioinal	Conventional
U22	Metaphoric	Yes	50	None	None	Isomorphic
U23	isomorphic	No	0	Isomorphic	Isomorphic	Isomorphic
U24	Conventional	Yes	20	Conventional	Convenetional	Conventional
U25	Metaphoric	Yes	40	None	None	Metaphoric
U26	isomorphic	Yes	60	None	Isomorphic	Isomorphic
U27	Conventional	No	0	Isomorphic	Convenetional	Conventional
U28	Metaphoric	Yes	60	Isomorphic	Metaphoric	Metaphoric
U29	isomorphic	Yes	20	None	None	Isomorphic
U30	Conventional	No	0	Metaphoric	Metaphoric	Conventional

Level of Understanding

User	Condition	Understanding	Grade
P5	Isomorphic	Strong	4
P6	Conventional	Poor	0
U1	Metaphoric	Partial (good content, poor system)	2
U2	Isomorphic	Strong	4
U3	Conventional	Partial (partial content, poor system)	1
U4	Metaphoric	Strong	4
R1	Conventional	Partial (partial content, poor system)	1
R2	Isomorphic	Partial (good content, partial system)	3
U7	Metaphoric	Partial (partial content, partial system)	2
U8	Isomorphic	Partial (partial content, poor system)	1
U9	Conventional	Partial (partial content, poor system)	1
U10	Metaphoric	Partial (partial content, poor system)	1
U11	isomorphic	Partial (partial content, poor system)	1
U12	Conventional	Partial (partial content, poor system)	1
U13	Metaphoric	Partial (partial system, good content)	3
U14	isomorphic	Poor	0
U15	Conventional	Poor	0
U16	Metaphoric	Partial (partial content, poor system)	1
U17	isomorphic	Partial (partial content, poor system)	1
U18	Conventional	Partial (partial system, partial content)	2
U19	Metaphoric	Partial (partial system, partial content)	2
U20	isomorphic	Partial (partial system, good content)	3
U21	Conventional	None	0
U22	Metaphoric	Partial (no system, partial content)	1
U23	isomorphic	Partial (no system, partial content)	1
U24	Conventional	Partial (partial system. good content)	3
U25	Metaphoric	None	0
U26	isomorphic	Partial (no system, partial content)	1
U27	Conventional	Partial (partial system, good content)	3
U28	Metaphoric	Partial (no system, partial content)	1
U29	isomorphic	Partial (no system, partial content)	1
U30	Conventional	Partial (no system, partial content)	1

Expectation

User	Condition	Expect-ation	What
P5	Isomorphic	Yes	
P6	Conventional	Yes	
U1	Metaphoric	No	Controls were not consistent.
U2	Isomorphic	Yes	At first confused but then it made sense and the music was helpful
U3	Conventional	No	Images change too fast, sound/vision present a high cognitive load
U4	Metaphoric	Yes	
R1	Conventional	No	Initial thought output was mapped to speed, but once she understood it was about her position, it made sense
R2	Isomorphic	Yes	
U7	Metaphoric	No	Wanted hard divisions between the different states.
U8	Isomorphic	No	
U9	Conventional	No	Sometimes he had to redo the movement for the system to recognie the change
U10	Metaphoric	No	
U11	isomorphic	No	Wanted it to be easier to manage - want images to stop, and did not get the states
U12	Conventional	Yes	
U13	Metaphoric	No	Wanted it to be like a scrubber - rewind and fast forward
U14	isomorphic	Yes	
U15	Conventional	Yes	
U16	Metaphoric	Yes	
U17	isomorphic	Yes	
U18	Conventional	No	I didn't think it be kind of like a spider thing. I thought it was about how fast you moved. So that's kind of what I expected.
U19	Metaphoric	Yes	It behaved as I expected it to in the beginning but my expectations seemed to change over time. I was less certain of what to expect as the tasks changed.
U20	isomorphic	No	Thought he would have more control and also use his hands
U21	Conventional	Yes	
U22	Metaphoric	No	In the beginning - thought I could do it with smaller movements with the arms "thought things were random and that I could only speed them up or slow them down"
U23	isomorphic	No	I wish I could have paused it
U24	Conventional	No	"Realized it had more to do with standing in a circle - had an easy time finding extremes but the ones in between are harder. Also not sure if the two sides are working in different axis or if they are working together.
U25	Metaphoric	No	Initially at the start no - didn't know what to do." "Somewhere in the middle"
U26	isomorphic	No	At first no, I noticed the sound more than the changes of the pictures. But then when you asked me to step to a postion, it became clear how the images changed.
U27	Conventional	Yes	
U28	Metaphoric	Yes	
U29	isomorphic	No	"Not as easy to control as I thought it would be. It seems to have its own schedule."
U30	Conventional	No	"It needs to be able to stop. There was no feedback or it was hard to spot because of the constant movement and constant change."

Conscious Attention

P6	CON	5.0	6.0	4.0	5.0	5.0
U3	CON	7.0	7.0	4.0	4.0	5.5
R1	CON	2.0	4.0	4.0	7.0	4.0
U9	CON	5.0	5.0	3.0	4.0	4.5
U12	CON	3.0	2.0	5.0	5.0	4.0
U15	CON	4.0	3.0	2.0	4.0	3.5
U18	CON	6.0	4.0	4.0	4.0	4.0
U21	CON	6.0	3.0	6.0	6.0	6.0
U24	CON	2.0	4.0	4.0	5.0	4.0
U27	CON	6.0	7.0	6.0	5.0	6.0
U30	CON	6.0	3.0	3.0	4.0	3.5
P5	ISO	7.0	4.0	6.0	6.0	6.0
U2	ISO	7.0	7.0	6.0	4.0	6.5
R2	ISO	5.0	3.0	4.0	4.0	4.0
U8	ISO	5.0	7.0	4.0	6.0	5.5
U11	ISO	1.0	5.0	3.0	5.0	4.0
U14	ISO	4.0	4.0	6.0	6.0	5.0
U17	ISO	6.0	6.0	6.0	6.0	6.0
U20	ISO	6.0	6.0	6.0	5.0	6.0
U23	ISO	6.0	5.0	4.0	5.0	5.0
U26	ISO	5.0	6.0	2.0	5.0	5.0
U29	ISO	7.0	7.0	1.0	4.0	5.5
U1	MET	4.0	4.0	2.0	3.0	3.5
U4	MET	6.0	5.0	6.0	3.0	5.5
U7	MET	4.0	5.0	1.0	1.0	2.5
U10	MET	4.0	6.0	3.0	6.0	5.0
U13	MET	5.0	5.0	3.0	2.0	4.0
U16	MET	4.0	3.0	3.0	3.0	3.0
U19	MET	5.5	6.0	4.0	4.0	4.8
U22	MET	7.0	4.0	1.0	1.0	2.5
U25	MET	3.0	1.0	4.0	3.0	3.0
U28	MET	6.0	4.0	2.0	5.0	4.5

Subconscious Action

P5	Isomorphic	No	
P6	Conventional	No	
U1	Metaphoric	No	
U2	Isomorphic	No	
U3	Conventional	No	
U4	Metaphoric	No	Was off screen - could not see
R1	Conventional	No	
R2	Isomorphic	No	
U7	Metaphoric	No	
U8	Isomorphic	No	
U9	Conventional	No	
U10	Metaphoric	No	
U11	isomorphic	No	
U12	Conventional	No	
U13	Metaphoric	Yes	First interview
U14	isomorphic	No	
U15	Conventional	No	
U16	Metaphoric	Yes	Second Interview
U17	isomorphic	No	
U18	Conventional	No	
U19	Metaphoric	Yes	First Interview
U20	isomorphic	No	
U21	Conventional	No	
U22	Metaphoric	No	
U23	isomorphic	No	
U24	Conventional	No	
U25	Metaphoric	No	
U26	isomorphic	No	
U27	Conventional	No	
U28	Metaphoric	No	
U29	isomorphic	No	
U30	Conventional	No	

Appendix E.

Statistical Tests

Effectiveness:

All Tasks:

Bartlett test of homogeneity of variances

data: effectiveness$V7 by effectiveness$V2

Bartlett's K-squared = 3.9652, df = 2, p-value = 0.1377

One-way between subjects ANOVA

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
effectiveness$V2	2	770.4	385.19	1.9059	0.1668
Residuals	29	5860.9	202.10		

Perfect Balance

Bartlett test of homogeneity of variances

data: effectiveness$V3 by effectiveness$V2

Bartlett's K-squared = Inf, df = 2, p-value < 2.2e-16

Shapiro-Wilk normality test

data: effectiveness$V3

W = 0.6416, p-value = 1.298e-07

Kruskal-Wallis rank sum test

data: effectiveness$V3 and effectiveness$V2

Kruskal-Wallis chi-squared = 9.021, df = 2, p-value = 0.01099

Effect size η2 = X2/N-1 = 9.021/20 = 0.45105

Specific States:

Bartlett test of homogeneity of variances

data: effectiveness$V4 by effectiveness$V2

Bartlett's K-squared = 0.6561, df = 2, p-value = 0.7203

One-way between subjects ANOVA

```
                Df  Sum Sq Mean Sq F value Pr(>F)
effectiveness$V2  2   39.15  19.576  0.4957 0.6142
Residuals        29 1145.20  39.490
```

Relative Change:

Bartlett test of homogeneity of variances

data: effectiveness$V5 by effectiveness$V2

Bartlett's K-squared = 1.4418, df = 2, p-value = 0.4863'

One-way between subjects ANOVA

```
                Df Sum Sq Mean Sq F value Pr(>F)
effectiveness$V2  2  10.27  5.1344  0.4484  0.643
Residuals        29 332.07 11.4507
```

Sequential Change:

Bartlett test of homogeneity of variances

data: effectiveness$V6 by effectiveness$V2

Bartlett's K-squared = 3.3412, df = 2, p-value = 0.1881

One-way between subjects ANOVA

```
                Df Sum Sq Mean Sq F value Pr(>F)
effectiveness$V2  2  76.53  38.264  2.1104 0.1394
Residuals        29 525.81  18.131
```

Efficiency

Overall tasks:

Bartlett test of homogeneity of variances

data: times$V7 by times$V2

Bartlett's K-squared = 1.1679, df = 2, p-value = 0.5577

One-way between subjects ANOVA

```
           Df  Sum Sq Mean Sq F value Pr(>F)
times$V2     2   652.6   326.3  0.5729 0.5702
Residuals   29 16518.3   569.6
```

Perfect Balance:

Bartlett test of homogeneity of variances

data: times$V3 by times$V2

Bartlett's K-squared = 7.4833, df = 2, p-value = 0.02372

Shapiro-Wilk normality test

data: times$V3

W = 0.874, p-value = 0.001438

Kruskal-Wallis rank sum test

data: times$V3 by times$V2

Kruskal-Wallis chi-squared = 3.1112, df = 2, p-value = 0.2111

Specific States:

Bartlett test of homogeneity of variances

data: times$V4 by times$V2

Bartlett's K-squared = 4.0404, df = 2, p-value = 0.1326

One-way between subjects ANOVA

```
            Df Sum Sq Mean Sq F value Pr(>F)
times$V2     2    208  103.95  0.0452 0.9559
Residuals   29  66677 2299.20
```

Relative Change:

Bartlett test of homogeneity of variances

data: times$V5 by times$V2

Bartlett's K-squared = 3.4044, df = 2, p-value = 0.1823

One-way between subjects ANOVA

```
            Df  Sum Sq Mean Sq F value Pr(>F)
times$V2     2   275.5  137.77  0.3834 0.6849
Residuals   29 10419.8  359.30
```

Sequential Change:

Bartlett test of homogeneity of variances data: times$V6 by times$V2

Bartlett's K-squared = 7.4242, df = 2, p-value = 0.02443

Shapiro-Wilk normality test

data: times$V6

W = 0.8638, p-value = 0.0008368

Kruskal-Wallis rank sum test

data: times$V6 by times$V2

Kruskal-Wallis chi-squared = 2.0931, df = 2, p-value = 0.3512

User Satisfaction and Perceived Competence

User Satisfaction:

data: V5 by V2

Kruskal-Wallis chi-squared = 3.2707, df = 2, p-value = 0.1949

Perceived Competence:

data: V6 by V2

Kruskal-Wallis chi-squared = 1.9156, df = 2, p-value = 0.383

Correlation: SUS and PCS

Spearman's rank correlation rho

data: sus$V5 and sus$V6

S = 1082.053, p-value = 3.502e-08

alternative hypothesis: true rho is not equal to 0

sample estimates:

rho

0.8016765

Perceived Intuitiveness

data: V3 by V2

Kruskal-Wallis chi-squared = 1.9917, df = 2, p-value = 0.3694

Conscious Attention

Perfect Balance:

Kruskal-Wallis rank sum test

data: ca$V3 by ca$V2

Kruskal-Wallis chi-squared = 1.5509, df = 2, p-value = 0.4605

Specific States

Kruskal-Wallis rank sum test

data: ca$V4 by ca$V2

Kruskal-Wallis chi-squared = 3.6183, df = 2, p-value = 0.1638

Relative Change:

Kruskal-Wallis rank sum test

data: ca$V5 by ca$V2

Kruskal-Wallis chi-squared = 5.0511, df = 2, p-value = 0.08001

Sequential Change:

Kruskal-Wallis rank sum test

data: ca$V6 by ca$V2

Kruskal-Wallis chi-squared = 10.4175, df = 2, p-value = 0.005469

data: ca$V6 and ca$V2

	CON	ISO
ISO	1.000	-
MET	0.032	0.015

P value adjustment method: bonferroni

Overall:

Kruskal-Wallis rank sum test

data: ca$V7 by ca$V2

Kruskal-Wallis chi-squared = 9.3271, df = 2, p-value = 0.009433

data: ca$V7 and ca$V2

	CON	ISO
ISO	0.196	-
MET	0.465	0.014

P value adjustment method: bonferroni

Awareness:

Pre-post comparisons: metaphoric

Wilcoxon signed rank test with continuity correction

data: r$V3 and r$V4

V = 14.5, p-value = 1

Pre-post comparisons: isomorphic

Wilcoxon signed rank test with continuity correction

data: iso$V3 and iso$V4

V = 13.5, p-value = 0.573

Pre-post comparisons: conventional

Wilcoxon signed rank test with continuity correction

data: con$V3 and con$V4

V = 40.5, p-value = 0.1937

Post ratings

Kruskal-Wallis rank sum test

data: awareness$V4 by awareness$V2

Kruskal-Wallis chi-squared = 1.032, df = 2, p-value = 0.5969

Impact:

Pre-post comparisons: metaphoric

Wilcoxon signed rank test with continuity correction

data: r$V5 and r$V6

V = 22, p-value = 0.6082

Pre-post comparisons: isomorphic

Wilcoxon signed rank test with continuity correction

data: iso$V5 and iso$V6

V = 18.5, p-value = 1

Pre-post comparisons: conventional

Wilcoxon signed rank test with continuity correction

data: con$V5 and con$V6

V = 47.5, p-value = 0.04401

Post ratings:

Kruskal-Wallis rank sum test

data: awareness$V6 by awareness$V2

Kruskal-Wallis chi-squared = 1.0383, df = 2, p-value = 0.595