A GUIDING HAND: AUGMENTING NOVICE GAMEPLAY WITH HAPTIC FEEDFORWARD GUIDANCE

by

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ABSTRACT

As video games continue to gain precedence outside the realm of entertainment, the potential of the medium for new uses, contexts and audiences expands. This raises the issue of how to design video games for an increasingly diverse set of players. Novice players, in particular, face a number of challenges in modern video game environments. Successful navigation and gameplay engagement are threatened by the learning curves associated with the medium's increasing sophistication. In this thesis, I designed a vibrotactile forearm display that provides feedforward guidance for navigating fast-paced, multimodal game environments. I conducted an exploratory experiment to evaluate the effectiveness of the prototype in reducing the learning curve by improving the early performance and user experience of novice players. The experimental findings show that feedforward guidance rises tentatively to the fore; however, the haptic condition was not as effective as the visual condition. Latent factors combined with discordant performance scores, self-reports and qualitative feedback suggest that more research needs to be conducted in order to conclusively elucidate the effectiveness of haptic feedforward guidance.

Keywords: Haptics; vibrotactile; wearable tactile display (WTD); forearm display; multimodal; modality comparison; attention; navigation; video games; game environments; game interface design; novice players; feedforward; guidance; usability; user experience; user-centred design; Wizard of Oz.

DEDICATION

To the residents of my locket, nearest and dearest to my heart.

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GLOSSARY

Feedforward	A method of directing user behaviour by communicating a suggested action. In contrast to feedback, information about the result of the action (the response) is communicated to the user *before* the user performs the action.
Guidance	The process of assisting the user towards some goal. In this research, I use pre-emptive visual and haptic cues to direct user action.
Haptic	Relating to the sense of touch.
Modality	One of the human senses, e.g. vision.
Multimedia	Integrating more than one form of media.
Multimodal	Affecting more than one sense, e.g. vision, audio and touch.
Novice Player	Digital game players who have little or no experience with games; characteristic of this audience are children, people born before 1960, females, people who are disabled, people from low income families, or people from undeveloped nations.
Vibrotactile	Vibration sensation experienced through the sense of touch.
Video Game	A digital, electronic or computerized game.

1: INTRODUCTION

In this thesis work, I explored how augmenting a navigation task with haptic feedforward guidance—a method of guiding future action via the sense of touch—in a fast-paced, multimodal game environment affects the user experience of novice players with respect to early, successful, and engaged play. Recent trends in the use of video games for learning and training raise the issue of how to make the medium accessible to novices. Further, video games are becoming increasingly sophisticated in terms of the cognitive demands they place on players. With the multimodal, attention-demanding nature of the video game medium in mind, I designed a prototype that provided salient but unobtrusive guidance information haptically.

This research proceeded in two stages. In the first stage, I developed a wearable feedforward display for novice players; while wearing this display, players received timely guidance via vibrotactile cues during gameplay. In the second stage, I conducted an exploratory, experimental evaluation of the prototype; this involved collecting performance and user experience data from novice players experiencing three conditions—haptic guidance, visual guidance and no guidance—while engaged in the prototype's intended context of use: unfamiliar, fast-paced, navigation-driven gameplay in a modern, multimodal game environment. The experimental findings tentatively showed that feedforward guidance is

an effective approach for supporting novice gameplay in this context. However, haptic feedforward guidance was not as effective as its visual counterpart. Latent factors combined with incongruous performance scores, self-reports and qualitative feedback suggest that more research needs to be conducted in order to clarify the effectiveness of haptic feedforward guidance.

1.1 Research Problem

As a maturing medium with a solid foundation in the entertainment industry, the video game is increasingly being embraced outside of entertainment contexts. In particular, the last decade has seen the advent of the video game as a tool for learning (Van Eck, 2010; Gee, 2003, 2007a, 2007d; Prensky, 2001). Although the potential cognitive benefits of video games were reported as early as two decades ago (Greenfield, 1984), the use of the medium for purposes such as learning failed to gain steam due to its dismissal as an entertainment medium (Prensky, 2001), economic factors, and low technology adoption (Crawford, 2003). But after decades of excessive financial success, a burgeoning reinvention of use and audience, and increasingly widespread acceptance in public and scholarly domains, the video game medium has finally gained the serious attention of certain sectors of academia, educators and designers.

Evaluating the video game medium as a tool for learning has been a principle point of inquiry in certain academic circles as a result of the recent Game Studies and Serious Games movements (Susi, Johannesson, & Backlund, 2007). The reconfigured use of this play medium for training and learning has occasioned a new learning paradigm that game-based learning expert Marc Prensky calls

"learning via play" (Prensky, 2001). Prensky provides three reasons why the video game medium is appropriate for learning: (1) the prevalence of video games in the current and coming generation of learners sets new demands on learning styles; (2) the inherent fun factor of video games is motivating; and (3) the last reason, which is actually two reasons combined, situates the versatility of the medium as all-encompassing in terms of learning content, and speaks to the effectiveness of the medium, particularly with respect to traditional pedagogy. These sentiments have been supported by the array of research on video games for learning; see Gee (2007a) and Salen (2008) for concrete examples. Prensky calls on academics to "… work with those producing the new tools to validate them and make their effectiveness known" (2001, p. 410). As an academic who is regrettably not in a position to work directly with companies developing cutting-edge tools, I content myself with augmenting the latest gaming technologies in an effort to advance their efficacy for learning.

1.1.1 Augmenting the Learning Process in Games

While the merits of the video game medium have garnered recognition in the domain of learning, the issue of *how* to design video games that are conducive to learning remains. In academia, game design has been monopolized by a "… visually biased, structural/semiotic angle" that includes visual representation and narrative (Shinkle, 2005, p. 21). In and outside of the academic circle, a debate on the supremacy of narrative—stories, characters, events—or ludic qualities—the play aspects of games—in the design of games has predominated (Ang & Rao, 2008). Both perspectives consider the design of games with respect

to the game world, but do not address those elements of the gaming experience that fall outside of it; namely, the player, their extra-game environment, and the interface that connects them to the game world. The existence of these integral, if overlooked, extra-game aspects of the gaming experience call for a focus on the design of not just the game itself, but the game interface, particularly when designing games for learning. In this research, I sought to contribute to a growing body of knowledge on the design of games from the perspective of user-centred design and human-computer interaction. I approached this work as an interaction designer, user experience developer, and experienced gamer. From this tripartite position, I considered three aspects of the video game medium for learning: its expanding audience, its increasing sophistication, and its multimodal nature.

1.1.1.1 Expanding Audience

Video games have enjoyed a dedicated, niche audience since their mainstream inception in the late 70s and 80s. The advent of the video game medium gave rise to a population primed for game-based learning. Prensky (2001) terms this population the “Games Generations” (p. 46). This group comprises those who were born in the sixties and thereafter, who can at best claim competency with and cognitive benefits from engaging in video games and other digital media, and at worst claim early exposure to these now pervasive cultural forms.

But this label and the audience of game-based learning are not inclusive, as Prensky himself admits to in a delicately phrased caveat: “…[Digital Game-Based Learning] is a new and important way for many people to learn—especially, although by no means exclusively, for people from [the Games Generations]

…" (2001, p. 8). Clearly, generations preceding the sixties are not included. Even those who categorically fit this age group may have missed or had only minimal exposure to video games and other digital media. Further, Prensky's description is implicitly Western-centric; those from non-Western or developing nations are not acknowledged, even though these populations' exposure to video games and other media vary because exposure is contingent upon social and economic factors and industrial growth. Also, Prensky does address people with disabilities, despite widespread recognition of this group's inhibited engagement with technology (Pullin, 2009) and endeavours toward inclusive game design, which have only recently introduced disabled children to the cognitive benefits of the video game medium (Pitaru, 2008). Catering video games to the Games Generation becomes less effective as video games move beyond the context of entertainment and their audience begins to expand.

Prensky continues: "But [digital game-based learning] is by no means the only way to learn, for the Games Generations or for anyone else. *There are plenty of things that people are motivated to learn without games, and plenty of people who do not prefer games as a way to learn.* What I am describing is not designed for them…" (p. 8, emphasis retained). Given the explosive elevation of video games since the publication of this text a decade ago, I am compelled to question the fitness of Prensky's assertions about the vague non-Games Generation population he describes in his uncertain and cautious demarcation of the audience of game-based learning. Who comprises this population, and why do they reject the option of learning through games? (And do they really?) Further,

Prensky seems to overlook the long history of non-digital games and play, which reaches back thousands of years, if not predating recorded history (Tylor, 1879). The game medium has been embraced for entertainment, learning, athletic and other purposes before the dawn of digital technologies; clearly, we should determine what it is about digital games that makes them inimical to certain audiences if history suggests that their non-digital forerunners were more widely embraced.

Prensky suggests that designers of games for learning should employ the following strategies if a Games Generations audience cannot be assumed: using a restricted set of game genres thought to be widely appealing (examples include puzzle and strategy games); creating multiple games to cater to multiple audiences; or providing a non-game alternative (2001, p. 153). The limitation of the first strategy should be self-evident, and the other two introduce scope issues. Also, the last strategy dismisses the benefits of the video game medium.

Although they may not comprise the majority, there is an important sector of novice players who, as potential users of video games for learning, deserve to have their needs and desires met. Digital game players who have little or no experience with games—including people born before 1960, females, people who are disabled, people from low income families, or people from undeveloped nations—constitute the novice player. Only recently have issues like teaching novices and increasing the accessibility of games begun to receive attention (Charles et al., 2007). Prominent game designer Chris Crawford has issued a call for game designers to not limit themselves to the requirements of the accepted audience, but instead "… cater to the requirements of the larger population" (2003, p.

114). In Crawford's words: "I felt that a healthy industry would have a wider array of games, including games for beginners …" (2003, p. 404). That novice players lack the skills and experience of those who comprise the Games Generations is not an excuse for their exclusion. Further, Prensky's list does not encompass all of the possibilities for embracing diversity in the video game audience of. Novice players—those who are not part of the Games Generation—can be supported during gameplay by augmenting video games with assistive tools.

Following Prensky's work on Digital Game-Based Learning came the games for learning movement. Falling under the title of "serious games," these games covered education, training, awareness, and more (Michael & Chen, 2005). Serious games have received a steady academic focus in the game studies movement of the last decade (Arango, Aziz, Esche, & Chassapis, 2008; Becker, 2010; Susi et al., 2007). However, few studies have looked at how to design games so that they are conducive to learning basic game skills, like navigation in a 3D environment. Further, attention has not been paid to the expanding audience: games must be approachable, usable, and accessible to a more diverse audience, particularly one that includes novice players.

1.1.1.2 Increasing Sophistication

Modern video games have become sophisticated multimodal artefacts, often boasting visually complex environments in tandem with cognitively demanding tasks (Van Eck, 2010). Economic and technical factors brought about the establishment of the video game market, which in turn occasioned a continuing trend of technical advances in computer hardware, visuals, and inter-

faces, in particular control devices. Each generation of video game systems unleashed a wave of advances in these areas. Consequently, managing cognitive load in working memory while maintaining engagement is of primary concern. This is particularly true for novice players, for whom learning to play games is made more difficult by the combination of sensory information, cognitive demands, and command of the interface.

The user interface is the intermediary between the player and the game environment. It is generally comprised of a visual display and a physical input mechanism for control, although novel game interfaces like Microsoft's *Kinect* (2010) are obviating the need for a physical controller. A well-designed user interface supports the player's interactions with the game world and their performance in game tasks. Two challenges arise from this: (1) for the player, the mastery of the interface, and (2) for the designer, an effective interface design.

Video game designers, groups and companies separately determine how physical controls link to in-game actions: there is no standard model of control. Often a learning curve is imposed even on those players who are familiar with a given interface. "Player control … often requires players to use game console controllers or personal computer input devices (keyboard and mouse) without consideration of how players might need time to get acquainted with the interface" (Huang & Tettegah, 2010, p. 144). Becoming comfortable with the controls, let alone mastering them, takes time. To optimize user experience, designers should work towards lessening the impact of the learning curve imposed by the control device.

Appropriate user interface design is highly contextual, but advancements and trends in gaming technology and interface design can facilitate the ideation process, if not yield novel design opportunities. Modern game interfaces, particularly those that incorporate some form of haptic interaction, are “blurring the boundaries between user and interface” (Taylor, 2007, p. 226). The notion of the cyborg player, whose bodily experience with the game is both physical and mental, proposes new ways of immersion and practice (Taylor, 2007). The haptic qualities of gameplay experience make possible a germane method of dealing with cognitive load in a visually and audibly sophisticated game environment.

1.1.1.3 Multimodal Nature

The multimodal nature of video games gives rise to design issues that become pertinent as the medium’s sophistication increases. In particular, the escalation in the intensity and amount of cognitive demands placed on the player calls for attention to be paid to how the player’s cognition as a whole is affected (Van Eck, 2010). In our previous work, my supervisors and I explored the demands that different modalities placed on one aspect of cognition: working memory (Seaborn, Riecke, & Antle, 2010). In particular, we explored whether or not an attentional bottleneck occurred when visual and haptic modalities were paired. Our findings suggested that while haptic modalities may be less viable on their own, their saliency was increased by the addition of a visual modality. However, our research was conducted in a highly controlled, unnatural context and our main task—a pattern-matching task—reduced the generality of our findings. This motivated me to continue research with haptic presentation modes in a more real

world multimodal setting: a gaming environment. This thesis research makes a case for more attention to be paid on player's cognition while building upon my and my supervisor's previous work on attentional bottlenecks and multi-modal information presentation.

1.1.2 Mitigating Learning Curves

The learning curves novice players encounter in sophisticated multimodal game environments can decrease the game's accessibility for these players (Becker, 2010). Learning curves can force novice players to expend effort on navigation, which in turn distracts them from gameplay tasks (Virvou & Katsionis, 2008). Attention needs to be paid to the problem of engaging novice players early without negatively contributing to cognitive load or detracting from game-play goals.

Video games have used a variety of techniques to aid the novice player in overcoming learning curves related to navigation and game tasks. Video games have traditionally employed a number of methods to facilitate learning new tasks. One is self-driven experimentation: the player is expected to learn through trial and error, where the assumption is that games "… are almost all designed to teach you as you go" (Prensky, 2001, p. 59). Another is extra-game instruction, for example a manual (Prensky, 2001) or walkthrough (Johnson, 2008). There is also in-game instruction, such as through an on-screen tutorial, which can be presented in various ways (Moshirnia, 2007). A well-known and universally detested approach is the "help wizard," an on-screen avatar that appears at (in)opportune moments to provide assistance (Crawford, 2003, p. 162). Another

approach is the use of visual cues that are incorporated into the game environment (Charles et al., 2007). Many of these methods have been prevalent in video games since their inception.

However, all of these methods disrupt flow and reduce the accessibility of games for novice players. Novice players can become frustrated and disengaged if required to learn purely experientially and without guidance. Being forced to refer to an external source for instruction may render the experiential learning ineffective (Gee, 2007b). Further, without an embodied, situated understanding of the game environment, making sense of extra-game materials is difficult (Gee, 2007a, p. 98). Facilitating learning through an in-game tutorial can maintain the experiential aspect of learning, but this is dependent on how the tutorial is presented: how the player is expected to respond and interact with the tutorial. Visual cues may be appropriate in visually unsophisticated game environments, but visual overload becomes an issue in more sophisticated environments. Ideally, games should engage novice players quickly and keep them engaged to support early, successful play, and so allow for a greater focus on more important gameplay tasks, such as achieving educational goals in a learning game.

Devising approaches to better support the needs and desires of individual players and types of players, particularly novices, is a nascent area of research in game studies. Charles et al. (2007) propose a player-centred approach they call adaptive game design. Games that are adaptive observe and tailor aspects of gameplay, such as difficulty, to the capabilities of the player. One drawback of this approach is that the underlying system cannot pre-emptively tailor itself to

the player, leaving open the possibility of a negative first experience for the player, who may lose interest and disengage before the game adapts.

Domains outside of gaming have explored ways to help novices gain expertise. In particular, the notion that novices can benefit from the experienced guidance of experts has been put forth. Bromme et al. developed an interactive learning environment for plant identification that scaffolded learning via expert guidance and help and feedback systems (Bromme, Stahl, Bartholomé, & Pieschl, 2004). They conclude, "… support of novices by means of expert guidance is an essential part of the development of expertise" (p. 46). Their success begs the question: Can the knowledge of expert gamers be harnessed to help novice players overcome challenges in gaming environments?

Drawing from the above, I propose a form of guidance to help novice players overcome one area that presents them with difficulty: navigation in 3D game environments. Guidance needs to be distinguished from other conceptual understandings of the term. Here, guidance refers to cognitive guidance: the goal of the guidance is to help the novice player learn how to navigate, e.g. when to turn, what constitutes an obstacle and how to avoid it, what movement is required after certain events, etc. In this way, the novice player is taught about navigation within the context of a particular game environment; they develop a schema for navigating within this domain of practice. In contrast, the guidance does not train the novice player, e.g. to improve their motor abilities, and the guidance is not single use, e.g. a one-off necessary to overcome some barrier. Instead, the guidance helps the novice player learn how to navigate over time while allowing them

to focus on other gameplay tasks. At some point, the guidance will become unnecessary: once the novice player has internalized how to navigate the game environment, they will no longer need guidance. Indeed, because the guidance allows them to focus on other gameplay tasks, the novice player may be positioned to move on to an intermediate level of gameplay upon successfully learning how to navigate the game environment.

1.1.3 Novice Players and Navigation

Guiding novice players through navigation tasks in a gaming environment is a new area of focus, and one that calls for attention. Virvou & Katsionis (2008) showed that novice players encounter a learning curve when engaging with virtual environments. In particular, novice players expend time and effort toward learning how to navigate 3D virtual environments, and are thus distracted from game tasks. Renowned game designer Chris Crawford has pointed out that games often require spatial reasoning skills (2003, p. 48). Even when spatial reasoning is obviated by the eventual automation of actions, spatial challenges afforded by fast-paced 3D game environments require players to employ spatial reasoning and readapt. As Crawford notes, “To master a fast-paced action game, you’ve got to practice, practice, practice” (Crawford, 2003, p. 85). But while gamers might be used to this practice paradigm, novice players may be dissuaded by it, especially if they lack the basic spatial reasoning skills needed for navigating 3D virtual environments. In this research, I sought to address this problem in the context of a 3D game environment using a novel approach to guidance: feedforward.

1.1.4 Supporting Novice Players with Feedforward

A potentially promising approach for augmenting the learning process is feedforward. Feedforward involves guiding future action in order to respond pre-emptively to conditions that would negatively affect the player's experience. In contrast to feedback, feedforward provides information about the result of an action before the user performs it.

Feedforward has not been adequately explored. The success of feedback in the design of systems (see 2.2) and prior technological limitations shifted early focus on feedforward to feedback; only recently has feedforward regained attention (Richard Heywood Swan, 2008). Complicating matters is a lack of a standard term to refer to the notion of feedforward. Forsyth and MacLean (2006) developed a "Look-Ahead" algorithm, which facilitates force cues via a steering knob (see 2.3); they used the term "predictive haptic guidance" to refer to the use of feedforward as a method of guidance in dynamic tasks. Their description is synonymous with that of haptic feedforward.

The results of Forsyth and MacLean's study support the use of haptic feedforward guidance. Their findings showed increased performance with and preference for the use of predictive haptic cues in tasks that involved differing path complexity and visibility. However, the value of predictive haptic cues for helping novice players in navigation tasks has yet to be determined in the context of a fast-paced, multimodal video game.

Interaction designers have proposed feedforward as a solution to the usability issue of action versus task. As Djajadiningrat et al. argue: "Clearly, the

user is interested in information that will enable him to complete his task: the action is not the goal of the user; fulfilling his task is" (2004, p. 295). To this end, designers have employed the "Interaction Frogger Framework" (Wensveen, Djajadiningrat & Overbeeke, 2004), which describes a model of feedback and feedforward, during the design and evaluation of their systems. But while their evaluations garnered promising results, they did not explicitly evaluate the effectiveness of feedforward, either because of a focus on the design as a whole (Dix, Ghazali, & Ramduny-Ellis, 2008) or unusable data due to the early state of the prototype (Kwak, Niezen, van der Vlist, Hu, & Feijs, 2011). Exploring the potential of feedforward is an area ripe for research.

Recent research has shown that feedforward affects player agency by anticipating and responding to player behaviours and expectations (Richard H. Swan, 2010). However, this form of feedforward is distinguished by being situated in the design of gameplay tasks; what merit feedforward has as an element of interface design is unknown. As a facet of interaction, feedforward could be a subtle yet salient way of guiding user actions while maintaining engagement and without disrupting flow. In this thesis, I explore the potential of feedforward as an effective means of improving the learning process for novice players involved in navigation tasks.

1.2 State of Problem

The video game medium continues to move beyond the entertainment sphere in parallel with a trend towards its increasing sophistication. The novice

has emerged as a category of player whose needs have not yet been adequately met. Previous research suggests that novice players are challenged by navigation learning curves, which distract them from primary gameplay tasks. A potentially promising approach to supporting this user base by attenuating navigation learning curves is haptic feedforward. Modern game environments focus on visual and auditory stimulation and in general neglect the haptic modality. Given this, haptic feedforward appears to be well suited because it distributes cognitive load to a third modality. However, this needs to be explored empirically.

1.3 Contributions

The contributions of this research are threefold:

1. **Knowledge**: Findings from an exploration of how augmenting navigation in a fast-paced, multimodal game environment with haptic feedforward affects the performance and user experience of novice players, and the viability of this approach.
2. **Demonstration:** An exhibition of a proof-of-concept approach through a prototype—the Gauntlet Guide—that seeks to increase the user experience potential of haptics in gaming through a new context of use.
3. **Guidelines:** A proposal of an initial set of design guidelines for feedforward guidance in games as a learning aid and a method of increasing accessibility for novice players.

1.4 Research Question

In light of the video game's increasing sophistication and focus on visual and auditory stimulation, haptic feedforward guidance appears to be a viable method of making games more accessible to novice players learning how to navigate multimodal environments. I ask:

> **Is haptically augmented feedforward an effective style of guidance for novice players learning how to navigate a fast-paced, multimodal game environment?**

2: BACKGROUND

2.1 Navigation in Virtual Game Environments

Novice players encounter a learning curve when engaging with virtual environments (Virvou & Katsionis, 2008). Virvou and Katsionis evaluated usability and likeability in a virtual reality game environment for novice, intermediate, and expert gamers. They specified three characteristics of gameplay experience that novice and intermediate players had difficulty with: (a) acquaintance with the user interface; (b) navigational effort; and (c) environment distractions. In particular, they found that novice players expended a significant amount of time and effort on learning how to navigate the virtual environment. Subsequently, these players were prevented from engaging with gameplay goals.

For acquaintance with the user interface, novice players wasted approximately 22.86 minutes compared to the 8.63 minutes of intermediate players and the 3.69 minutes of advanced players. For navigational effort, novice players wasted approximately 8.82 minutes compared to the 3.05 minutes of intermediate players and the 1.34 minutes of advanced players. For environment distractions, novice players wasted approximately 2.9 minutes compared to the 5.2 minutes of intermediate players and the 4.2 minutes of advanced players. In total, novice players wasted 34.58 minutes compared to the 16.88 minutes of intermediate players and the 9.63 minutes of expert players. In a post-play interview, only 6.7% of novice players indicated that the game was easier than non-

game educational applications. However, 59% of novice players preferred the game. The results of a *t*-test showed that there was a difference between the time novice players spent playing the game versus the non-game educational application, $t = 1.99$, favouring the game. Further, 93.3% of novice players found the game more motivating than the non-game educational application, and 95% of novice players found the game more interesting than the non-game educational application.

The authors suggest providing more maps or adaptive help, which would involve the system observing user actions in trouble areas and responding with personalized assistance. In this thesis, I suggest another option: haptic feedforward guidance, through the use of vibrotactile cues to guide player action.

2.2 Haptic Feedback for Guidance and Training

The term "haptic" refers to two styles of touch-based information presentation: tactile and force (K.E. MacLean & Hayward, 2008). The following review of the literature makes reference to both styles of haptics. However, these styles, tactile and force, must not be conflated. Tactile sensation is felt directly on the skin, usually as texture or patterns, e.g. Braille text (Hayward & Maclean, 2007), and the vibrotactile sensations of the main prototype in this research. Force sensation is comprised of pull or resistance, e.g. computer mice that pull the user's hand in a certain direction. Tactile and force are fundamentally different in terms of the kinds of information they can provide, what areas of the human body they are best suited to, the level of agency they afford the user, and what technology is used to instantiate them. While I cover both styles of haptic information

presentation with respect to guidance and training in the following discussion, it is important to note that the main prototype in this research uses the tactile style.

2.2.1 Haptic Feedback for Guidance

Using haptic feedback to guide user action has received substantial attention. Dennerlein et al. (2000) discovered that adding force feedback to a mouse improved performance in steering and targeting tasks. They used a prototype force-feedback mouse called the *FEELIt* Mouse by Immersion Corporation. The mouse uses three-ounce (0.84 N) maximum force to move the mouse along any x-y vector parallel to the surface; the mouse can then be attracted to important UI elements like buttons, if it enters the element's force zone radius. Force feedback could be contextually provided because the position of the mouse was tracked both in the physical and virtual environment. For the steering task and movement directions condition, a paired Student *t*-test for movement times across difficulty showed significance for all cases (p = 0.000 to 0.015) except the smallest index of difficulty for horizontal movement (p = 0.067). For the combined steering and targeting task, a paired Student *t*-test showed that movement times significantly improved from 15-35% ($p < 0.023$). They concluded that the addition of force feedback to a mouse was beneficial for steering and targeting tasks.

Dennerlein and Yang (2001) evaluated user performance in a haptically augmented point-and-click task in a GUI interface using the *FEELIt* Mouse. For the single attractive force field targeting task, a *t*-test showed that participants performed 23% faster with the field than without it ($t < 0.0001$). For the same task but with smaller targets, a *t*-test showed that participants performed 28% faster

with the field than without it ($t < 0.0001$). The addition of distraction fields did not affect movement times. The findings indicated that users targeted more quickly and comfortably when haptic cues were present. These findings are, however, restricted to 2D mouse-driven interfaces. Whether or not they are applicable to navigation tasks in a 3D gaming environment that do not involve point-and-click targeting needs to be explored.

2.2.2 Haptic Feedback for Training

Recent studies have looked at the value of haptic cues for training. Feygin et al. (2002) used the *Phantom* by Sensable Technologies to evaluate the effectiveness of haptic guidance in the training and recall of a motor task in a 3D environment. Participants were physically guided along 3D paths by a force-based algorithm. For time, a repeated measures ANOVA showed a significant main effect of training mode ($p < 0.005$) that favoured the haptic+visual condition. They found that haptic guidance was more effective compared to visual guidance for timing. They suggest that haptic guidance is well suited to guiding motion and the learning of perceptual motor skills in virtual environments. This finding supports the exploration of haptic feedforward guidance as a promising approach in my research, especially because timing is crucial in a fast-paced game environment. I also wanted to address a problematic aspect of their experimental design: learning over trials was not accounted for. A paired *t*-test showed a significant performance increase over trials ($p < 0.001$), even with the inclusion of a training period. In this research, I counterbalanced conditions and provided participants with training for both the device and game.

Crespo and Reinkensmeyer (2008) found that haptic guidance improved short-term learning of a motor task with both persistent and progressive guidance cues. They developed a 3D graphical representation of a 120 m long track and used the Logitech *MOMO* force-feedback steering wheel, which provides 2 nm of torque and a 270-degree rotation. The system provided two types of guidance: "guidance-as-needed" (scaffolded guidance) and "fixed guidance" (ever-present guidance). An ANOVA showed that both forms of guidance reduced the tracking error on the first trial, and improved the unassisted steering performance following training ($p < 0.001$). An ANOVA comparing Trial 21 (out of 30 trials) for the guidance conditions showed that guidance-as-needed was more effective for short-term learning ($p = 0.04$); however, this effect levelled out at Trial 30. A *t*-test showed that participants performed more accurately with guidance ($p = 0.04$). The findings suggest that guidance is effective, and that guidance-as-needed (scaffolded guidance) is effective for early performance.

Huegel and O'Malley (2009) sought to explore the effectiveness of progressive guidance as a way of maintaining the short-term learning benefits found in other studies while preventing user reliance on guidance. They used a 2-DoF force feedback joystick called the *Immersion IE2000*. The main task involved targeting as many targets as possible in a 20 sec long trial. Their pilot study showed that progressive guidance in both visual and haptic conditions had expected effects: the gains made due to guidance decreased over time, while hit count (indicating success with the main task) increased. It is possible that dependence on continued assistance could transfer to video games, even given that

gaming and training applications are distinct in their requirements for learning. However, I expected that in a gaming context continued assistance would have no detrimental effect because the player is not training for skill acquisition. Instead, the player is being supported in performing a required navigational task. Even so, some novice players may seek agency over their navigation abilities and wish to “remove the training wheels” of haptic feedforward. In this research, I explored the relevancy of this issue in a gaming context by including an interface style that features haptic feedforward.

2.3 Haptic Feedforward for Guidance in Non-Gaming Contexts

Forsyth and MacLean (2006) explored the effectiveness and preference of suggestive, rather than demanding, predictive haptic cues to guide users in dynamic tasks. Their research idea arose from the notion of the attentional and dictatorial problems associated with nonsalient haptic feedback, which they and others had previously encountered. In their literature review, the authors point out that haptic guidance for fast, complex systems has not been adequately explored; they provide an unpublished work in which they found that force-feedback prompted oscillations negatively impacted usability. In their published effort, the authors used a 1-DoF haptic controller (a small steering knob manipulated by one arm/hand) in conjunction with a driving simulator based on the *OpenSteer* simulator. The main dynamic task was involved steering to maintain position inside a complex path. The three guidance conditions were: (a) no guidance, (b) Potential Field Guidance (based on previous work), and their own (c) Look-Ahead Guidance. The two guidance conditions defer with respect to gradations in

presentation of guidance, where the Look-Ahead Guidance algorithm provides more gently introduced force.

A repeated measures ANOVA showed that all main effects were significant (guidance method at $p = 0.014$, path at $p = 0.001$, and visibility at $p = 0.042$), although no interactions were significant. Pairwise comparisons showed a significant difference between Look-Ahead Guidance and Potential Field Guidance ($p = 0.012$) and Look-Ahead Guidance and no guidance ($p = 0.004$). Pairwise comparisons also showed a significant difference for path complexity between low and medium ($p = 0.018$) and low and high ($p = 0.010$). Mean MSE trajectory-following metric scores showed that Look-Ahead Guidance, low path complexity, and high visibility resulted in the lowest average errors for the three conditions. Self-reports showed that the Look-Ahead Guidance maintained participants' agency and was well liked; guidance as a whole was considered helpful; overall, 13/17 participants preferred the Look-Ahead Guidance.

The findings showed increased performance and preference for the use of predictive haptic cues, in particular the Look-Ahead Guidance Their work extended the value of haptic cues for guidance to the context of a driving environment, but did not cover a more complex, real world (e.g. fast-paced, multi-modal) setup. Additionally, a limitation of their work is the size of the haptic knob, meant to remediate a steering wheel; in my thesis work, I use the Wii Wheel, an augmented gaming controller whose look and feel (and size) accurately reflects a typical driving steering wheel, albeit lacking anchorage to a dashboard. The authors also observed that guidance was not conducive to helping users who had left the

main path; they suggest that an intelligent system would observe and respond to new goals, such as recovering from deviating from the path. In this thesis study, the Wizard of Oz setup allowed me to act as an intelligent agent, so I was able to include recovery from error, including deviation from the path, as a guideline for when to provide feedback. Finally, the authors suggest that haptic guidance needs to be compared to visual guidance; I addressed this limitation with the inclusion of a visual guidance condition, against which the haptic feedforward guidance condition was compared.

The authors suggest that consideration needs to be paid to how haptic cues are designed and integrated to avoid introducing additional cognitive load or distracting the user from the primary task. Their findings support the notion that haptic feedforward should be gradually introduced and maintain the user's sense of control. These guidelines seem well suited to a gaming context, where maintained engagement and agency are crucial. However, they need to be explored empirically in the context of a video game that features a fast-paced, multimodal environment and that requires novice players to learn navigation tasks to engage with other elements of gameplay.

2.4 Dual-Modality Feedforward for Navigation

Ho, Tan, & Spence (2005) explored whether or not the use of feedforward vibrotactile cues in a visually demanding navigation task could be used increase users' response rate. Participants engaged in a simulated driving scenario in which they were required to attend to the visual environment via front and rear-view mirrors in order to check for the approach of other vehicles. A belt lined with

vibrotactile actuators was worn by participants; warning signals were triggered whenever the participant was expected to use the front mirror (stomach vibration) or rear-view mirror (back vibration). In the first experiment, 80% of the cues were matched with the mirror, e.g. when the front stomach cue was triggered, the participant needed to use the front mirror. The authors found that participants responded more quickly and accurately when aided by the vibrotactile warning signals if the cue was in the correct direction. In the second experiment, 50% of the cues were in the correct direction, and 50% were not. The authors found that the results from the first experiment held insofar as cues properly coupled with the correct mirror went. Overall, the authors concluded that the spatial arrangement of cues is integral to leading visual attention.

2.5 Wearable Tactile Displays for Navigation

A great deal of research has been conducted around the concept of wearable tactile displays (WTD) for navigation (Matscheko, Ferscha, Riener, & Lehner, 2010). Wearable tactile displays have been designed for wear on a number of different areas of the body. Here, I present two examples of WTDs whose design goals match those of this thesis research.

2.5.1 Waist-Worn Display

Van Erp and colleagues (2005) explored the effectiveness of a vibrotactile belt for waypoint navigation tasks in real world settings Their goal was to show that haptic information presentation would be an effective alternative to visual information presentation in this context.

The prototype consisted of a backpack containing a minicomputer, digital compass, GPS receiver and batteries, and the belt, worn on an elastic waistband over shirt. Eight pager motors were arranged on the belt; each had a contact point of 1.5 by 2 cm and vibrated at 160 Hz. Waypoint in-formation was presented through 1 sec playback of the actuator closest to the correct direction, with a pause between pulses that was either the same in length as the distance away from the waypoint target (absolute) or a percentage of the distance (relative). Each actuator covered a 45-degree cone.

In the first experiment, absolute and relative presentation of distance information was compared. The results showed the participants were able to find the waypoint within 30 minutes at normal speeds (4.2-4.4 km/h). There was no significant difference between the absolute and relative conditions.

In the second experiment, the prototype was tested in a realistic environment; based on the results of the first experiment, the researchers decided not to code for distance. To indicate that the waypoint was reached, all actuators would be triggered at once. An extension of the cone was introduced: the vibrations would gain intensity when the user was within a 20-degree cone. Two participants were recruited: experienced pilots of a helicopter and a boat. Their paths were recorded and reviewed for accuracy. The results showed that despite the noisy environments (both vehicles produced their own vibrations) the pilots were able to successfully navigate to waypoints with the aid of the belt.

The success of this approach supports the continued exploration of wearable (vibro)tactile displays for navigation, especially in light of the non-trivial per-

formance in a real-world, noisy environment. In this thesis work, I sought to extend these findings in two ways: a display worn on another part of the body—the forearm—and a navigation task encumbered by essential gameplay tasks.

2.5.2 Wearable Tactile Display

Only recently has the use of vibrotactile stimuli for presenting discreet secondary information gained attention. Lee and Starner (2010) developed a WTD that presented two-dimensional navigation information via directional vibration cues. Their design featured a triangular array of 3 vibrotactile actuators placed on the volar side of the wrist; the triangular positioning of the actuators allowed for a rich selection of patterns. In a pilot test, they validated the intensity at 0.71g (175Hz) for strong patterns and 0.43g (133Hz) for weak patterns.

The main study involved two experiments. In the first, they sought to determine how well participants were able to perceive patterns. Accuracy was 94.44% for the practice session and 99.32% for the main session. Reaction time was 8.82 sec for the practice session and 7.13 sec for the main session. Overall, they found that participants achieved up to 99.32% accuracy and a reaction time of 6.05 sec when identifying 24 tactile patterns.

In the second experiment, they sought to determine the effectiveness of their WTD compared to a cell phone in visually distracting conditions with a primary and secondary task. A paired *t*-test showed that visual distraction affected perception with respect to reaction time ($p = 0.002$) but not accuracy for the secondary task. No statistically significant effects were found with respect to reaction

time and accuracy for the primary task. They conclude that WTDs are more suitable for dual-task conditions than cell phones.

Overall, Lee and Starner found that users needed to undergo 40 minutes of training to perform at 99% accuracy. Their design, while rich with regard to information presentation, presents issues for the problem under question in this research because the goal is to support early and consistent gameplay for novice users. To address this issue, I designed a simpler wearable tactile display with the expectation that learning a simpler display would take less time and therefore not present a hurdle for early novice gameplay. Further, one of the limitations of their study was the lack of diversity in types of distractions. They suggest a more realistic setting in which to evaluate WTDs; I take them up on this suggestion in this research, which involves a sophisticated, fast-paced, multimodal 3D gaming environment.

2.6 Learning to Play Games

Recent research has focused on understanding which properties of games positively influence learning. Kiili (2005) proposed a model for designing and analyzing games for use as experiential learning tools. The model integrates aspects of experiential learning theory, flow theory and game design. It was structured around the metaphor of the human blood vascular system, such that motivation and engagement are “pumped” from three main “ventricles”: the challenge bank, ideation loop, and experience loop. The challenge bank issues challenges to the player to overcome. The ideation loop involves active experimentation, reflective observation, and schemata construction. The ideas brain-

stormed in the ideation loop are tested out experientially in the experience loop. As the skill of the player increases, it is registered by the challenge bank, which issues greater challenges in order to maintain the flow state. Ancillary to the model is a suggestion for the use of haptic feedback to optimize cognitive load. The author bases this conclusion on Mayer's (2001) modality principle, which states that working memory capacity may be increased by the use of simultaneous multiple modality processing. This notion motivated the choice of a haptically augmented display in my research.

Gee (2007c) derived a list of 25 learning principles from the game *Rise of Nations.* He proposes this list as both a reason for why games are motivating, and a tool that can be used to increase motivation in students. Transcribing his list is beyond the scope if this review; however, I will draw out principles that were applicable to the design of the Gauntlet Guide, the central research instrument in this thesis work. Principle 5 states: “Let learners themselves assess their previous knowledge and learning styles and make decisions for themselves (with help).” This principle implies that choice is crucial, and that players should be able to acknowledge or ignore help at will; the haptic cues provided at the Gauntlet Guide are expected to do just this. Principle 8 states: “‘Basic skills’ means what you need to learn in order to take more control over your own learning and learn by playing.” This principle is central to my thesis: the basic skills required of the gaming environment are navigational, and so the Gauntlet Guide was designed to support these basic skills for optimal learning of less basic gameplay skills. Principles 12 and 13 discuss the offering of “supervised (e.g. guided)” tutorials;

the Gauntlet Guide collapses the distinction of real game-play and tutorial by offering help *during* gameplay for early play. Principle 14 states: “Give information via several different modes (e.g. print, orally visually). Create redundancy.” This principle, like Mayer’s multimedia and modality principles, restricts itself to visual and auditory modalities; in this thesis I explore the potential of the haptic modality as a presentation mode. Principle 15 states: “Give information ‘just in time’ and ‘on demand.’” This principle places import on timely presentation of information, or haptic feedforward guidance cues in this thesis work. Finally, Principle 19 states: “Ensure that there is a smooth transition be-tween tutorials and actually playing.” Like Principles 12 and 13, this “smooth transition” is obviated by the real-time guidance. I empirically evaluated these principles in the design of the Gauntlet Guide.

Wilson et al. (2009) analyzed the literature on the characteristics of games that impact learning. The greater portion of their review focuses on studies by Garris and Ahlers in 2001 and 2002, who found that 12 out of 39 game descriptors were statistically significant, and later distilled these twelve into the following key features of games for learning: (a) fantasy, (b) rules/goals, (c) sensory stimuli, (d) challenge, (e) mystery, and (f) control. Wilson et al. used this final set as a starting point for their list of key characteristics, which are: (a) fantasy, (b) representation, (c) sensory stimuli, (d) challenge, (e) mystery, (f) assessment, and (g) control. Of these, the characteristics of sensory stimuli and assessment are most salient in this thesis work. Sensory stimulation increases the effect of fantasy believability as well as provides viable channels for feedback on performance.

Assessment is used to teach the player how to play the game by pointing out what aspects of gameplay are important, as well as providing evaluations and guidance. These two characteristics are found in the design of the haptic feed-forward guidance display I designed. The evaluation of this display will add empirical evidence to validate the importance of these characteristics for teaching players, particularly novices, how to play games. As the use of games for learning gains precedence, designers would do well to ensure that games are accessible to an expanding audience.

3: SYSTEMS DESIGN

3.1 Overview of Design Goals and Requirements

My goal was to design a haptic display that presents vibrotactile feedforward guidance information in order to explore whether the user experience of novice players can be improved by providing guidance during a navigation task in a fast-paced, multimodal gaming environment.

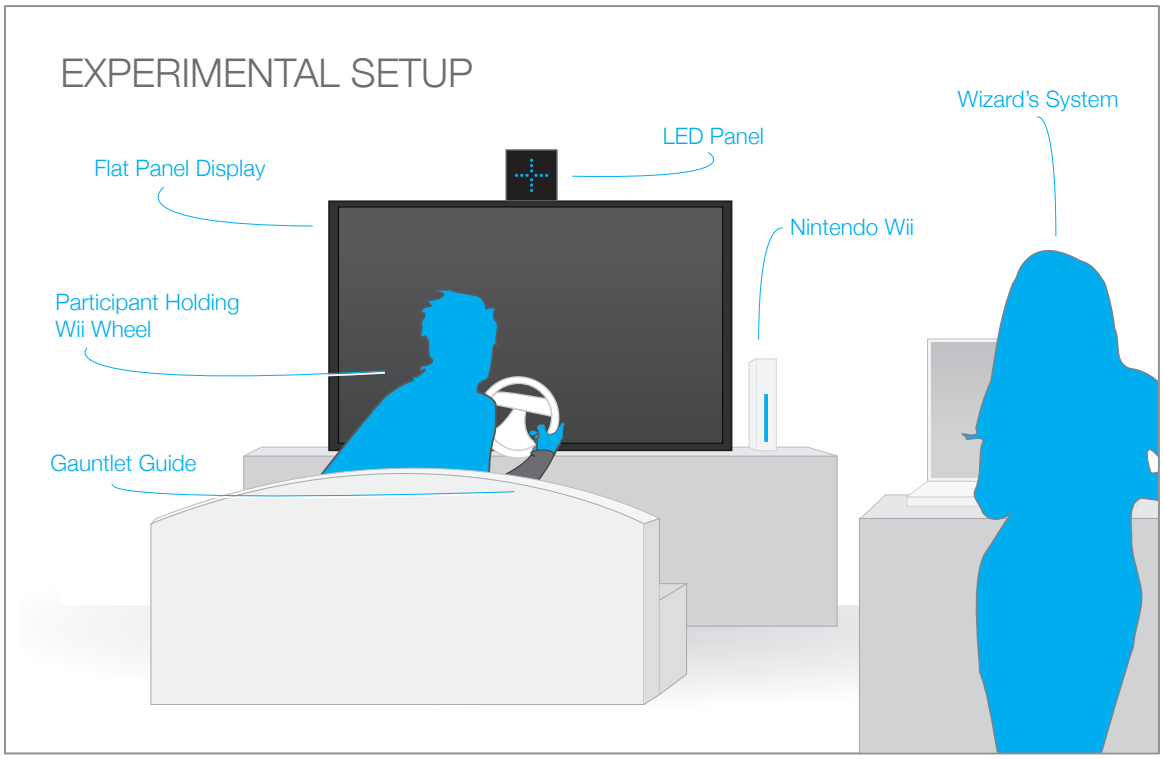

Figure 1 An overview of the experimental setup, which has a home entertainment feel.

The system (Figure 1) is comprised of seven components: a wearable tactile display (WTD); a LED display; a fast-paced, multimodal, 3D racing game;

a video game console system; a flat-screen display; a laptop; and the Wizard's control system.

I designed the system to investigate three feedforward configurations: (1) no feedforward, (2) visual feedforward, and (3) haptic feedforward. By comparing these configurations, I was able to explore what effect vibrotactile feedforward has on performance, navigation, ease of use, engagement, and enjoyment in a fast-paced, multimodal game environment. In particular, I was able to illuminate two important aspects of my argument for the use of haptic feedforward in this context: (1) the benefit of feedforward guidance, and (2) the effectiveness of visual versus haptic presentation modes.

The comparison of visual and haptic presentation modes draws directly from my previous work. My first foray into comparing presentation modes involved juxtaposing light and heat information in a simple "hot and cold" game (Seaborn & Antle, 2010); this work was discontinued due to insurmountable technological difficulties combined with a lack of electrical engineering experience on my part. More recently, my co-authors and I explored the interplay of visual and haptic modalities in a pattern-matching task that involved deliberately encumbering working memory in order to evaluate the effectiveness of different modalities (Seaborn et al., 2010). The findings from this study suggested that people prefer and perform best with visual and dual-coded visual and haptic presentation modes as opposed to the haptic mode alone. One of the limitations of this study was its specialized task and context; the findings could not be generalized beyond the lab, and consequently any design principles remained untenable. I

conducted this thesis work in part to remedy the limitations of this previous study. As a direct continuation of this research, my goal was to confront this limitation by evaluating visual and haptic presentation modes in a more complex and practical context, namely that of a fast-paced, multimodal game environment. Further, I wished to explore how task- and context-dependent the results were, which required a new study featuring a new context and task: this thesis work.

3.2 Wearable Tactile Display: The "Gauntlet Guide"

I constructed a vibrotactile forearm display that provides feedforward navigation information for guidance through vibrotactile cues activated against the skin (Figure 2). In light of the nature of its use and wear, and in homage to the traditions and history of the video game medium and Nintendo in particular (Sturman & Zeltzer, 1994), I nicknamed the display the "Gauntlet Guide". The display is coupled with a Nintendo Wiimote embedded in a Nintendo Wii Wheel, the standard control devices for the Nintendo Wii gaming console (see Game Console) and the Mario Kart Wii video game (see 3.4). The Wii Wheel is used to direct the in-game avatar through navigation tasks in the game.

3.2.1 Hardware

Coin type pager motors actuate the vibrotactile stimuli that constitute the feedforward guidance information. Twelve coin type vibrotactile actuators were used. The contact point is roughly 0.4 cm (this approximation is due to the perpendicular orientation of the actuators and their curved sides). The distance between actuators along each cardinal direction is 0.7 cm. The centre-to-centre

distance is 0.9 cm. The actuators are spatially situated in the four cardinal directions on the underside of the forearm (along the pinkie finger side). The actuators are arranged such that they can provide directional, not localized, information. When a direction is played, each actuator along that line is played for 300 ms, with a pause of 150 ms between each. A human operator controls the motors through a computer program (see The Wizard's Control System). Commands are sent to a Bluetooth-enabled Arduino circuit board on the wearable display.

3.2.2 Inspiration

The concept of a guidance display for novice players was drawn from two existing cases. The first is a tool familiar to many of us: bicycle training wheels. Training wheels are used to support novice cyclists in maintaining balance on a bicycle. They provide scaffolded support because the training wheels are not level with the bicycle wheels, affording their use only when the novice cyclist tips to either side. From this I adopted the idea of contextual, scaffolded guidance in the form of an omnipresent guide that administers aid only when needed.

The second case is experiential: an objective, experienced player supporting a novice in overcoming video game learning curves by spotting points of challenge and offering *ad hoc* guidance. This scenario was observed during an ethnographic study on game-life integration (Stevens, Satwicz, & McCarthy, 2008). My supervisor's and my experiences with friends, siblings and children gave us an intrinsic source from which to draw inspiration.

3.2.3 Design Requirements

The wearable display satisfies two design requirements: (1) the spatial coupling of feedforward guidance information and the control device, with which

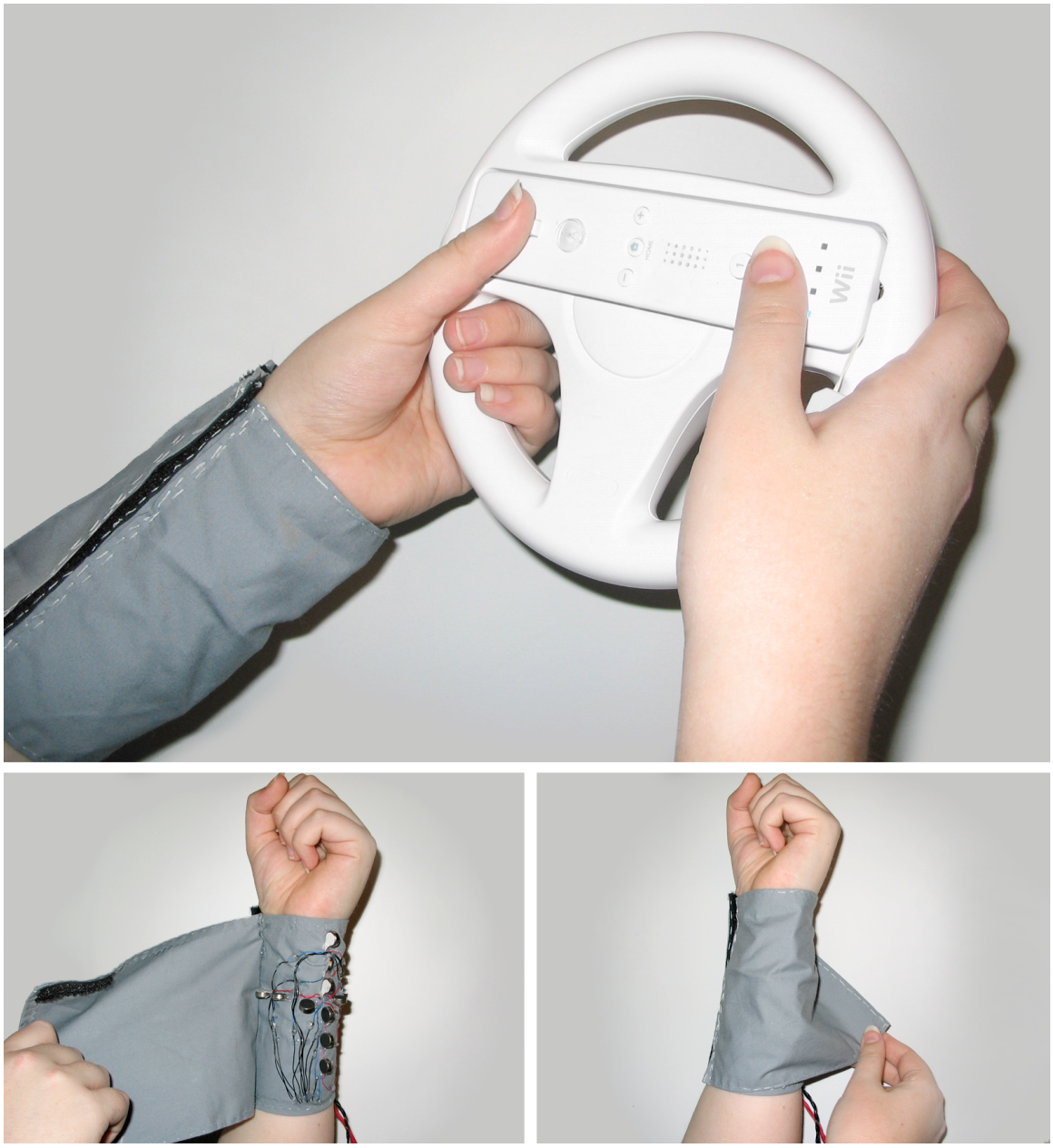

Figure 2 The "Gauntlet Guide" wearable tactile display provides guidance through vibro-tactile cues. The bottom photos illustrate how the actuators are covered. The actuators are aligned along the underside of the forearm.

players direct the in-game avatar, and (2) an appropriate presentation of feedforward guidance information for the game environment, which is multimodal and in particular visually arresting.

3.2.3.1 Purpose and Use of Haptic Cues for Navigation Guidance

Guidance cues are provided to direct the novice player through navigation tasks, which are essential to gameplay success. Guidance cues help the novice player learn when and how they should move their avatar; in effect, the guidance cues shape the players' schema of navigation in the context of the fast-paced racing game environment. Further, the guidance cues allow the novice player to concentrate on other gameplay tasks by offloading navigation and relying on haptic cues for accurate directions in the game environment. The cues are arranged in the cardinal directions, remediating the design of a compass: north (forward), south (backward), east (right) and west (left). In this way, the haptic cues provide directional guidance to the novice player on a horizontal plane; the novice player uses these cues to control their in-game avatar via the game controller. One direction is triggered at a time; the vibration sensation appears to move in the direction that the novice player is expected to go, e.g. if the "right" direction is triggered, the novice player is expected to turn to the right. Although the novice player is afforded the opportunity to concentrate on other gameplay tasks, they are required to enact the navigation movements indicated by the directional cues. Over time, the consistent, reinforced guidance cues are expected to automate the player's ability to navigate.

3.2.3.2 Placement of Haptic Cues for Navigation Guidance

Players receive haptic feedforward cues through the wearable tactile display and control their game avatar using the hand-held Wii Wheel. In this way, navigation guidance is spatially coupled with the means for directional control. This is important because as the novice player learns how to use the interface, they are in the process of crafting a mental model of how the interface works (Norman, 1988). The intended conceptual model is that the vibrotactile sensation the wearable display provides constitutes the navigation guidance information; as such, the haptic cues are best mapped to the directional control device. Spatially coupling this information with the control device affords the user shaping a mental model that is closely related to the intended conceptual model.

The design of the Gauntlet Guide also embodies the spatial contiguity principle, one of Mayer's multimedia principles for learning (Mayer, 2001). This principle states that related elements should be grouped spatially for optimal learning. It must be noted that Mayer's principles were established with traditional multimedia modalities in mind: images, animations, sound and text. Navigation information could be presented visually within the game environment, perhaps spatially coupled with the avatar under the player's control. However, game environments have become and continue to be increasingly visually sophisticated, which places demands on the visual modality. In the face of visual overload, I advocate a non-visual alternative: vibrotactile information processed by the haptic modality and coupled with the control device. Further, I explore the applicability of this principle for designing haptic displays.

Additionally, and unlike with other methods of instruction, the player is provided with the information necessary for learning while remaining immersed in the game world, which is the context of practice (Gee, 2007a, p. 114). Displaying directional cues means overlaying the game's existing multimodal presentation, which could distract the player, disrupt flow, and impede the experience of immersion. In this way, the visually and audibly intensive, multimodal aspect of modern game environments lends itself to the use of an underused modality—the haptic modality—for feedforward. I designed the Gauntlet Guide as a haptic feedforward display to determine the viability of this method.

The Gauntlet Guide was designed to be worn on the left forearm, and was therefore handed. Although it has the potential to be worm on either arm, the wires and battery case, which are arranged on one side, would likely cause discomfort if the Gauntlet Guide was worn on the right forearm. Future, streamlined versions of the Gauntlet Guide would not be handed. In the context of the gameplay and game controller, which requires the use of both hands at the same time, hand dominance was not expected to play a role.

3.2.3.3 Vibrotactile Pattern Design

At the heart of this research is feedforward guidance. As such, I paid special attention to how I could represent guidance information using vibrotactile stimuli; these stimuli comprise the patterns of directional information presented to the novice player. I considered two main attributes of these patterns: spatial configuration (Figure 3) and animation style (Figure 4). For each of these attributes, I

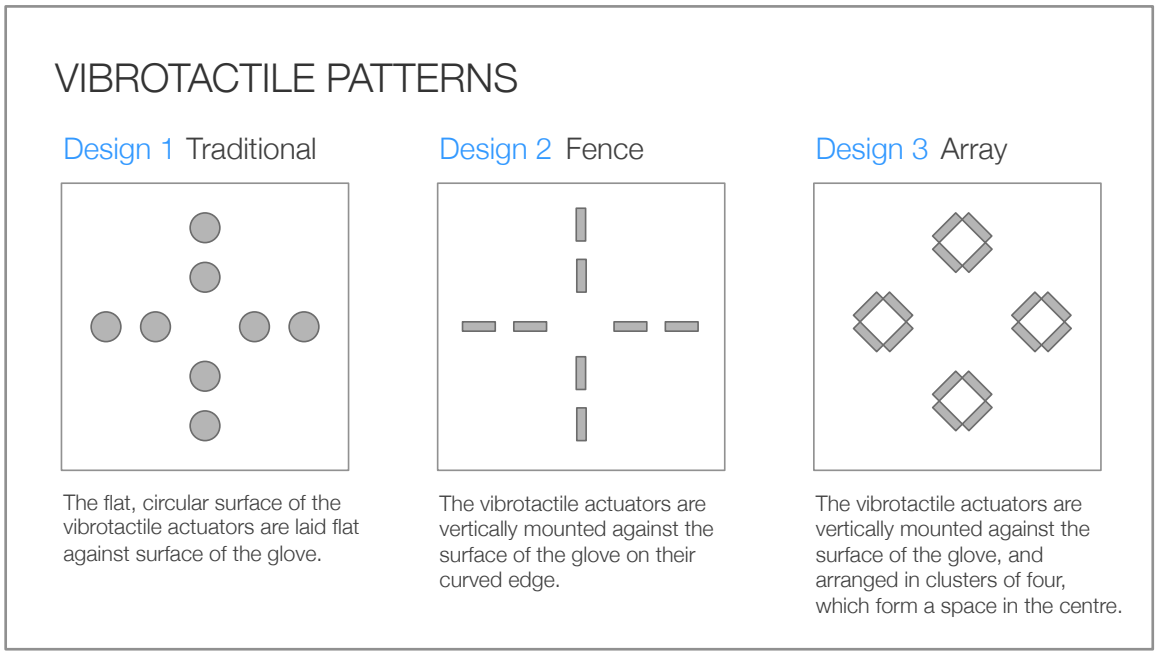

Figure 3 Three designs for presenting vibrotactile stimuli as directional information.

ideated three design possibilities. Due to scope, I implemented one of the spatial designs without testing; I argue for my choice below. In a preliminary design evaluation (3.2.4), I assessed the three animation styles and chose the option participants performed best with and preferred.

Spatial configuration is how the vibrotactile actuators are oriented and spatially arranged on the surface of the gauntlet. Traditionally, coin type actuators are laid flat, as afforded by their shape. But having multiple actuators proximally located on a small surface area yields discrimination problems and leads to adaptation. To avoid these issues, I ideated three pattern designs: (1) traditional, (2) fence, and (3) array (Figure 3). I implemented Design 2 for a number of reasons. First, I wished to evaluate an approach that has not yet been explored; to my knowledge, this is the case for Designs 2 and 3. Further, I be-

lieved this mounting option, which has the smallest surface area coverage, could counter the haptic discrimination problems inherent in haptic designs that make use of only a small area of skin real estate. Finally, technological and ergonomic constraints limited my choice to Design 2 because it does not require an extension to the Arduino board powering the device. This is important because the user carries the board on an upper armband, and any adaded weight could negatively affect their performance and experience.

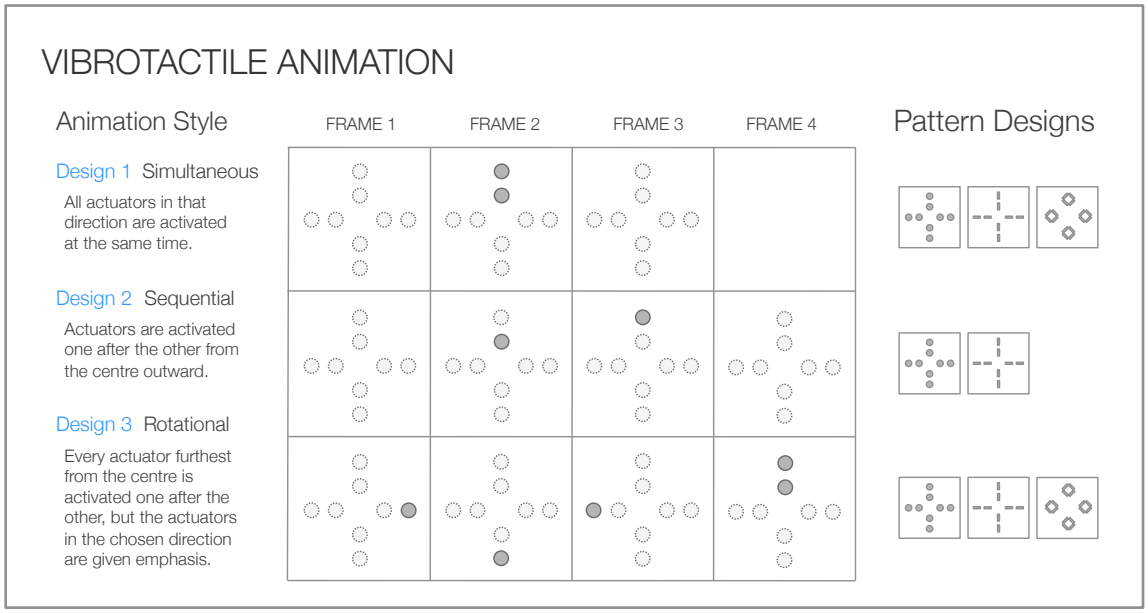

Figure 4 Three designs for presenting directional cues. The example direction is "up."

Directional information is provided by vibrotactile stimuli from the actuators, which are spatially arranged in the cardinal directions. Previously reported stimuli discrimination problems called for attention to be paid to the design of vibrotactile motion (Cholewiak & Craig, 1984; Gescheider, Stanley J. Bolanowski, Verrillo, Arpajian, & T. F. Ryan, 1990; Perez, Holzmann, & Jaeschke, 2000). Apparent motion—the illusion of motion produced by the appearance and disap-

pearance of a sequence of stimuli, instead of actually moving a single stimulus—drives the sensation of a directional pattern. This perceived movement is known as sensory saltation (Lee & Starner, 2010). I ideated three possibilities for pattern design and animation styles, shown in Figure 4. All three designs are longitudinal; I decided on this arrangement (a) to best remediate the compass design and (b) to make use of as much skin real estate as possible in order to avoid sensory discrimination issues inherent in spatial arrangements where the actuators are clustered closely together, e.g. circular and patch designs. I implemented Design 2 after initial evaluations during the prototyping stage suggested that it was best suited; Design 1 was either too alarming or too hard to distinguish, and Design 3 was confusing because triggering the actuator in each direction drew focus away from the intended direction.

3.2.4 Preliminary Design Evaluation

My design choices for spatial configuration and animation style were validated in a preliminary design evaluation. For this evaluation, I made it possible to re-program animations on the fly (Seaborn & Antle, 2011). In this way, I was able to elicit and implement participant feedback after each trial, which quickly narrowed the option possibilities to one for animation style: sequential motion, where each actuator in a given direction being triggered in sequence. After this stage, participants underwent 20-30 trials of “Guess the Direction,” during which they were asked to state which direction they felt. The results showed that participants were able to correctly identify directional motions 86.7% of the time, with an observed improvement over trials. These positive findings supported contin-

ued exploration of the perpendicular mounting of vibrotactile actuators in the full study. Further, we discovered that the “attention-grabbing” play of the first stimulus opposite to the actual sequence was found to be unsuitable. I modified the program to remove it. Finally, given observations of orientation difficulties, I decided that the prototype should be worn along the left side of the left forearm in the full study, complementing how the Wii Wheel is held.

3.2.5 Related Work

3.2.5.1 History of Haptic Sensory Substitution

Haptic displays, in particular vibrotactile and electric displays, have a long and rich history in the domain of sensory substitution (Loomis, 2010). Paul Bach-y-Rita and colleagues (1969) conducted the first, classic research in the late sixties; they developed a vibrotactile display worn on the back that provided haptic patterns converted from video imagery In the seventies, Bach-y-Rita’s colleague, Carter Collins, continued this thread of research with a stomach display that used electrical pulses instead of vibrotactile stimulation (Collins & Madey, 1974). By the eighties, Collins was tackling navigation tasks, albeit under unrealistic conditions (Collins, 1985). Thereafter, research revolved around the idea of general-purpose sensory substitution. Loomis notes, “A major hypothesis of the general-purpose sensory-substitution approach is that perceptual learning … will occur so that people will eventually be able to process the tactile or auditory stimuli and automatically perceive relevant features of their surroundings” (2010, p. 7). Another approach, explored in this thesis, is presenting only those features that are relevant to the user’s goal; instead of features or descriptions or patterns from

the environment, the display would prevent information necessary to the user being able to make sense of it. For example, the display could provide directional information in order to help the user achieve the goal of successfully navigating the environment. While not explicitly substitution, it is implicit and undeniably helpful information derived from and involving the environment.

3.2.5.2 Tactile Compass

The design of the display was informed by a comparable navigation interface. Researchers at the University of Caen Basse-Normandie worked with industrial partner Caylar on the design of a “tactile compass” that provided directional, cinematic and kinesiological information for a variety of purposes, including navigational, therapeutic, and artistic (Lestienne, Thullier, & Lepelley, 2010). The compass is comprised of 7x7 matrix of 49 microvibrator “pin” actuators laid 6 mm apart; they are stimulated by micromotors that are 2 mm in diameter. Their prototype is comprehensive and provides a breadth and depth of haptic feedback that is hard to parallel. For example, the interface not only provides guidance for the cardinal directions but also Y-axis movement (up and down), granularity of movement (speed or sudden change in movement), and rotational motion. In comparison, the Gauntlet Guide provides haptic information for the cardinal directions only; this limited form of information presentation is well suited for an action-adventure 3D game environment, where control of the avatar is typically restricted to the cardinal directions, and control granularity is not required for gameplay.

3.2.5.3 Tactile Watch

The notion of using vibrotactile stimuli to present information haptically has been explored previously. Swiss manufacturer Tissot produced a vibrotactile watch, with the intention of designing inclusively for the visually impaired (Pullin, 2009). This watch, *Silen-T*, has a number of haptically enhanced features implemented for a visually impaired audience, but that are of benefit to people who are visually able as well. The watch can be used in a variety of con-texts, from outdoor activities for which an eyes-free approach to telling time may be well suited, to social situations for which a discrete approach to checking the time circumvents possible social misconduct. To tell the time haptically, the user runs his or her finger around the rim of the watch, which presents vibrotactile information for the big and small hands using two different patterns. The standard alarm feature comes equipped with the option of vibrotactile sensation. The design of the prototype in this thesis work is a natural extension of these methods of haptic information presentation, albeit with a hands-free as well as eyes-free approach.

3.3 Visual Feedforward: LED Display

The LED display (Figure 5) was designed to be analogous to the wearable display in order for the presentation modes of light and vibration to be compared. A series of twelve LEDs are spatially arranged in complement to the spatial arrangement of the vibrotactile actuators on the wearable interface. The LEDs are embedded in a black foam plate, which is light enough to be attached to the frame of a television; the display was positioned on the top centre of the televi-

Figure 5 The visual condition, which is a 6" x 6" panel featuring an array of LED lights.

sion frame. The LED array presents the same directional motion information as does the array of haptic actuators on the wearable display.

One difference between the displays is that the haptic display is coupled with the control device, whereas the visual display is coupled with the screen. Even though the information in both cases is connected to the game avatar, the coupling is not as strong for the LED display as it is for the forearm display because the control device is closely coupled with the game avatar. Given the scope of this thesis work, I cannot perfectly account for this discrepancy. However, I suspect that positioning the LED display on the frame of the television affords its clustering with the game's heads-up display (HUD). The HUD is made up of visual information related to the game avatar; it frames the game environment, and thus the screen. The LED display is positioned at the top centre of the screen, where HUD retail estate is available. This complements both the most common camera perspective, in which the game avatar is centred horizontally on

the screen, and the position of the participant, who is parallel to the display and primarily concentrated on the location of the game avatar. Thus, the position of the LED display is best suited for their expected line of sight. If it had not been out of scope, I would have developed a system that used camera vision to track the game avatar and a projector to display the directional feedforward information visually in sync with the game avatar.

3.4 Video Game

I chose “Mario Kart Wii” (2008) for the Nintendo Wii gaming console. This racing game features a fast-paced, multimodal 3D game environment. The game comes with a special case with which to augment the Wiimote; the case remediates the look and feel of a steering wheel (Figure 6). The game provides a number of different tracks to choose from, each visually and audibly distinct and varying in difficulty. I chose three tracks that I perceived to be roughly equal in terms of difficulty; in order to validate my choices retrospectively, I asked participants to rate the difficulty of each track in the post-test questionnaire.

Figure 6 A participant wearing the Gauntlet Guide prepares to begin the game level. The Wii Wheel remediates the look and feel of a traditional steering wheel. To turn left or right, the player turns the Wii Wheel left or right.

3.4.1 Main Task

The main task is the completion of three rounds (or laps) of a given racing track. To do this, the player must successfully navigate the game environment, which affords a fast pace and requires overcoming environmental obstacles. Additionally, the player races against eleven other NPCs (non-playable characters) for placing and best time; NPCs present obstacles for the player to overcome.

The main task is both cognitively demanding and requires fast perception-motor skills in real-time. The player must respond to incoming perceptual data that is constantly changing due to the fast pace of gameplay. The sophisticated, multimodal nature of the game environment coupled with the fast pace of gameplay places pressure on the player's cognitive system. Further, the number of obstacles the player must be aware of at a given time can place load on working memory. For example, the player must navigate a complex path through the environment while avoiding rough patches (e.g. grass, dirt, sand), pitfalls (e.g. cliffs, deep water) and other obstructions (e.g. pillars, crates, moving walk-ways), the multitude of other players on the track (who can block the player or knock them aside), and an almost continuous influx of negative item effects (e.g. bombs, bananas, oil slick); at the same time, the player is expected to seek out aspects of the environment that will aid their quest to the finish line, including speed bursts and items they can collect and use for their positive gain. The player must perceive this ever-changing cacophony of discrete elements moment-by-moment and respond in a timely and appropriate manner to each of them. This involves properly interpreting what each element means for the player, and what response

is appropriate when multiple reactions are necessary at the same moment. Effectively dealing with potentially overwhelming perceptual data and reacting quickly is key to succeeding at the game.

3.4.2 Requirements

The central issue that novice players encounter that I seek to address in this research involves successfully navigating a challenging virtual environment. The within-subjects design dictates that all participants must experience all configurations of the interface. However, learning and carryover effects are a primary concern for studies that implement this setup. “Mario Kart Wii” allowed me to combat this by ensuring a novel experience for each condition. Having the option to choose visually and audibly dissimilar environments of similar difficulty allowed me to explore how different styles of feedforward guidance may benefit the experience of novice players.

Perspective matters when it comes to spatial navigation in games. The camera perspective affects how the player perceives motion and spatiality in games (Swalwell, 2008) as well as the player’s sense of engagement and embodiment (Taylor, 2002). The camera in “Mario Kart Wii” offers a third-person perspective. The player controls a visible avatar: the popular and widely recognized main character, Mario, positioned in a racing car. The main game task is to direct Mario through the game environment. The result of this interaction is bodily identification with the digital avatar of Mario (Taylor, 2007). The avatar is tightly coupled to the Wii Wheel controller, whose shape remediates and represents Mario’s digital steering wheel and is physically held in the player’s hands. Consequently,

I chose an arm-based display to present the vibrotactile feedforward guidance so that navigation information would be coupled with the Wii Wheel controller. My intent was to complement the control devices' coupling with the avatar, and in doing so maintain the embodiment afforded by the third-person perspective.

Finally, my familiarity with the game, especially in terms of navigating the environment and completing game tasks, benefited my performance as the Wizard during the study, which involved a Wizard of Oz setup (see 4.2).

3.5 Game Console and Controller

The game is played on the Nintendo Wii (2006) gaming console. This console is widely recognized for its novel approach to control and interfacing with video games: physically active, embodied interaction. Nintendo has marketed their system to a wide audience, ranging from young children to senior citizens. The Wii's market audience reflects the lack in Prensky's definition of the "Digital Game Generations", which makes it a viable point of entry for novice players.

The Nintendo Wii console's main controller is the Wii Remote, or Wiimote. Additionally, "Mario Kart Wii" provides an optional casing that resembles a steering wheel; when combined with the Wiimote, it becomes the Wii Wheel (Figure 7). The Wii Wheel is used to control the in-game avatar, which lends itself to the pairing of this device with the "Gauntlet Guide" wearable tactile display.

The Wii Wheel remediates the look and feel of a steering wheel. To make turns, the player physically turns the Wii Wheel left or right. Some aspects of driving a real car are embedded in the controller affordances as well. The "2"

button is the gas pedal button, and must be held down to move the avatar forward, similarly to how foot pedals work (indeed, you could call this version a thumb pedal). The “1” button, positioned beside the “2” button,” acts as a break; this is a similar in setup to the locations of the gas pedal and break in a real car.

The other buttons are tied to game-specific uses, or are unused. The “A” button, the largest button on the left, acts as a menu select button. The “Home” button in the middle pauses the game. The “B” button, which resides on the underside of the Wii Wheel (not pictured), allows the player to use collected items. The directional pad, traditionally used to control avatars, is only used for selecting menu items, although using the Wiimote as a pointer is also an option.

Figure 7 The Wiimote is embedded in the Wii Wheel, which is held like a steering wheel.

Participants were taught how to use the Wii Wheel during a training session. Each of the buttons required for gameplay was explained to participants. Participants were encouraged to use the training session for experimenting and becoming comfortable with the controls, in particular the novel steering wheel motions for turns.

3.6 Display

A 42” Toshiba widescreen display was used to present the game environment to participants. The context featured low-lit lighting for optimal vision.

3.7 The Wizard’s Control System

This study involves a Wizard of Oz setup, in which a human operator, called the Wizard, presents responses on behalf of the computer system to a user, who believes they are interacting with a computer. The Wizard is responsible for observing the novice player during game-play and preemptively responding to navigation difficulties with haptic feedforward guidance. The Wizard uses a laptop-based program to control both the vibrotactile actuators on the wearable display and the LEDs on the panel for the visual condition. Commands are communicated via a Bluetooth-enabled Arduino on each display, to which the actuators are connected. This setup allows the Wizard perform from afar: It is critical that the user maintains the illusion that he or she is interacting with a system and not another human, and so the Wizard must be positioned close enough to be able to observe and react to the user’s actions, but distanced enough to be perceived as disconnected from the user’s experience. At best, the user is engaged

in gameplay and thus inattentive to what the Wizard is doing; at worst, they are under the impression that the Wizard is taking notes on a laptop. See 4.8.1 for the Wizard's Guideline.

3.7.1 The "Feedforward" Program

The "Feedforward" program provides the Wizard with a way to control both the wearable display and the LED panel positioned above the screen. The program is run on a laptop; this allows the Wizard to control the displays from afar, thus maintaining the impression that the Wizard is not directly involved in the user's experience. The program was written in Max 5, a visual programming language that provides readymade graphical user interface elements. Commands are communicated via Bluetooth-enabled Arduino boards installed on both displays. This communication is made possible by Thomas Ouellet Fredericks's "Messenger" library for Arduino. The directional patterns are pre-programmed

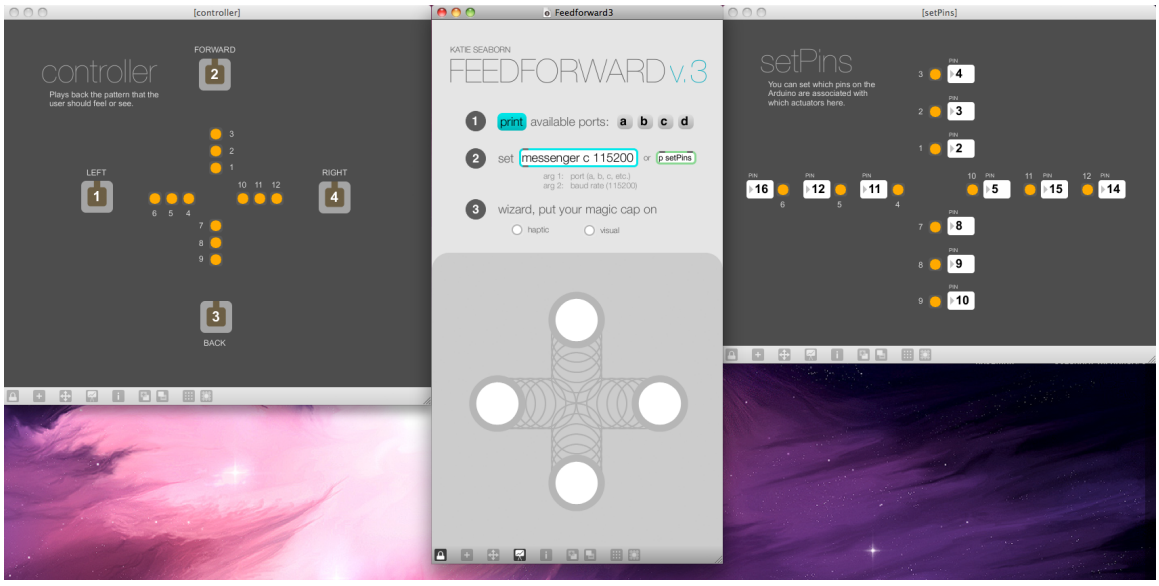

Figure 8 The final version of the 'Feedforward' program.

and then selected by the Wizard via a directional pad made up of button objects spatially arranged in complement to the actuators on the displays. The Wizard is able to use the interface haptically and thus sightlessly: each button is linked to the corresponding button the keyboard directional pad. In this way, the Wizard can focus on observing the participant's gameplay rather than dividing their visual attention between screens.

The program is comprised of three main windows: (1) the pattern playback window, (2) the main control window, and (3) the settings window (Figure 8). The control window (centre) instructs the Wizard through the setup procedure and allows them to execute feedforward guidance in four directions. The pattern playback window (left) visually shows what each pattern looks or feels like in terms of spatial direction and animated motion.

3.7.2 Adaptive Feedforward

The "Feedforward" program allows the Wizard to provide artificially adaptive feedforward guidance. In video games, adaptive feedback is the system's response to the player's observed competence; the system modulates the difficulty level depending on how well or how poorly the player is performing (Prensky, 2001). Similarly, adaptive feedforward is provided only when the Wizard observes that the player is in need of guidance. The goal of providing feedforward guidance is not to remove all challenge from the gameplay; a healthy balance must be found between too little challenge and too much challenge (Lazzaro, 2009). This is especially true for maintaining engagement and flow, as evidenced by similar game-based agents: "It adapts itself, so as [the user starts]

to do better it backs off, but if [the user is] struggling it … increases itself automatically, so that [the user is kept] in [her or his] 'learning sweet spot'. In other words, in the 'flow' state" (Prensky, 2001, p. 246). Providing constant directional information would eliminate the challenge, disrupt engagement, and encourage dependence on feedforward guidance.

Appropriate feedforward guidance is best understood through the analogy of bicycle training wheels. Like the novice player to the feedforward interface, the novice cyclist acknowledges the presence of the training wheels as a guiding mechanism and safety net. Just as the training wheels are not level with the larger, permanent wheel of the bicycle, but are elevated from the ground in such a way as to only connect with the ground if the novice cyclist topples right or left, so too should the Wizard via the feedforward interface provide guidance only when the novice player is in danger of "toppling" in gameplay. However, the limits of this analogy need to be acknowledged. Feedforward guidance, unlike bicycle training wheels, may be gradually reduced and removed. Further, feedforward guidance does not restrict the novice player's movements, whereas bicycle training wheels prevent the novice cyclist from taking sharp turns. In this way, feedforward guidance may be a more advanced and beneficial form of guidance than that of bicycle training wheels, albeit in a different domain. The guideline used by the Wizard for deter-mining when to respond with feedforward guidance is found in the Procedure section.

4: METHODOLOGY

4.1 Study Design

In this within-subjects exploratory study, I used a Wizard of Oz setup to explore the effectiveness of feedforward guidance with novice players. A within-subjects design was chosen in order to account for individual differences. Participants were presented with three conditions: vibrotactile feedforward, visual feedforward, and no feedforward (see 4.4). The main task involved the participant completing one level of the video game per condition. To account for the learning and carry-over effects inherent in a within-subjects approach, I counter-balanced level and condition (see Table 3). The measured constructs were performance, ease of use, navigation, enjoyment/satisfaction, and engagement (see Table 2). The purpose of this study was to explore how augmenting navigation in a fast-paced, multimodal game environment with haptic feedforward affects the experience of novice players, and what design implications arise from these findings.

4.2 Methodological Approach

I employed a Wizard of Oz setup for the main study. As a methodological approach, a Wizard of Oz setup is well suited for early testing of prototypes that are not fully functional, and was therefore a good fit given the scope of this thesis research. The approach involves a human operator acting on behalf of the computer. This operator, called the “Wizard”, indirectly interacts with participants

without their knowledge; participants believe they are interacting with a computer. As the experimenter, I took on the role of the Wizard. The Wizard of Oz approach is common in the domain of HCI and has been validated by number studies, including those meant to evaluate prototypes for navigation and video games (Andersson et al., 2002; Dahlbäck, Jönsson, & Ahrenberg, 1993; Höysniemi, Hämäläinen, & Turkki, 2004; Höysniemi, Hämäläinen, Turkki, & Rouvi, 2005). This approach has shown to be effective in spite of inherent drawbacks, such as the time and effort needed to train the Wizard (which can be arduous in expansive game environments), and time delays in the Wizard's response to participant actions (which can be more or less disruptive, depending on how tightly coupled responses are to actions, from the perspective of the participant).

4.3 Pilot Study

I conducted a pilot study to test the granularity of the haptic stimuli with respect to depicting motion. The pilot study also allowed me to practice and refine the Wizard of Oz approach—essential to maintain the illusion of system response instead of human control. The pilot study had four participants between the ages of 20 and 50 and equally split between genders. Participants were asked to play through three levels of the Mario Kart Wii game with three feedforward conditions: haptic, visual and none. Half of the participants reported no effect with respect to the haptic feedforward guidance. These participants suggested repositioning the Gauntlet Guide on the head or re-envisioning it as a full-body display. Half of the participants reported a positive effect with respect to the haptic feedforward guidance. They stated that the guidance was beneficial for

their performance. Interestingly, the two female participants reported positive results while the two male participants reported less positive results; however, the low sample size and nature of the pilot study leaves the possibility of a gender effect open. One participant reported uneven difficulty with respect to one of the game levels; as a result of this, I re-reviewed the possibilities and ultimately chose to replace this level. Finally, the lighting of the study environment was modified to enable participants to see the LED panel more clearly: instead of low lighting, the lighting was completely diminished.

4.4 Prototype

Please see the Systems Design section.

4.5 Participants

Thirty (30) novice players between the ages of 18 and 28 were recruited to participate in the study. This number was derived from an analysis of effect size with respect to the within-subjects design of the study and its constructs. However, one participant was found to be an outlier, and his data was removed, reducing the total data set to twenty-nine (29) participants; see 4.5.2. Seventeen (17) participants were females and twelve (12) were males. Participants were recruited from the undergraduate student population at Simon Fraser University Surrey Campus. As part of an on-going collaboration with the undergraduate teaching staff, graduate student researchers work with interested professors to enlist students from the classes that they teach. This collaboration allows undergraduate students to learn about research practices, current projects, and oppor-

tunities for participating in research. For this study, I solicited student participation through a short presentation at the start of the term. Students were asked to sign up with the School of Interactive Arts and Technology's participant pool system located at http://sfu-siat.sona-systems.com. Students had the option of being compensated in one of two ways: course credit (the amount of which varied and was dictated by professor of each course), or a $20 gift card. Only one form of compensation was awarded per participant. Consent was obtained via a form at the start of each session. Participants were informed that there would be no risks in participating, that their data would be kept confidential, and that they could stop without penalty at any time. The Office of Research Ethics at Simon Fraser University approved the study.

4.5.1 Defining the Novice Player

The target audience is novice players. Novice players were defined as non-gamers or casual gamers who have little or no experience with navigation in 3D environments and who are not familiar with "Mario Kart Wii". Participants were screened for their novice status in a pre-test questionnaire (Appendix A). They were asked to rate their experience with video games as a whole, and the Nintendo Wii system and Mario Kart Wii game in particular. Participants who ranked their experience as less than "Neither Experienced nor Inexperienced" were allowed to participate. Participants who ranked their experience as "Neither Experienced nor Inexperienced" were asked to qualify their choice; participants who had not played recently or expressed a subjectively weaker ranking were

allowed to participate. Participants who ranked their experience as higher than “Neither Experienced nor Inexperienced” were disqualified.

4.5.2 Removal of Outlier

One male participant was found to be an outlier. During the study, my assistant and I flagged his data because we observed that his performance with and knowledge of the game were greater than those of previous participants. During analysis, I found that his performance scores for errors, task time and placing were +2 standard deviation points away from the mean for at least one condition per measure. In his pre-test data, he reported that he was be experienced with video games but not at all experienced with the game in this study, Mario Kart Wii (he reported never having played it previously). However, it is clear from his performance scores and from the observations my assistant and made that this participant performed significantly better than expected and in relation to the other participants in this study. For these reasons, I determined this participant to be an outlier and removed his data from the set.

4.6 Setting

The study took place a controlled lab setting at Simon Fraser University Surrey Campus. The room was equipped with a 42” Panasonic flat screen display, Nintendo Wii, video camera, and couch. During the study, the room was set to low-lit lighting. The home entertainment-like nature of the room made it ideal for a study involving video games.

4.7 Tasks

"Mario Kart Wii" is a racing game, and adopts the basic premise of the racing sport, including looped tracks with obstacles and competition against other racers for the first place position and the fastest time. The main task involved the participant completing three game levels (or racing tracks), each with a different feedforward condition. To complete a level, the player must successfully navigate the game environment from start to finish three times (or laps) over.

4.7.1 Game Goals

The main goal is to complete the level. The secondary goals are to place first and achieve the fastest time. Participants were informed of these goals during the training session.

4.7.2 Gameplay

The gameplay of "Mario Kart Wii", common to other games of its type, is structured by three dimensions: (1) successfully navigating each level to completion; (2) finding secrets (items, events or pathways) hidden within the environment, which can only be discovered through exploration; and (3) timed gameplay, which motivates quick learning, limits exploration to players who are already navigationally adept, and promotes replay (Koster, 2005, p. 72). In this research, I focus on the first and third dimensions, as they are most relevant to the problem under study.

4.7.3 Scenario

After an introductory animation, the level begins. A stoplight counts down from red to amber to green: go. The player then holds down the gas pedal button and moves forward. They navigate the looping track three times to reach the finish line while manoeuvring around the other racers and avoiding environmental obstacles. Once they do so, the game level is completed. A finishing animation is played and their ranking is displayed in a chart contrasted with the other racers.

4.7.4 Winning and Losing States

In the context of this study, the winning state is completing each level by successfully navigating it three times over. The losing state is failing to complete the level, which can only be achieved by dropping out.

4.7.5 Obstacles

Players encounter any of three types of obstacles: environmental obstacles, items and other racers.

4.7.5.1 Environmental Obstacles

Each game level is features a unique environment; however, all levels are based off of the racing track schema and share some commonalities.

Common Obstacles:

- **Turns:** Turns, especially sharp turns, are difficult to navigate.
- **Stuck in a wall or a corner:** Sometimes if the player's avatar goes off the track, it can get stuck in the environment, usually in a wall outcropping or corner.

- **Recovering:** If the participant is hit by a negative item or runs off course (e.g. misses a bridge and ends up in the bottom of a valley) they are required to press the gas pedal button to start moving again.

Game Level #1: Flower Cup: Coconut Mall

- **Parking Vehicles:** Non-racer vehicles move back-and-forth horizontally in front of the player, blocking their path.
- **Pillars, waterfalls and palm trees:** These structural elements of the environment can impede or block the player's path.
- **Glass:** Its transparent surface gives the impression that the player can go through them, misleading them into crashing.
- **Escalators:** Two escalators are available; only one goes in the correct direction, and they switch direction after each round.
- **Split Pathways:** The mall environment features a number of split routes, e.g. the double escalators described above.

Game Level #2: Mushroom Cup: Toad's Factory

- **Compressors:** Large mechanical beams fall in front or on top of the player, possibly crushing them temporarily.
- **No railings:** Some tracks don't have railings; the player could fall off.
- **Moving platforms:** Some platforms move back and forth; the player could fall off.
- **Crates:** The player can run into crates on moving platforms.
- **Backwards paths:** Some paths force the player to slow and go backwards; the player is required to choose paths that have arrows in the forward facing direction.

Game Level #3: Star Cup: Koopa Cape

- **Water**: Part of the racing track is submerged in water. If the water is rushing in the direction the player desires to go, they receive a speed boost. If not, they will be pushed off a cliff.
- **Goombas**: Little monsters walk back-and-forth horizontally across the player's path. The player must dodge them.

- **Grass**: Driving through grass slows the player's speed considerably.
- **Electric Spins**: Rotating electric arms block certain sections of the racing track. The player is required to time their passage through the arms without hitting them.

4.7.5.2 Collectible Items

The player and the other racers can collect items on the track by running into sparsely placed rainbow-coloured cubes. Items can have negative or positive effects, depending on who is employing them. The result of almost all negative effect items is that the player's progress is temporarily halted, negatively affecting their performance score.

- **Bananas**: Racers lay bananas on the track by letting them go; if run into the player will slip, spin and stop.
- **Single Shells:** Can be used like missiles to hit another racer; if they do not hit another racer, they ricochet along the track until they do.
- **Multiple Shells:** Revolve in a ring around the racer. If another racer bumps into the player, the shells will hit and stop them.
- **Bob-omb:** Dropped on the track; explodes if hit.
- **Spiny Shell:** Targets the racer in first place, but will hit all other racers in its path.
- **Fake Item Block:** Looks like an item block but is a bomb in disguise.
- **Blooper:** A grey squid will squirt liquid on the screen, decreasing visibility for a time.
- **Lightning:** Turns all racers but the executer into tiny, slower versions of themselves. The executer can run over and flatten them.
- **Lightning Cloud:** A cloud will hover over the racer. They will receive a burst of speed and may be able to escape it. If they do not, they will be shrunken and slowed for a limited time.
- **POW Block:** Temporarily freezes all racers within its perimeter.

- **Mushroom:** Use once for a boost of speed.
- **Golden Mushroom:** The racer hits the item button repeatedly to get a successive boost of speed. Time limited.
- **Bullet Bill:** Turns the player's car into a bullet and places it on auto-pilot to speed them ahead. Time limited.
- **Star:** Makes the racer invincible and very quick. They can run into other players, knocking them off the track. Time limited.
- **Mega Mushroom:** Turns the racer into a larger version of themselves that are invincible and can flatten other racers. Time limited.

4.7.5.3 Other Racers

The player's avatar and the avatars of other racers can physically bump into each other – they cannot both occupy the same space at once. Other racers will use items they collect on the track against the player; these have a variety of effects, described above. Racers will block the player's path requiring the player to navigate around them. *Note: Racers will not lead the player astray, e.g. off the track or into an obstacle; however, they may take hidden corridors which might be too challenging to navigate.*

4.8 Procedure

Participants were greeted and introduced to the study. They were led to the questionnaire computer and given instructions on how to fill out the questionnaires in Excel. They were asked to fill out a screening questionnaire to confirm that they were novice players. After completing the screening questionnaire, they were asked to read over and sign the consent form; in the meantime, the host reviewed the screening questionnaire. Participants were then introduced to the Gauntlet Guide and underwent a 5-10 minute training period outside of the

context of the game. Training involved a two-part procedure: (1) the participant stating which direction for the experimenter to play, so that they could get a sense of what each feels like, and then (2) the experimenter playing directions for the participant to identify. This continued until the participant was comfortable with their ability to detect patterns. After training with the display, participants were lead to the main study area, and requested to sit on the couch. They were then introduced to the game controller, and played through a simple level of the game, without characters or other obstacles present, and without guidance. Participants then began the main session, comprised of three trials. After each trial, participants were asked to fill out a post-task questionnaire geared toward the guidance condition experienced during that trial. During this time, the host prepared for the next condition. Before starting the visual condition trial, participants were introduced to the visual display via a quick playback of each direction. After completing the final trial, participants were asked to fill out a post-test questionnaire. Once completed, participants were allowed to ask questions and talk about their experience in a debriefing session. Finally, they were compensated and thanked for their time. Each session took between forty minutes and a hour.

4.8.1 The Wizard's Guideline for Providing Feedforward Guidance

Video games feature highly dynamic environments; the multitude of elements that make up these environments interact in complex and sometimes unexpected ways. Even an experienced gamer is unable to foresee and preemptively respond to all of these interactions all of the time. For this reason the

following list is best understood as a guideline for responses based on known, possible and expected situations.

4.8.1.1 General Guidelines

Feedforward guidance is pre-emptive; therefore, guidance cues should be provided to the participant a few moments in advance of their expected response. Guidance was only be repeated if the participant has not responded within the expected time frame, which is within two seconds of the completion of the played directional pattern. This short time frame is dictated by the game's fast pace: any shorter and the participant does not have time to decipher and respond to the directional cue, and any longer the fast pace and changing path render the cue unsuitable, if not obviate the need for a cue.

4.8.1.2 Forward Direction Guidance

- **Starting a race:** When the race begins, all racers are in the stop position. A countdown begins. When the light turns green, the participant is expected to push the gas pedal button to move forward.
- **Resuming movement:** If the player's avatar is stopped due to failing to avoid an obstacle, forward guidance is used to indicate that they should resume forward movement (and, indirectly, that they should press the gas pedal button on the Wii Wheel again).

4.8.1.3 Left or Right Direction Guidance

- **Approaching turns:** Provide guidance when a turn is approaching; to avoid over-turning, do not provide guidance after the midpoint of the turn unless the first guidance cue was ignored.
- **Avoiding obstacles:** Provide guidance to signal going around the obstacle; note that the Wizard will have to be responsive to the back-and-

forth movement of the impeding racer and the changing track environment, which might lessen the viability of a certain direction.

4.8.1.4 Backward Direction Guidance

- **Recovering from displacement:** Provide guidance to indicate to the participant that they should break and back up. Then use right or left direction guidance to turn them away from the obstruction. Finally, use forward guidance to send them on their way.

4.9 Measures and Data Collection

Good experience for novice players means being able to effectively navigate the game environment. I define effective guidance by these constructs: performance, enjoyment, engagement, ease of navigation, and ease of use. In the post-test questionnaire, I asked participants to rank and compare the difficulty of the game levels I chose so as to assess the validity of my choices. A summary of the measures is found in Table 1. The questionnaires can be found in Appendices A, B and C. Note that in questions to participants “haptic” is referred to as the more colloquial and specific “vibration.”

4.9.1 Performance

Performance was measured as task time, number of errors, and placing. Task time refers to the amount of time in minutes and seconds that it takes the player to successfully complete the level; this data was recorded by the game. Number of errors refers to the number of navigation mistakes the player makes before successfully completing the level; this data was recorded by observing researchers. Placing refers to what placing the player achieves out of twelve pos-

sible places, where first place is optimal. This data was recorded in real-time by an observer or derived from video records.

4.9.1.1 Observer Guideline for Recording Navigation Mistakes

A research assistant and I observed and recorded navigation mistakes separately. We recorded a mistake every time the participant was unable to avoid an obstacle (listed and described in 4.7.5). At the end of each session, we would compare our counts and take the mean score if they did not match.

4.9.2 Enjoyment

Enjoyment data was collected in each post-task questionnaire (Q1-7) using questions from the Intrinsic Motivation Inventory (IMI), a 7-point Likert measurement scale designed to evaluate the subjective experience of participants after engaging with a specific activity (Deci & R. M. Ryan, 2005). Questions were drawn from the Interest/Enjoyment set of items and their wording slightly modified for the activity of gameplay.

4.9.3 Engagement

Engagement data was collected in each post-task questionnaire (Q8-10) using questions from Game Engagement Questionnaire (GEQ), a 3-point measurement scale designed to evaluate engagement as defined by immersion, presence, flow, psychological absorption, and dissociation (Brockmyer et al., 2009). Please see their paper for a rich description of GEQ engagement. The response options were: “No,” “Sort of” and “Yes.”

4.9.4 Ease of Navigation

Ease of navigation data was collected in each post-task questionnaire (Q11-18) using a 5-point Likert scale. Questions were developed by pairing opposite user experience constructs: easy/hard, competent/incompetent, etc. For example, “I found learning how to navigate the game environment hard” and “I found learning how to navigate the game environment easy.”

4.9.5 Ease of Use (Guidance)

Ease of use for guidance data was collected in each post-task questionnaire (Q19-26) using Likert scale questions and an open-ended question. The questions were adapted from Davis’s measurement scale for perceived ease of use with information technology (Davis, 1989). This scale has been validated in numerous studies, and has even been extended to the context of online social gaming experiences (Hsu & Lu, 2004). I used modified versions of Davis’s questions from this measurement scale to collect self-reports of satisfaction. The open-ended question allowed participants to provide additional commentary on their experience and expand on their Likert scale responses.

4.9.6 Replay

Replay data was collected in the post-test questionnaire using a 3-point scale. Three questions were presented for each condition, e.g. “Would you play the game again with vibration guidance?” The response options were: “Yes,” “Maybe” and “No”.

4.9.7 Preference

Preference data was collected in the post-test questionnaire using a 4-point scale. One question was asked: “Which form of guidance did you prefer?” The response options were: “None,” “Either/Both,” “Visual” and “Vibration”.

4.9.8 Difficulty

Game level difficulty data was collected in the post-test questionnaire using a 3-point scale. One question was asked: “How would you compare the difficulty of the game levels?” The response options were: “About Equally Difficult,” “About Equally Easy” and “Some Were More Difficult Than Others”.

4.10 Analysis

A summary of the analysis methods is found in Table 1.

4.10.1 Performance Data

Performance data included ratio task time data, number of errors (interval data), and interval placing data (ranking in race, out of twelve placements, where the cumulative average of placing 1st and 3rd would be 2nd place). Descriptive statistics included frequency distribution, mean, and standard deviation. Mauchly’s tests were conducted to ensure that sphericity was not violated and ANOVAs could be run on the data. Inferential statistics involved conducting repeated measures ANOVAs for task time and number of errors, a Friedman ANOVA for placing, and crossover design ANOVAs for all measures.

4.10.2 Self-Reports

Self-reports comprised the post-task questionnaire data, which was a mixture of ordinal and nominal (categorical) data types. Measures are categorized by data type and discussed below:

4.10.2.1 Enjoyment, Engagement, Ease of Navigation and Ease of Use

These measures used a 5-point Likert scale. Likert data was treated as ordinal data because of the fixedness of values, the few values to choose from, and polarized scoring at either the middle or extremes of the scale (Gardner & M. A. Martin, 2007). Descriptive statistics included frequency distribution, median, and standard deviation. Inferential statistics involved a Kruskal-Wallis test for each series of questions relating to a given measure.

4.10.2.2 Replay, Preference and Difficulty

These measures used a 3- or 4-point nominal scale. Descriptive statistics included frequency distribution, median, and standard deviation. Inferential statistics involved a Chi-Square test for each series of questions relating to each measure. Nonparametric tests were used because the data was not normally distributed.

4.10.3 Qualitative Data

Three open-ended questions in the post-test questionnaire and a verbal debriefing session provided qualitative data. This data was reviewed for commonly repeated comments and interesting, if unique, comments; these were counted and each was presented as a sum out of the total number of participants

who agreed. Quotes were selected that would best illustrate general or unique impressions.

Table 1 Summary of constructs that were measured in this study.

Construct	Measure	Data Type	Collection Method	Analysis
Performance	Task time	Ratio	Video/Observation	Repeated measures ANOVA, Crossover design ANOVA
	Number of errors	Ratio	Video/Observation	Repeated measures ANOVA, Crossover design ANOVA
	Placing (rank out of 12)	Ordinal	Video/Observation	Friedman ANOVA, Crossover design ANOVA
Enjoyment	Self-reports of enjoyment via IMI scale	Ordinal	Post-task Questionnaire	Kruskal-Wallis
	Open-ended question	Qualitative	Post-test Questionnaire	N/A
Engagement	Self-reports of engagement via GEQ scale	Ordinal	Post-task Questionnaire	Kruskal-Wallis
Navigation	Self-reports Likert scale	Ordinal	Post-task Questionnaire	Kruskal-Wallis
Ease of Use (Guidance)	Self-reports via Davis scale	Ordinal	Post-task Questionnaire	Kruskal-Wallis
Preference	Self-reports via multiple choice	Ordinal	Post-test Questionnaire	Chi-Squared
Desire to Replay	Self-reports via 3-point scale	Ordinal	Post-test Questionnaire	Chi-Squared
Difficulty	Rating scale	Ordinal	Post-test Questionnaire	Chi-Squared

5: RESULTS

5.1 Performance

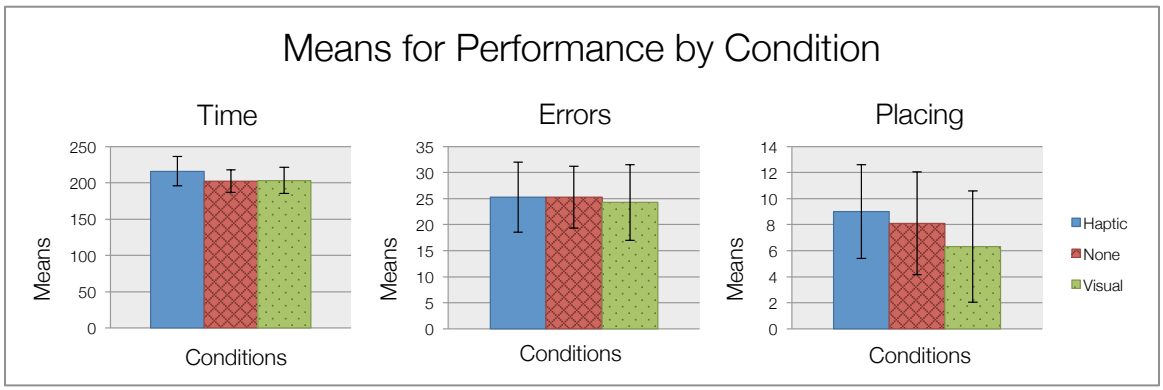

Figure 9 Means for performance measures by condition.

In summary, significant differences were not found for the performance measures time and errors. A repeated measures ANVOA revealed a significant difference for the performance measure placing between the haptic and visual conditions. Means (with error bars) by condition are shown in Figure 9.

5.1.1 Task Time

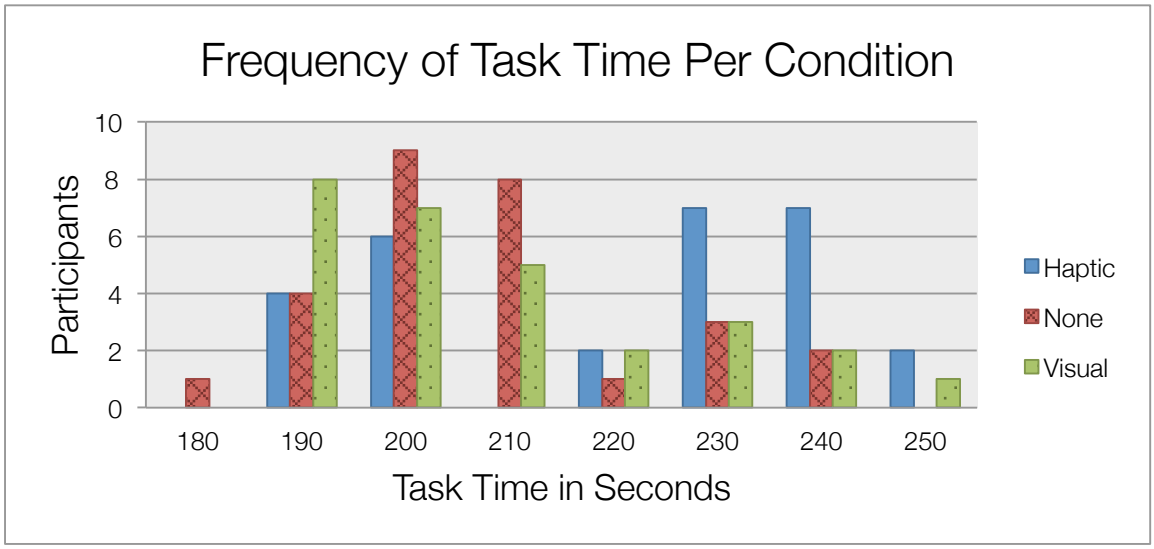

Figure 10 This histogram shows an uneven distribution for all conditions.

The frequency distribution of task time per condition is shown in Figure 10. The means for each condition are: 215 s for haptic; 202 s for no guidance; and 205 s for visual. The standard deviations for each condition are: 20.1 s for haptic; 15.7 s for no guidance; and 17.9 s for visual. Mauchly's test indicated that the assumption of sphericity was met, $\chi^2 = 2.994$, $p > .05$. The results of a repeated measures ANOVA show that task time was not significantly affected by condition at the $p > .05$ level, F (2, 54) = 3.518, $p = .037$. The results of a crossover design ANOVA show that task time was not significantly affected by condition at the $p > .05$ level, F (2, 54) = .463, $p = .632$. The partial Eta squared was .171, suggesting that 17% of the variability of the data can be explained by task time.

5.1.2 Errors

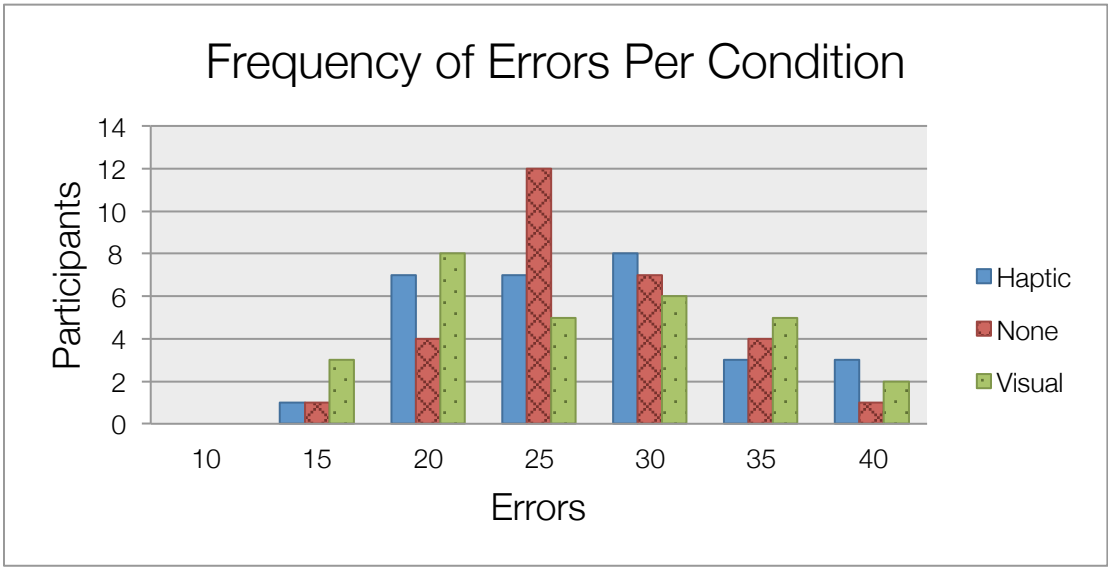

Figure 11 This histogram shows that the distribution for each condition is fairly normal.

The frequency distribution of errors per condition is shown in Figure 11. The means for each condition are: 25.3 for haptic; 25.3 for no guidance; and 24.3 for visual. The standard deviations for each condition are: 6.6 for haptic; 5.8 for no guidance; and 7.1 for visual. Mauchly's test indicated that the assumption of sphericity was met, $\chi^2 = 1.066$, $p > .05$. The results of a repeated measures ANOVA show that the number of errors was not significantly affected by condition at the $p > .05$ level, $F\ (2, 54) = .351$, $p = .705$. The results of a crossover design ANOVA show that error was not significantly affected by condition at the $p > .05$ level, $F\ (2, 54) = .391$, $p = .678$. The partial Eta squared was .031, suggesting that 3% of the variability of the data can be explained by the factor errors.

5.1.3 Placing

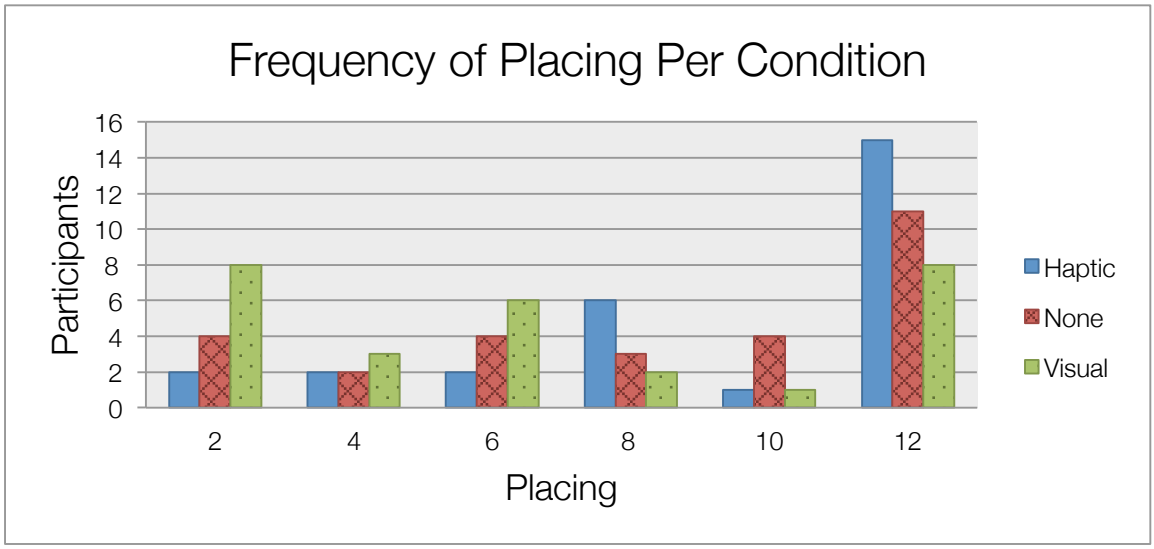

Figure 12 This histogram shows that the data is skewed to the right for all conditions.

The frequency distribution of placing per condition is shown in Figure 12. The means for each condition are: 9.0 for haptic; 8.1 for no guidance; and 6.3 for visual. The standard deviations for each condition are: 3.6 for haptic; 4.0 for no guidance; 4.3 for visual. The results of a repeated measures ANOVA show there was a significant effect of condition on placing at the $p < .05$ level, F (2, 54) = 3.985, $p = .024$. Pairwise comparisons indicated that the mean score for the visual condition was significantly different than the no guidance condition. However, the haptic condition did not significantly differ from the visual and no guidance conditions. The results of a crossover design ANOVA show that placing was not significantly affected by condition at the $p > .05$ level, F (2, 54) = 1.544, $p = .224$. The partial Eta squared was .21, suggesting that 21% of the variability of the data can be explained by the factor placing.

5.2 Self-Reports

Figure 13 Comparison of averages for self-reports of enjoyment, engagement, ease of navigation, and ease of guidance.

5.2.1 Enjoyment

Medians and standard error for enjoyment are found in Figure 13. The standard deviations for each condition are: 1.2 for haptic; 1.3 for no guidance; and 1.1 for visual. The results of a Kruskal-Wallis test show that enjoyment was not significantly affected by condition at the $p > .05$ level, $H\ (2) = .284$, $p = .867$.

5.2.2 Engagement

Medians and standard error are found in Figure 13. The standard deviations for each condition are: 0.5 for haptic; 0.5 for no guidance; and 0.4 for visual.

The results of a Kruskal-Wallis test show that engagement was not significantly affected by condition at the $p > .05$ level, H (2) = .048, p = .976.

5.2.3 Ease of Navigation

Medians and standard error for ease of navigation are found in Figure 13. The standard deviations for each condition are: 1.0 haptic; 1.0 for no guidance; and 0.8 for visual. The results of a Kruskal-Wallis test show that navigation was not significantly affected by condition at the $p > .05$ level, H (2) = 1.172, p = .556.

5.2.4 Ease of Use (of Guidance)

Medians and standard error for ease of use (guidance) are found in Figure 13. The standard deviations for each condition are: 0.8 for haptic, and 0.9 for visual. The results of a Kruskal-Wallis test show that ease of guidance was not significantly affected by condition at the $p > .05$ level, H (2) = .845, p = .358.

5.2.5 Replay

Means and standard error for replay are found in Figure 14. The standard deviations for each condition are: 0.8 for haptic; 0.6 for no guidance; and 0.9 for visual. The results of a Kruskal-Wallis test show that there was a significant effect at the $p < .01$ level of condition on desire to replay, H (2) = 11.258, p = .004, with a mean rank of 38.7 for haptic, 55.8 for no guidance, and 37.5 for visual.

5.2.6 Preference

A comparison of sums for preference is found in Figure 14. Ten out of 29 participants (34%) preferred haptic guidance, four participants (14%) preferred

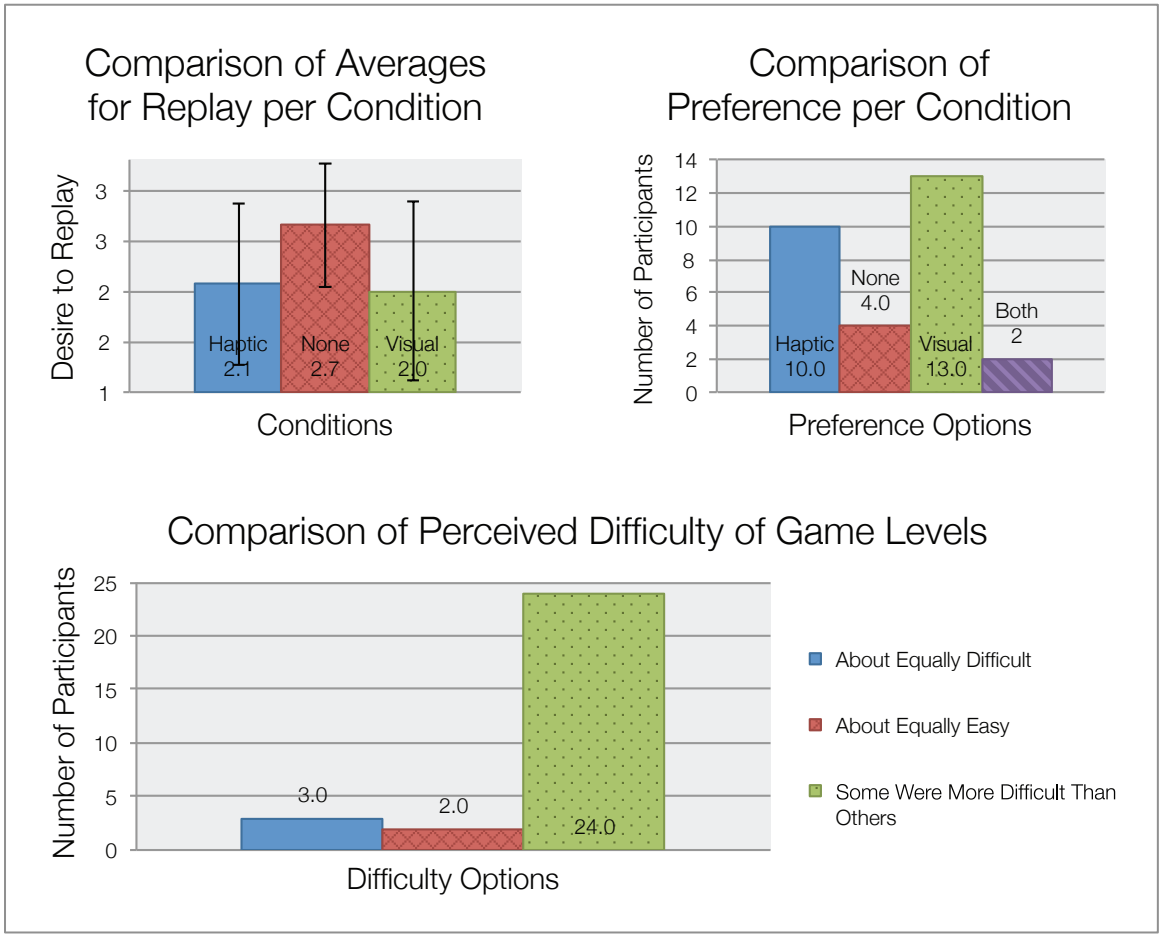

Figure 14 Graphs showing comparisons for replay, preference and game level difficulty.

no guidance, two participants (7%) preferred both or either forms of guidance, and thirteen participants (45%) preferred visual guidance. Overall, twenty-five out of 29 (86%) participants preferred having guidance. The results of a Chi-Square test show that there was a significant effect for preference, χ^2 (3, N = 29) = 10.862, p = .012, with visual and haptic guidance receiving the highest scores.

5.2.7 Difficulty

A comparison of sums for game level difficulty is found in Figure 14. Game level difficulty was assessed via the "How would you compare the difficulty of the

game levels?" question in the post-test questionnaire. Three options were provided: "About Equally Difficult," "About Equally Easy" and "Some Where More Difficult Than Others." Three out of 29 participants (10%) chose the "About Equally Difficult," two participants (7%) chose "About Equally Easy," and twenty-four participants (83%) chose "Some Were More Difficult Than Others." The results of a Chi-Square test show that there was a significant effect for preference, χ^2 (2, N = 29) = 31.931, p = .0000001, with the "Some Were More Difficult Than Others" option receiving the highest score.

5.3 Other Factors

Given the inconsistent performance and preference results in tandem with the significant difficulty rating, I compared the descriptive statistics for task time, errors and placing by game level and order to elucidate their effects, if any (Table 2). For both game level and order, none of the means for any of the measures are more than one standard deviation different from each other. For game level, Koopa Cape and Toad's Factory have lower scores for placing. For order, there is a slight improvement over time that is likely due to a small learning effect.

To determine the statistical significance of these effects, a crossover design ANOVA with three treatments (guidance conditions) in three periods (order) and an additional blocking factor (game level) was run for performance measures. The results for task time, errors and placing show that guidance condition did not affect these measures; however, statistically significant affects were found for period (p = .003 for all) and game level (p < .0001 for task time and placing, and p = .02 for errors) at the p > .05 level. The effect of period is expect-

ed due to the learning curve. The effect of game level indicates that the Coconut Mall level was easier in a way that affected performance.

Table 2 Exploration of other factors: game level and order.

	Errors		**Task Time**		**Placing**	
	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.
Game Level						
Coconut Mall	23.1	8.3	0:03:20	0:00:09	4.6	3.8
Koopa Cape	26.5	6.0	0:03:52	0:00:06	9.8	3.1
Toad's Factory	25.1	4.8	0:03:10	0:00:05	9.0	3.2
Order						
1	27.1	6.8	0:03:33	0:00:18	8.8	3.7
2	24.9	6.7	0:03:24	0:00:19	7.4	4.3
3	22.8	5.7	0:03:25	0:00:21	7.3	4.1

To account for the significant affect of game level, two game blocks were introduced: easy (Coconut Mall) and difficult (Toad's Factory and Koopa Cape). Repeated measures ANOVAs were conducted for task time, errors and placing for each game level block. The results for the easy game level block are: $F(2,24) = .277$, $p = .76$ for task time; $F(2,24) = .004$, $p = .996$ for errors; and $F(2,24) = .256$, $p = .777$ for placing. The results for the difficult game level block are: $F(2,54) = 3.193$, $p = .049$ for task time; $F(2,54) = .164$, $p = .849$ for errors; and $F(2,54) = .608$, $p = .548$ for placing. The repeated measures ANOVA for task time showed a significant affect on guidance for the difficult game level block. Student *t* pairwise comparisons showed a significant difference between haptic guidance and no guidance at the $p < .05$ level, indicating that participants were faster without guidance in the more difficult game levels, $t(54) = 2.005$, $p = .015$.

5.4 Qualitative Data Analysis

5.4.1 Preference: Guidance Likes and Dislikes

Seven out of 29 participants (24%) reported that the visual guidance was useful and nine participants (31%) reported that the haptic guidance was useful. Six participants (21%) reported that the visual guidance was easy to understand. Thirteen participants (45%) reported that the visual guidance forces a distracting shift in attention, while five participants (17%) reported that the haptic guidance was *not* distracting. One participant reported that the visual guidance was confusing and nine participants (31%) reported as much for the vibration guidance.

Two out of 29 participants (7%) noted that the haptic guidance worked well in the context of a multimodal game environment. One explained: “The screen is very busy so the additional guidance [allows] me to [rely less] on my eyes.” This participant also clarified how the guidance was useful: “It feels like the guidance is helping me stay on the short-cut track, which is very useful for me to achieve a better ranking.” Explaining their position on haptic guidance, another participant said, “What I didn't like about the vibration is that it required a lot of processing to understand what he vibration meant. It was not something that is done automatically.”

One participant described the haptic guidance as “very creative,” while another described the Gauntlet Guide as “an interesting device.”

5.4.2 Other Comments

After experiencing the benefits of the nonintrusiveness of the haptic condition, one participant explained: “I expected that I would like the visual guidance because I know my [peripheral] vision to be quite good, however I discovered that it proved more distracting. … I remember paying attention to the haptic feedback when correcting a mistake […] up until this point I ignored the haptic feedback it was giving me and was focused on the screen. I think the haptic feedback worked to be not overly intrusive if the user preferred to ignore this guidance but could choose to be more sensitive to it by choice.” This participant suggests that haptic guidance was less demanding on attention than visual guidance, which afforded the participant the choice of whether to attend to the guidance or not.

Two out of 29 participants (7%) stated that after learning the track, they did not need the guidance and chose to ignore it. One explained: “At a certain point, the [LED panel] felt unnecessary because it gave me a little too much information.” Another quantified the number of times they would need to use guidance in order to learn a game level: “I'd say 6-7 more times, or if I haven't played the game in a long time. It only really helps beginners.”

One participant ascribed their performance to the order and difficulty of the game levels: “Overall, I think that my performance attributed to a learning curve across the 3 sessions and varying difficulty of the courses rather than the guidance that was provided.” They also note that guidance could be effective in visually overloaded game environments: “I think the courses in the game were well chosen though as someone who's never played before, I found the courses to be

overwhelming visually and could understand how additional guidance would be helpful."

One participant compared the guidance to a GPS: "It is like a [GPS] letting me know what is ahead."

5.4.3 Design Ideas

Some participants offered design suggestions for future versions of the Gauntlet Guide and its visual counterpart.

5.4.3.1 Presentation of Visual Guidance

One participant said, "The light is somewhat distracting. [Since] the game [relies] mostly on [the] visual sense, it would aid better if the [LED] light [gave] directions with dim light (e.g. left-centre is very, very dim light, centre-left goes to half dim light, and left goes to [full intensity] light)." In other words, the intensity of the stimuli should be modulated such that the furthest actuator along a directional line of actuators is the most intense.

Alternatively, two out of 29 participants (7%) suggested using colour in place of intensity. One stated: "I strongly believe that I actually would have liked the visual feedback if the different directions were represented in different colours."

One participant suggested placing the visual directions on the frame of the television screen, similar to how each direction is placed along each side of the forearm for the haptic display.

5.4.3.2 Size of Visual Display

Two out of 29 participants (7%) suggested increasing the size of the visual display. One explained: “For the visual one, the placement of the light pad is good, but I found that it got out of my way to look at it sometimes as I focused more attention on the [LEDs] rather than where I am in the 3D world. I could not focus on both at the same time, maybe because it is on a small display.”

5.4.3.3 Timing of Guidance

Four out of 29 participants (14%) noted having trouble with the timing of the guidance. One participant said: “What I don’t like about both guidance is the timing of the signals, they came quite late. Most of the time I already made the turns before [I received] the signals.” This suggests that the guidance needs to be executed well in advance of the intended action.

5.4.3.4 Speed of Animation

Three out of 29 participants (10%) suggested speeding up the guidance animation. One noted: “If the sequence of the vibrations were to be sped up a little the information would've been a lot more clear.”

5.4.3.5 Location of Haptic Cues

Six out of 29 participants (21%) noted having trouble distinguishing between the haptic directions because they were located too close to one another. One participant suggested: “Maybe if it was … located on a different part of the body, the vibration would work better.” Another suggested moving the Gauntlet Guide to the participant’s dominant hand: “I would suggest trying to attach the

vibration tool on the more dominant hand of the user … because it [is] the limb with the faster response." Another suggested using both hands. One participant noted that the Gauntlet Guide was "clunky and heavy," while another explained: "Since I was playing the game with my hands already, I would not suggest to add another piece of instrument on it to confuse the player."

5.4.3.6 Guidance Information

One participant noted that the guidance gave them a sense of comfort after recovering from an error. Another suggested guidance should be provided in advance to another racer "attacking" their avatar, to be forewarned of an action that could disrupt their ability to navigate the environment successfully.

6: DISCUSSION

The variability of results paints a complex picture of the overall effectiveness of feedforward guidance. The multifaceted nature of the independent variable made it difficult to tease out how different conditions affected the experience of novice players engaged in the process of learning how to navigate a fast-paced, multimodal game environment while contending with gameplay tasks. While novice players preferred feedforward guidance, its effect on performance and user experience is less clear. Haptically augmented feedforward guidance was not found to be significantly effective for performance; visually augmented feedforward guidance was found to be significantly effective for performance via the measure placing, although this effect was lost when other factors were considered. However, participants preferred both forms of guidance. Complicating matters further, participants desired to replay the game *without* guidance. But despite their complexity, the results offer an initial understanding of the effectiveness of feedforward guidance. This includes design implications, which can be distilled into an emerging set of guidelines for designers of systems or interfaces that provide feedforward guidance. These findings pave the way for a kaleidoscope of future research.

6.1 Performance

Overall, the performance results were inconclusive but provisionally favour visual feedforward guidance. There were no statistically significant effects on condition for errors or task time. And while there was a statistically significant effect on condition for placing between the visual condition and no guidance condition, this effect was lost in a crossover ANOVA. In other words, while the haptic condition and the no guidance condition were not significantly different, the visual condition was potentially, albeit ambiguously effective. This suggests that this style of feedforward guidance may have benefited the performance of novice players in terms of placing. However, I come to this conclusion tentatively, given the lack of statistically significant results for errors and task time, and the incongruity of the repeated measures and crossover ANOVA results.

6.2 Self-Reports

Participants' self-reports of enjoyment, engagement, ease of navigation, and ease of use with guidance did not reveal statistically significant differences between the haptic, visual and no guidance conditions. However, the replay, preference and difficulty measures received significantly different scores between their respective options. Difficulty is discussed in 6.3.

Interestingly, participants indicated that they desired to replay the game *without* guidance, although their preference scores indicated that haptic and visual guidance were preferred, as opposed to no or either guidance styles. Further, the performance results show that the visual condition had a significant effect on

placing. This contradiction can be resolved by considering the influence that a strong performance with visual guidance might have on participants' confidence. A desire to replay without guidance despite a preference for guidance could indicate that participants appreciated the guidance but felt confident enough to take on the challenge of gameplay without it; in other words, exposure to guidance decreased the perceived need for it. Although not directly measured in this study, the potential epiphenomenon of increased self-efficacy is highly relevant to improving the experience of players in general, and novice players in particular. I therefore suggest that feedforward guidance, in particular visual feedforward guidance, was effective, with the caveat that other data collected suggests the influence of other factors.

6.3 Other Factors

The null performance results for errors and task time despite a provisionally significant effect of the visual feedforward guidance condition on placing give rise to the possibility that other factors may have been at play. Further, the statistically significant results for participants' reports on a perceived uneven difficulty across game levels posed game level difficulty as a contender. I explored this possibility by comparing the descriptive statistics (mean and standard deviation) of errors and task time with order and game level, and conducting an inferential crossover design analysis. I also reviewed my design decisions and the qualitative commentary elicited from participants to evaluate whether the results were affected by shortcomings in the design of the Gauntlet Guide and LED panel.

6.3.1 Perceived and Actual Game Level Difficulty

To discover if the perceived unevenness in game level difficulty affected participants' scores, I reviewed the descriptive statistics for order and game level. However, on the whole, the means and standard deviations did not suggest that either order or game level affected performance scores. A slight decrease in task time by order can be accounted for by the learning effect inherent in a within subjects design; in fact, I believe that this effect would have been *more* pronounced had I not accounted for it by counterbalancing condition and game level, and having participants engage in a training level prior to the main session.

What the descriptive statistics did reveal was that the Coconut Mall level differed from the other two game levels. The results of a crossover design ANOVA indicated that it was easier rather than more difficult than the other two. I can speculate on factors that could account the difference. Roughly two thirds of the Coconut Mall course is visually homogenous: a large, open mall space with repeated elements, including elevators and decorative water fountains, and a uniform environment treatment, with little change in the floor, wall, and ceiling colours and textures. This is not so for the other two levels, which have more diversity and contrast between sections of the environment. The Coconut Mall level also lacks some of the environmental obstructions found in the other two levels, e.g. grass or dirt, which disrupt player performance if encountered, and water or cliffs, which significantly disrupt player performance if encountered. In other words, there were fewer opportunities for participants to make mistakes, especially significantly disruptive mistakes.

I did not ask participants to rank specific game levels; in retrospect, I should have collected this data, because doing so would have allowed me to determine specifically which level or levels were responsible without having to rely solely on the performance data, complicated inferential statistics, and my own speculation.

6.3.1.1 Accounting for Game Level Difficulty

After discovering that one game level was significantly easier than the other two, I created two blocks to distinguish between the easy and difficult game levels and ran repeated measures ANOVAs for task time, errors and placing. The only statistically significant difference was for task time between the haptic and no guidance conditions, with a faster task time for the no guidance condition. This difference was not seen in the previous inferential tests. After accounting for the differences in game level difficulty the significant effect of visual guidance on placing seen with three game levels groups wasn't apparent. This suggests that game level difficulty affected the statistical results for (a) the effect of visual guidance on placing and (b) the difference between haptic guidance and no guidance on task time. As such, visual feedforward guidance remains a tentatively beneficial approach.

6.3.1.2 Lessons on Researcher Bias

That the Coconut Mall game level differed from the rest ran counter to my expectations. Given what my assistant and I had observed during the study, I expected that participants had found the Koopa Cape game level more difficult

than the others. My unfulfilled expectation provides a lesson in experimenter susceptibility, perhaps especially because of the Wizard of Oz setup.

I suspect that a particular feature of the game environment design for the Koopa Cape level skewed my expectation. At the end of this level is a navigational hazard in the form of a waterfall running perpendicular across the course, such that its crosswise waters push participants off a cliff if they run over it. My assistant and I observed that this was a particularly salient hazard because most participants did not navigate around the waters, and some participants continued not to even after experiencing the effects of their actions, i.e. they did not learn the first time around. The other game levels do not have a comparable ending hazard. It may be that because this hazard occurred at the end of the level, it coloured my perception of the game level's difficulty. In other words, my last impressions of participant's difficulty with this game level brought about my expectation that it was more difficult than the others. This demonstrates the importance of engaging in metacognitive review and eliciting participants' feedback on the choices re-searchers make for the design of experiments. The design of studies involving games may benefit from a pre-emptive external validation study, perhaps especially for studies that involve novice players and researchers who are expert gamers; such a study may circumvent problems resulting from unsuccessful applications of theory of mind.

6.3.2 Effects of Design Decisions

The results could point to shortcomings in the designs of the Gauntlet Guide and LED panel, which would unquestionably affect the performance and

user experience of participants. Reviewing the qualitative data reveals some support for this possibility. However, there was substantial variability in the critiques of and suggestions for both the visual and haptic displays. For this reason, it is difficult to pinpoint salient design issues.

The top three design issues are as follows: Participants reported both a modality-independent desire for cues to be triggered earlier (14%) and an increase in animation speed (10%). Participants also suggested repositioning the vibrotactile actuators, such as on the dominant hand, both hands, or elsewhere on the body (21%). The other design issues reported were acknowledged by less than 10% of the total participant pool.

Participants provided a diverse set of design ideas for both the visual and haptic displays. While this could indicate that participants felt the designs needed improvement, it could also speak to the range of design possibilities imaginable for the context of this research. Indeed, in the design phase, I brainstormed a number of design ideas that could be explored in future work (see 3.2.3). Given the scope of this thesis work, I was unable to explore all of the spatial arrangements that I ideated; it is possible that another spatial arrangement would be better suited. Further, the Gauntlet Guide provides direction cues on only one side of the body, i.e. only on one forearm. A number of participants suggested that wearing two Gauntlet Guides, one on each arm, would improve their experience. Other participants suggested arranging the directional cues over the entire body. Perhaps the asymmetry of a single Gauntlet Guide degraded users' experience. This suggests an exploration of other designs is needed.

As far as the design of the Gauntlet Guide and LED panel go, it is difficult to conclude what particular design issues affected the performance and user experience of novice players based on the qualitative feedback. Clearly, even the top three design issues do not represent the majority of participant opinion. Further, participants' assorted thoughts on design solutions suggest that there may be multiple valid solution options, if not personal preference at work.

Overall, my exploration of other factors proved inconclusive. Although I was able to discover and account for a flaw in my study design, I was unable to uncover a clear effect of feedforward guidance on performance, thereby maintaining the discrepancy between performance and preference scores. Other unaccounted factors may be at play; however, these factors remain elusive.

6.3.3 Effects of Wizard's Performance

The design issues discussed in 6.3.2 suggest that the Wizard's performance may have had an effect on the results. In particular, the timing of the Wizard's responses, combined with the confusion and/or distraction of the guidance cues, may have had an impact on participants' performance and confidence in the feedforward guidance.

6.4 Qualitative

The feedback I received in the three open-ended questions on the post-test questionnaire combined with the debriefing sessions I conducted post-study with each participant were both rich and varied. But like the quantitative data, it did not paint a clear picture of the effectiveness of either style of guidance. Par-

ticipants found both styles of guidance useful, and noted that they each had unique detriments: the visual guidance was distracting because it drew attention away from the screen and the vibration guidance was confusing because it was hard to distinguish at times. Participants described the haptic guidance as more effective in the sense that they had control over it and could attend to it or ignore it at will, which was more difficult to do with the visual guidance; this echoes the findings of Forsyth and MacLean's (2006) research on adaptive haptic cues. Participants' comments also supported the notion that feedforward guidance is beneficial for novice players, and suggested that guidance would not be needed as they gained more experience with the game.

Participants' qualitative comments on deciphering confusing haptic cues suggests that these cues may not have become automated for all participants, which means that they continued to be cognitively processed. Indeed, the results from the blocked repeated measures ANOVA for game level difficulty, which showed a barely significant difference in task time between the no guidance and haptic conditions, suggest that participants needed a bit of time to cognitively decipher the haptic guidance cues. In contrast, such time delays were not seen in the visual condition data, although participants' qualitative comments suggest that the visual condition was distracting. Why this is so is unclear. Perhaps the addition of a new modality—the haptic modality—to an already multimodal environment had a negative effect, rather than a positive one. Even so, the data and statistical results do not conclusively point to either possibility; the effect of introducing a new modality remains unsettled.

6.5 Relation to Previous Work

In their research on virtual learning game environments, Virvou and Katsionis (2008) found that novice players had difficulty with navigation, and expended time and effort on learning how to navigate, which distracted from gameplay tasks. My research sought to address this issue through an exploration of feedforward guidance as a method of supporting novice players in navigation tasks. I can tentatively conclude that feedforward guidance is a viable support method, although more research is needed generally, and in particular with respect to navigating virtual environments.

Haptic guidance has received considerable attention in the areas of 2D GUI navigation (Dennerlein & Yang, 2001; Dennerlein et al., 2000) and training (Crespo & Reinkensmeyer, 2008; Feygin et al., 2002; Huegel & O'Malley, 2009). The success of this style of guidance in point-and-click tasks, targeting and training of motor tasks supported the exploration of haptic feedforward guidance. However, the findings from this research are incongruous with the success of this previous research. I cannot conclude with confidence that haptic feedforward guidance was effective. Even so, other factors need to be considered. In particular, the context of use in this study differed from all of these examples of previous work. It is likely that a fast-paced, multimodal game environment provides substantially different challenges than 2D GUI interfaces and training simulators. Perhaps haptic feedforward guidance is best suited to slower paced, modally undemanding environments; however, this needs to be explored.

Forsyth and MacLean (2006) explored a form of haptic feedforward guidance using haptic cues to guide users through dynamic tasks in a simple 3D environment. They found an increase in performance and preference for the use of predictive haptic cues. In this research, I sought to replicate their findings in the context of a more sophisticated environment: a fast-paced, multimodal gaming environment. Additionally, I hoped to address two limitations of their study: increasing the size of the haptic steering wheel (they used a knob that required the use of only one arm) and conducting the study in a more complex and realistic environment (a sophisticated, fast-paced, multimodal gaming environment). My findings suggest that while haptic and visual feedforward guidance were preferred, only visual feedforward guidance may benefit performance. Subsequently, I cannot conclude that I was able to replicate their results in this new context. Further, there are critical differences between the haptic knob Forsyth and MacLean used and the Wii Wheel and Gauntlet Guide combination I used in this research. Forsyth and MacLean's knob used the force style of haptic information presentation, which made turning the wheel in a certain direction compulsory, whereas I used the tactile style in this research, which could be attended to or ignored at will. Further, their knob was grounded and the Wii Wheel was ungrounded. For these reasons it is difficult to draw conclusive comparisons between these two feedforward guidance devices. More research is needed to untangle and clarify the discord between performance and preference in this context.

As a wearable tactile display, the Gauntlet Guide comes out of a long line of research for the use of these interfaces for navigation (Matscheko et al.,

2010). A prototype that found great success in providing navigation cues haptically via a vibrotactile belt motivated continued research in this area. Van Erp and colleagues (2005) explored the effectiveness of a vibrotactile belt for waypoint navigation tasks in real world settings. They evaluated their prototype in two real world contexts: a helicopter and a boat, both of which provide their own vibrations and other noise. Their results showed that the belt was a success. It therefore seemed likely that the Gauntlet Guide would find similar success in a vibration-less environment that was also visually and cognitively demanding. However, this was not the case. A number of reasons could account for our differing findings. First, the waist has a larger spatial area on which to present vibration stimulation, even though it may not be as sensitive as the forearm. Further, the belt design makes use of an embodied approach to mapping the information: the front, back, left and right sides are mapped to the dial of a compass, whereas the Gauntlet Guide only couples the directional information to the source of control. Indeed, qualitative feedback suggests more embodied approaches, for example spatially arranging the actuators on the back and arms, or on the head. Finally, the real world cases explored by Van Erp and colleagues were in some ways simpler than the game environment I explored in this research. The pilots had to contend with navigating and controlling, but no other factors, whereas players must contend with game-play tasks and a fast-paced, ever-changing environment that demands quick reaction times. It would be interesting to see how the Gauntlet Guide performs as a minimal navigation system in tasks

that, for instance, do not require the use of the hand, or for which the use of the hand is coupled with navigation tasks.

I designed and developed the Gauntlet Guide with the designs of previous WTDs in mind, in particular the WTD that Lee and Starner (2010) developed. Following the design stage, I conduced an evaluation that assessed the saliency and ergonomics of the Gauntlet Guide (Seaborn & Antle, 2011). My goal was to decrease the amount of required training of 40 minutes reported by Lee and Starner while maintaining the effectiveness of the haptic directional cues. I found that training could be reduced to about 10 minutes. In this research, I required participants to train for this length of time with the Gauntlet Guide. The performance results indicate that the Gauntlet Guide allowed participants to perform with the same level of effectiveness as no guidance and visual guidance for virtually all measures. However, in an open-ended question posed at the end of the session, some participants reported difficulty with respect to attending to the haptic cues, although not in deciphering them. Participants suggested faster playback of haptic directional patterns, i.e. fewer pauses between the executions of each vibrotactile actuator in order to more quickly perceive the directional pattern as apparent motion. This suggestion is valid with respect to the fast-paced gameplay. Even so, having each participant engage in 10 minutes of training was sufficient for performance. Further, participants reported preference for both of visual and haptic feedforward guidance. These findings provide some validation the concept of a simple, quick-to-pick-up wearable tactile display, although the

lack of a statistically significant improvement over the no guidance condition suggests that additional design explorations and research are needed.

6.6 Design Guidelines

I propose the following initial set of guidelines for designers looking to improve the accessibility of video games for novice users with feedforward guidance. These guidelines draw from the findings of this research, particularly participants' qualitative data, as well as the design considerations proposed by Forsyth and Maclean (2006) and the design guidelines proposed by Kiili (2005), Gee (2007c) and Willis et al. (2009).

6.6.1 Coupling the Haptic Cues to the Means of Control

Norman's (1988) concept of mental mapping and Mayer's (2001) spatial contiguity principle for multimedia learning suggest that information should be spatially mapped; in this case, the haptic feedforward guidance information should be spatially coupled to the means of directional control, which is the Wii Wheel game controller. Placing the haptic guidance cues on the forearm, was thought to be appropriate because the Wii Wheel is held in the user's hands. However, the results do not indicate that this was an effective design. Although supported by theory, this approach was rendered unsuitable in practice.

The qualitative feedback can be mined for a number of other potential design choices: haptic cues on the wheel, haptic cues on both forearms, haptic cues on some other area of the body, like the back or head. As game interfaces

evolve, other approaches may be more appropriate; for example, the embodied control afforded by the Microsoft *Kinect* system would suggest that guidance cues should be placed on the arms and torso.

6.6.2 Size of Cues Relative to Surface Area

The size of the cues needs to be considered with respect to the surface area on which they are placed. In this study, even though the vibrotactile actuators were placed on a sensitive area of the skin—the underside of the forearm—in order to increase the saliency of the perceived vibrations, the small surface area reportedly disrupted identification of the cues.

6.6.3 Timing of Feedforward

Consideration needs to be paid to *when* feedforward guidance is issued. If issued too far in advance, users will not be able to match the cues to the environmental hazard and therefore not perform the intended action correctly. If issued too soon, participants will not have time to register the cue and react to it.

6.6.4 Gradual Introduction of Cues

Guidance cues that are directional should be gradually introduced. I suggest modulating the intensity of the stimulus such that the beginning of the pattern playback features less intense stimuli, with increasing intensity until full intensity is reached at the end of the pattern. This echoes findings from Forsyth and MacLean's (2006) work on predictive haptic cues. Their findings showed that Look-Ahead Guidance, which featured a gentle, gradual introduction of stimula-

tion, was more effective and preferred over Potential Field Guidance, which was more abruptly introduced.

6.6.5 Maintaining Agency

Guidance cues should not disrupt the user's sense of agency. Haptic presentation modes afford the user the ability to selectively attend to or ignore guidance cues; in contrast, visual presentation cues command the user's visual attention, which distracts them from the game environment display. This is an important distinction because most modern game environments do not make use of haptic information presentation, but virtually all make heavy use of visual information presentation. However, if haptic cues are not designed well, they may disrupt the user's attention regardless of the modal composition of the game environment. This echoes findings from Forsyth and Maclean's (2006) study on predictive haptic cues, as well as design considerations they determined from their previous work and those proffered by other researchers working with haptics. This also supports the design guidelines proposed by Kiili (2005), Gee (2007c) and Willis et al. (2009), who suggest guidance cues should be unobtrusive and not demand or engulf the user's attention.

6.6.6 Feedforward Guidance for Self-Efficacy

Feedforward guidance may increase the confidence of novice players. In this study, participants preferred feedforward guidance, even when given a "no guidance" preference option, but expressed a desire to replay without feedfor-

ward guidance. This suggests that feedforward guidance had an effect on participants' confidence, and may be used to improve participants' self-efficacy.

Self-efficacy refers to the ability to perceive ourselves as competent in different situations (Bandura, 1977). Self-efficacy influences the choice of tasks we are willing to take on; those of us who have a strong sense of efficacy are more motivated, less stressed, more willing to spend time and effort on tasks, less hindered by errors and obstacles, and more productive overall than those who suffer from self-doubt (Bandura, 1982). Self-efficacy can therefore positively rein-force learning and agency, and predict future behaviour in similar tasks.

However, self-efficacy was not directly measured in this study; this guideline, however provocative, is tentative and needs to be explored empirically.

7: CONCLUSION

In this research, I explored the potential of haptic feedback for providing feedforward in order to improve the experience of novice players learning to navigate a fast-paced, multimodal game environment. I assessed the effectiveness of feedforward for this user base in this context, and explored haptic augmentation as an alternative to harnessing sight and sound in a gaming environment already rich with visual and auditory stimuli. My goal was to explore how augmentting navigation with haptic feedforward affects the user experience of novice players, and what design implications arise from these findings. I discovered that feedforward guidance was tentatively beneficial, independent of modality. Although my haptic prototype, the Gauntlet Guide, was not as effective as the visual condition, the likelihood that latent factors played a role in the experience of novice players, combined with discordant performance scores, self-reports and qualitative feedback, suggest that more research needs to be conducted in order to conclusively elucidate the effectiveness of feedforward guidance in general, and haptic feedforward guidance in particular.

7.1 Main Contributions

7.1.1 Knowledge

Feedforward guidance tentatively emerged as a viable method for improving the user experience of novice players. However, haptic feedforward guid-

ance was not shown to be effective. Further, the effects of feedforward guidance on performance were null. I expect preference for feedforward guidance to generalize beyond the context of this study because of the interesting conflict raised by the preference and replay results. Also, the effectiveness of haptic feedforward guidance may prove to increase should other styles and designs be explored.

7.1.2 Demonstration

The Gauntlet Guide exhibited a proof-of-concept approach to increase the user experience potential of haptics in gaming through a new context of use. However, the haptic quality of the Gauntlet Guide was not found to be effective. Even so, participants expressed preference for feedforward guidance, including haptic feedforward guidance. It remains to be seen whether an evaluation of a similar haptic feedforward display in a different context (e.g. a different game, perhaps one that is not fast-paced) or the exploration of other haptic styles and feedforward display designs would have a more significant effect on the performance of novice players.

7.1.3 Guidelines

I have proposed of an initial set of design guidelines for feedforward guidance for improving the user experience of novice players. These guidelines were built from or support previous work and recommendations. More research and prototyping is needed to assess the generalizability of these findings, especially in light of the limited performance benefits found in this study.

7.2 Future Work

The nature of the findings presents many opportunities for future research. An unknown factor or factors were at play in this research, which prevented me from conclusively determining the effectiveness of haptic feedforward guidance, even though visual feedforward guidance appears to be effective. More research is needed to tease out these other factors. Other styles of haptic information presentation could be explored: vibrotactile stimulation is but one of many styles, which include pressure, motion, and temperature. Exploring different ways of presenting guidance information deserves a more in depth design evaluation. I ideated a number of patterns and analytically chose a pattern and animation style; however, the other concepts could be evaluated for their effectiveness. Additionally, the placement of feedforward guidance cues may not be limited to a wearable forearm display: other possibilities may be equally or more effective, such as a full body integration with localized buzzing for the greatest surface area and an embodied sense of direction.

A number of limitations could also be addressed. For instance, I did not collect measurements of forearm circumference, but informally observed that this may have been a factor in participants' ability to distinguish vibrotactile cues. Additionally, the results indicate that design issues in both the Gauntlet Guide and LED panel were likely a factor in the performance results; future research could explore alternative designs. Further, the qualitative feedback suggests that the Wizard's performance may have adversely affected the performance of participants. It is extremely difficult for a human to operate at the precision of a com-

puter. One way to determine if this had an impact would be to run a similar study after completing the automated feedforward guidance program. Finally, I did not ensure that the salience of the visual and haptic stimuli were equal, which may have limited their comparability. This is especially important because of individual differences in the perceived saliency of stimuli. Each participant should be calibrated and the quantitative salience of each presentation mode per participant recorded to investigate whether or not individual differences are a factor.

Participants' self-reports suggest that feedforward guidance had a positive impact on their confidence, and may be used to increase self-efficacy. However, confidence and self-efficacy were not directly measured in this study. A longitudinal study could assess confidence through self-reports and determine whether or not there is a significant effect on participants' self-efficacy over time. Such a study could empirically validate the final guideline I propose in this work.

Using feedforward information in adaptive systems is another area ripe for exploration. In this research, the Wizard as the system observed and responded to issues they perceived the player to be encountering. Another approach is to give the player agency over system aid, for example toggling hints, opting in and out of tutorials, or peripheral text help. This approach has been explored in video games previously (Crawford, 2003, p. 425) but has been limited to the traditional presentation modes of visuals and sound. Haptic feedforward offers a new design space for exploring player agency over in-game assistance. Additionally, this approach is not exclusive, and pairing both approaches could strengthen haptic

feedforward overall by addressing the limitations of each, such as when the system fails to observe that the player is having difficulties.

The notion of expert gamer guidance is another area worthy of research. While this thesis research featured a Wizard of Oz setup, in which participants were under the impression that a computer system was monitoring and reacting to their experience instead of a human operator, a less clandestine setup can be imagined. Drawing from an ethnographic study in which friends and siblings were seen engaging in mentored play (Stevens et al., 2008), as well as my own experiences as a sibling growing up in the age of the single-player video game, I see a place for the notion of haptic feedforward as an unobtrusive method of providing guidance in social, instructive, but non-multiplayer settings. Designers could develop collaborative technologies that would assist the expert gamer in providing guidance in discreet ways. For example, the novice could wear a display like the Gauntlet Guide, and the expert gamer could observe and provide *ad hoc* guidance cues haptically, which could be a more salient and non-disruptive approach than using visual channels. Anecdotes of these experiences show how proffered help can be either helpful or interfering, or an unruly combination of the two. The efficacy of aid is potentially debilitated by overloaded modalities and split attention: the combination of audio and visual communication with the predominantly audio and visual video game experience. Further ethnographic research on this topic could illuminate the potential of a haptic feedforward device employed by the mentor for the benefit of the novice player.

Haptic feedforward guidance is a novel technique, and the greater portion of its applications remains unexplored. While the findings of this research do not clearly speak to its success, I see haptic feedforward guidance at the prologue of its Bildungsroman, with a long arc of exploration ahead. As more research is conducted, its story will play out, perhaps ending with its acceptance and maturation as an assistive learning paradigm; an established repertoire of its uses, contexts, con-figurations, and the kinds of user experiences it affords; and its continued exploration in the domains of video games, learning, and beyond.

REFERENCE LIST

Works Cited

Andersson, G., Höök, K., Mourão, D., Paiva, A., & Costa, M. (2002). Using a Wizard of Oz study to inform the design of SenToy. *Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 349-355). Presented at the Designing Interactive Systems, London, England: ACM.

Ang, C. S., & Rao, G. S. V. R. K. (2008). Computer Game Theories for Designing Motivating Educational Software: A Survey Study. *International Journal on E-Learning*, *7*(2), 181-199.

Arango, F., Aziz, E. S., Esche, S. K., & Chassapis, C. (2008). A review of applications of computer games in education and training (pp. 22-25). Presented at the Frontiers in Education Conference, Saratoga Springs, NY, USA: IEEE. Retrieved from http://ieeexplore.ieee.org.proxy.lib.sfu.ca/xpls/abs_all.jsp?arnumber=4720514&tag=1

Bach-y-Rita, P., Collins, C. C., Saunders, F. A., White, B., & Scadden, L. (1969). Vision Substitution by Tactile Image Projection. *Nature*, *221*(5184), 963-964. doi:10.1038/221963a0

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, *84*(2), 191-215. doi:doi:10.1037/0033-295X.84.2.191

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist*, *37*(2), 122-147. doi:doi:10.1037/0003-066X.37.2.122

Becker, K. (2010). Distinctions Between Games and Learning: A Review of Current Literature on Games in Education. *Gaming and Cognition: Theories and Practice from the Learning Sciences* (pp. 22-54). IGI Global.

Brockmyer, J. H., Fox, C. M., Curtiss, K. A., McBroom, E., Burkhart, K. M., & Pidruzny, J. N. (2009). The development of the Game Engagement Questionnaire: A measure of engagement in video game-playing. *Journal of Experimental Social Psychology*, *45*(4), 624-634.

Bromme, R., Stahl, E., Bartholomé, T., & Pieschl, S. (2004). The case of plant identification in biology: When is a rose a rose? Development of expertise as acquisition and use of robust and flexible knowledge. *Professional Learning: Gaps and Transitions on the Way from Novice to Expert*, Innovation and Change in Professional Education (Vol. 2, pp. 29-48). Netherlands: Kluwer Academic Publishers.

Charles, D., McNeill, M., McAlister, M., Black, M., Moore, A., Stringer, K., Kuklich, J., et al. (2007). Adaptive Game Technology as a Player-Centered Approach to Game Design. In S. de Castell & J. Jenson (Eds.), *Words In Play: International Perspectives on Digital Games Research*, New Literacies and Digital Epistemologies (pp. 249-265). New York, NY: Peter Lang.

Cholewiak, R., & Craig, J. (1984). Vibrotactile pattern recognition and discrimination at several body sites. *Attention, Perception, & Psychophysics*, *35*(6), 503-514.

Collins, C. C. (1985). On Mobility Aids for the Blind. *Electronic Spatial Sensing For the Blind* (pp. 33-64). Dordecht: Martinus Nijhoff Publications.

Collins, C. C., & Madey, J. M. J. (1974). Tactile Sensory Replacement. *Proceedings of the San Diego Biomedical Symposium* (Vol. 13, pp. 15-26).

Crawford, C. (2003). *Chris Crawford on game design*. Inianapolis, Indiana, USA: New Riders Publishing.

Crespo, L. M., & Reinkensmeyer, D. J. (2008). Haptic Guidance Can Enhance Motor Learning of a Steering Task. *Journal of Motor Behavior*, *40*(6), 545-557.

Dahlbäck, N., Jönsson, A., & Ahrenberg, L. (1993). Wizard of Oz studies — why and how. *Knowledge-Based Systems*, *6*(4), 258-266.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, *13*(3), 319-339.

Deci, E. L., & Ryan, R. M. (2005). Intrinsic Motivation Inventory (IMI). Retrieved from http://www.psych.rochester.edu/SDT/measures/IMI_description.php

Dennerlein, J. T., & Yang, M. C. (2001). Haptic Force-Feedback Devices for the Office Computer: Performance and Musculoskeletal Loading Issues. *Human Factors and Ergonomics Society*, *43*(2), 278-286.

Dennerlein, J. T., Martin, D. B., & Hasser, C. (2000). Force-feedback improves performance for steering and combined steering-targeting tasks. *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 423-429). Presented at the Conference on Human Factors in Computing Systems, The Hague, The Netherlands: ACM.

Dix, A., Ghazali, M., & Ramduny-Ellis, D. (2008). Modelling Devices for Natural Interaction. *Electronic Notes in Theoretical Computer Science*, *208*, 23-40. doi:doi: 10.1016/j.entcs.2008.03.105

Djajadiningrat, T., Wensveen, S., Frens, J., & Overbeeke, K. (2004). Tangible products: redressing the balance between appearance and action. *Personal and Ubiquitous Computing*, *8*(5), 294-309.

Van Eck, R. (Ed.). (2010). *Gaming and Cognition: Theories and Practice from the Learning Sciences*. IGI Global.

Van Erp, J. B. F., Veen, H. A. H. C. V., Jansen, C., & Dobbins, T. (2005). Waypoint navigation with a vibrotactile waist belt. *ACM Trans. Appl. Percept.*, *2*(2), 106-117.

Feygin, D., Keehner, M., & Tendick, F. (2002). Haptic Guidance: Experimental Evaluation of a Haptic Training Method for a Perceptual Motor Skill. *Proceedings of the 10th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator System*. Presented at the HAPTICS, ACM.

Forsyth, B. A. C., & MacLean, Karon E. (2006). Predictive Haptic Guidance: Intelligent User Assistance for the Control of Dynamic Tasks. *IEEE Transactions on Visualization and Computer Graphics*, *12*(1), 103-113.

Gardner, H. J., & Martin, M. A. (2007). Analyzing Ordinal Scales in Studies of Virtual Environments: Likert or Lump It! *Presence*, *16*(4), 439-446.

Gee, J. P. (2003). What video games have to teach us about learning and literacy. *Computers in Entertainment (CIE)*, *1*(1), 1-4.

Gee, J. P. (2007a). *What Video Games Have to Teach Us About Learning and Literacy* (2nd ed.). Palgrave Macmillian.

Gee, J. P. (2007b). Good Video Games, the Human Mind, and Good Learning. *Good Video Gams and Good Learning* (pp. 22-44). New York, New York, USA: Peter Lang Publishing, Inc.

Gee, J. P. (2007c). Learning about Learning from a Video Game: Rise of Nations. *Good Video Games and Good Learning* (pp. 45-66). Peter Lang Publishing, Inc.

Gee, J. P. (Ed.). (2007d). *Good Video Games + Good Learning: Collected Essays on Video Games, Learning and Literacy*. Peter Lang Publishing, Inc.

Gescheider, G. A., Stanley J. Bolanowski, J., Verrillo, R. T., Arpajian, D. J., & Ryan, T. F. (1990). Vibrotactile intensity discrimination measured by three methods. *The Journal of the Acoustical Society of America*, *87*(1), 330-338.

Greenfield, P. M. (1984). *Mind and Media: The Effects of Television, Video Games, and Computers*.

Hayward, V., & MacLean, K.E. (2007). Do It Yourself Haptics: Part I. *Robotics & Automation Magazine, IEEE*, *14*(4), 88-104.

Ho, C., Tan, H. Z., & Spence, C. (2005). Using spatial vibrotactile cues to direct visual attention in driving scenes. *Transportation Research Part F: Traffic Psychology and Behaviour*, *8*(6), 397-412. doi:doi: 10.1016/j.trf.2005.05.002

Höysniemi, J., Hämäläinen, P., & Turkki, L. (2004). Wizard of Oz prototyping of computer vision based action games for children. *Proceedings of the 2004 conference on Interaction design and children: building a community* (pp. 27-34). Presented at the Interaction Design and Children, Maryland, USA: ACM.

Höysniemi, J., Hämäläinen, P., Turkki, L., & Rouvi, T. (2005). Children's intuitive gestures in vision-based action games. *Communications of the ACM*, *48*(1), 44-50.

Hsu, C.-L., & Lu, H.-P. (2004). Why do people play on-line games? An extended TAM with social influences and flow experience. *Information & Management*, *41*(7), 853-868.

Huang, W.-H. D., & Tettegah, S. (2010). Cognitive Load and Empathy in Serious Games: A Conceptual Framework. *Gaming and Cognition: Theories and Practice from the Learning Sciences* (pp. 137-150). IGI Global.

Huegel, J. C., & O'Malley, M. K. (2009). Visual versus haptic progressive guidance for training in a virtual dynamic task. *Proceedings of the World Haptics 2009 - Third Joint EuroHaptics conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems* (pp. 399-400). Presented at the WHC, IEEE Computer Society.

Johnson, M. S. S. (2008). Public writing in gaming spaces. *Computers and Composition*, *25*(3), 270-283.

Kiili, K. (2005). Digital game-based learning: Towards an experiential gaming model. *The Internet and Higher Education*, *8*(1), 13-24.

Koster, R. (2005). *A Theory of Fun*. Scottsdale, Arizona, USA: Paraglyph Press.

Kwak, M., Niezen, G., van der Vlist, B., Hu, J., & Feijs, L. (2011). Tangible Interfaces to Digital Connections, Centralized versus Decentralized. *Transactions on Edutainment V*, Lecture Notes in Computer Science (Vol. 6530, pp. 132-146). Springer Berlin / Heidelberg. Retrieved from http://dx.doi.org/10.1007/978-3-642-18452-9_11

Lazzaro, N. (2009). Understand Emotions. *Beyond Game Design: Nine Steps Toward Creating Better Videogames* (pp. 3-48). Course Technology PTR.

Lee, S. “Claire”, & Starner, T. (2010). BuzzWear: alert perception in wearable tactile displays on the wrist. *Proceedings of the 28th international conference on Human factors in computing systems* (pp. 433-442). Atlanta, Georgia, USA: ACM.

Lestienne, F. G., Thullier, F., & Lepelley, M. C. (2010). Tactile perception and virtual guidance of movement: from clinical to artistic applications. *Schedae*, *4*(1), 49-58.

Loomis, J. M. (2010). Sensory Substitution for Orientation and Mobility: What Progress Are We Making? Sidebar 1.1 (pp. 7-10) to Chapter 1, Perceiving to Move and Moving to Perceive: Control of Locomotion by Students with Vision Loss by David A. Guth, John J. Rieser, and Daniel H. Ashmead. In W. R. Wiener, Welsh, Richard L., & B. B. Blasch (Eds.), *Foundations of Orientation and Mobility*, History and Theory (Third Edition., Vol. 1, pp. 3-44). New York, NY: AFB Press.

MacLean, Karon E., & Hayward, V. (2008). Do It Yourself Haptics: Part II Interaction Design. *Robotics & Automation Magazine, IEEE*, *15*(1), 104-119.

Matscheko, M., Ferscha, A., Riener, A., & Lehner, M. (2010). Tactor placement in wrist worn wearables. *Wearable Computers (ISWC), 2010 International Symposium on* (pp. 1-8). Presented at the Wearable Computers (ISWC), 2010 International Symposium on.

Mayer, R. E. (2001). *Multimedia Learning*. Cambridge, New York: Cambridge University Press.

Michael, D. R., & Chen, S. (Eds.). (2005). *Serious games: Games that educate, train, and inform*. Muska & Lipman/Premier-Trade.

Moshirnia, A. (2007). The educational potential of modified video games. *Issues in Informing Science and Information Technology*, *4*, 511-521.

Norman, D. A. (1988). *The Design of Everday Things* (Second Edition.). New York, New York: Basic Books.

Perez, C., Holzmann, C., & Jaeschke, H. (2000). Two-point vibrotactile discrimination related to parameters of pulse burst stimulus. *Medical and Biological Engineering and Computing*, *38*(1), 74-79.

Pitaru, A. (2008). E is for Everyone: The Case for Inclusive Game Design. *The Ecology of Games: Connecting Youth, Games, and Learning* (pp. 67-86). Massachusetts, USA: MIT Press.

Prensky, M. (2001). *Digital Game-Based Learning*. Two Penn Plaza, New York, NY, USA: McGraw-Hill.

Pullin, G. (2009). *Design Meets Disability*. Massachusetts, USA: MIT Press.

Salen, K. (Ed.). (2008). *The Ecology of Games: Connecting Youth, Games, and Learning*. Massachusetts, USA: MIT Press.

Seaborn, K., & Antle, A. N. (2010). The Tiresias Effect: Light versus Temperature in a Tangible User Interface. *Proceedings of the 28th international conference extended abstracts on Human factors in computing systems* (pp. 3427-3432). Presented at the Conference on Human Factors in Computing Systems, Atlanta, Georgia, United States: ACM. Retrieved from http://portal.acm.org.proxy.lib.sfu.ca/citation.cfm?id=1753996

Seaborn, K., & Antle, A. N. (2011). Gauntlet Guide: Designing a Wearable Vibrotactile Feedforward Display for Novice Gameplay. *Proceedings of GRAND Annual Conference 2011*. Presented at the GRAND 2011, Vancouver, British Columbia, Canada.

Seaborn, K., Riecke, B. E., & Antle, A. N. (2010). Exploring the interplay of visual and haptic modalities in a pattern-matching task. *Proceedings of the 9th IEEE International Symposium on Haptic Audio Visual Environments and Games* (pp. 61-66). Presented at the IEEE Symposium on Haptic Audio-Visual Environments and Games (HAVE), Phoenix, Arizona, USA: IEEE.

Shinkle, E. (2005). Corporealis Ergo Sum: Affective Response in Digital Games. *Digital Gameplay: Essays on the Nexus of Game and Gamer* (pp. 21-35). Jefferson, North Carolina, USA: McFarland & Company, Inc.

Stevens, R., Satwicz, T., & McCarthy, L. (2008). In-Game, In-Room, In-World: Reconnecting video game play to the rest of kids' lives. *The Ecology of Games: Connecting Youth, Games, and Learning* (pp. 41-66). Massachusetts, USA: MIT Press.

Sturman, D. J., & Zeltzer, D. (1994). A survey of glove-based input. *Computer Graphics and Applications*, *14*(1), 30-39.

Susi, T., Johannesson, M., & Backlund, P. (2007). *Serious games – An overview* (Technical Report). Sweden: University of Skövde.

Swalwell, M. (2008). Movement and kinaesthetic responsiveness: A neglected pleasure. *The Pleasures of Computer Gaming: Essays on Cultural History, Theory and Aesthetics*. MacFarland.

Swan, Richard H. (2010). Feedforward as an Essential Active Principle of Engagement in Computer Games. *Gaming and Cognition: Theories and Practice from the Learning Sciences* (pp. 108-136). IGI Global. Retrieved from http://www.igi-global.com/bookstore/Chapter.aspx?TitleId=41469

Swan, Richard Heywood. (2008, April). *Deriving Operational Principles for the Design of Engaging Learning Experiences* (Doctor of Philosophy). Brigham Young University. Retrieved from http://contentdm.lib.byu.edu/ETD/image/etd2573.pdf

Taylor, L. N. (2002). *Video games: Perspective, point-of-view, and immersion* (Masters). University of Florida, Gainesville, FL, USA. Retrieved from http://www.laurientaylor.org/research/taylor_l.pdf

Taylor, L. N. (2007). Platform Dependent: Console and Computer Cultures. *The Players' Realm: Studies on the Culture of Video Games and Gaming* (pp. 223-237). Jefferson, North Carolina, USA: McFarland & Company, Inc.

Tylor, E. B. (1879). The History of Games. *Popular Science Monthly*, *15*. Retrieved from http://en.wikisource.org/wiki/Popular_Science_Monthly/Volume_15/June_1879/The_History_of_Games

Virvou, M., & Katsionis, G. (2008). On the usability and likeability of virtual reality games for education: The case of VR-ENGAGE. *Computers & Education*, *50*(1), 154-178.

Wensveen, S. A. G., Djajadiningrat, J. P., & Overbeeke, C. J. (2004). Interaction Frogger: A Design Framework to Couple Action and Function through Feedback and Feedforward. *Proceedings of the 5th conference on Designing Interactive systems: Processes, practices, methods, and techniques* (pp. 177-184). Presented at the Designing Interactive Systems (DIS '04), Cambridge, Massachusetts, USA: ACM.

Wilson, K. A., Bedwell, W. L., Lazzara, E. H., Salas, E., Burke, C. S., Estock, J. L., Orvis, K. L., et al. (2009). Relationships Between Game Attributes and Learning Outcomes. *Simulation and Gaming*, *40*(2), 217-266.

Online Sources

Websites Consulted

http://www.arduino.cc

http://www.arduino.cc/playground/Code/Messenger

Thesis Websites

http://katieseaborn.com/masters

http://katieseaborn.com/research

http://katieseaborn.com/guide

http://sfu-siat.sona-systems.com

APPENDICES

Appendix A: Pre-test Questionnaire (Screening Test)

PRE-TEST QUESTIONNAIRE

Your Age: _____
Your Gender: _____

To answer the questions below, type an "x" beside your choice.

How would you rank your expertise with video games? (choose one)
- Experienced
- Somewhat Experienced
- Neither Experienced or Inexperienced
- Somewhat Inexperienced
- Inexperienced

How would you rank your interest in video games? (choose one)
- Interested
- Somewhat Interested
- Neither Interested or Uninterested
- Somewhat Uninterested
- Uninterested

Have you played the Nintendo Wii before?
- Yes
- No

If so, how would you rank your expertise with the Nintendo Wii? (choose one)
- Experienced
- Somewhat Experienced
- Neither Experienced or Inexperienced
- Somewhat Inexperienced
- Inexperienced

Have you played Mario Kart Wii before?
- Yes
- No

If so, how would you rank your expertise with Mario Kart Wii? (choose one)
- Experienced
- Somewhat Experienced
- Neither Experienced or Inexperienced
- Somewhat Inexperienced
- Inexperienced

Appendix B: Post-task Questionnaire

POST-TASK QUESTIONNAIRE

PART A: YOUR EXPERIENCE
Please answer the following questions about your experience while playing this round of the game (cho

1 I thought playing the game was quite enjoyable.
1 - Not at all true
2
3
4 - Somewhat true
5
6
7 - Very true

2 Playing the game was fun to do.
1 - Not at all true
2
3
4 - Somewhat true
5
6
7 - Very true

3 I thought this was a boring activity.
1 - Not at all true
2
3
4 - Somewhat true
5
6
7 - Very true

4 I enjoyed playing the game very much.
1 - Not at all true
2
3
4 - Somewhat true
5
6
7 - Very true

5 While I was playing the game, I was thinking about how much I enjoyed it.
1 - Not at all true
2
3
4 - Somewhat true
5
6
7 - Very true

6 This activity did not hold my attention at all.

1 - Not at all true
2
3
4 - Somewhat true
5
6
7 - Very true

7 I would describe playing the game as very interesting.
1 - Not at all true
2
3
4 - Somewhat true
5
6
7 - Very true

8 Playing seemed automatic.
No
Sort of
Yes

9 I played without thinking about how to play.
No
Sort of
Yes

10 I really got into the game.
No
Sort of
Yes

PART B: NAVIGATION
Navigation means finding your way through the game environment.
Please answer the following questions about learning how to navigate this game level:

11 I found learning how to navigate the game environment hard.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

12 I felt competent while learning how to navigate the game environment.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

13 I found learning how to navigate the game environment complicated.
Agree

Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

14 Learning how to navigate the game environment was difficult for me.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

15 I found learning how to navigate the game environment frustrating.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

16 Learning how to navigate the game environment was easy for me.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

17 I felt incompetent while learning how to navigate the game environment.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

18 I found learning how to navigate the game environment simple.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

PART C: GUIDANCE
Guidance means the vibration or light direction cues provided by the system.
Please answer the following questions about guidance (circle one):

19 Navigating would be difficult to do without guidance.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

20 The guidance makes it easier to navigate.

Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

21 I was confused by the guidance.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

22 The guidance caused my performance to suffer.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

23 I found the guidance frustrating.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

24 I found it easy to recover from mistakes while receiving guidance.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

25 The guidance often behaved in unexpected ways.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

26 Overall, I found the guidance useful.
Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Disagree

Appendix C: Post-test Questionnaire

POST-TEST QUESTIONNAIRE

Would you play the game again with visual guidance?
- Yes
- Maybe
- No

Would you play the game again with vibration guidance?
- Yes
- Maybe
- No

Would you play the game again with no guidance?
- Yes
- Maybe
- No

Which form of guidance did you prefer?
- None
- Either/Both
- Visual
- Vibration

How would you compare the difficulty of the game levels?
- About Equally Difficult
- About Equally Easy
- Some Were More Difficult Than Others

What did you like about the guidance? (either visual or vibration)

What did you dislike about the guidance? (either visual or vibration)

Do you have any other comments?

Appendix D: Levels and Conditions

Table 3 Counterbalancing game levels and conditions by participant and trial.

Participant #	Trial #	Condition	Game Level
1	1	Visual	Coconut Mall
	2	None	Toad's Factory
	3	Haptic	Koopa Cape
2	1	None	Coconut Mall
	2	Haptic	Koopa Cape
	3	Visual	Toad's Factory
3	1	Haptic	Koopa Cape
	2	Visual	Coconut Mall
	3	None	Toad's Factory
4	1	Visual	Koopa Cape
	2	Haptic	Toad's Factory
	3	None	Coconut Mall
5	1	None	Toad's Factory
	2	Visual	Coconut Mall
	3	Haptic	Koopa Cape
6	1	Haptic	Toad's Factory
	2	None	Koopa Cape
	3	Visual	Coconut Mall
7	1	Visual	Coconut Mall
	2	None	Toad's Factory
	3	Haptic	Koopa Cape
8	1	None	Coconut Mall
	2	Haptic	Koopa Cape
	3	Visual	Toad's Factory
9	1	Haptic	Koopa Cape
	2	Visual	Coconut Mall
	3	None	Toad's Factory
10	1	Visual	Koopa Cape
	2	Haptic	Toad's Factory
	3	None	Coconut Mall

11	1	None	Toad’s Factory
	2	Visual	Coconut Mall
	3	Haptic	Koopa Cape
12	1	Haptic	Toad’s Factory
	2	None	Koopa Cape
	3	Visual	Coconut Mall
13	1	Visual	Coconut Mall
	2	None	Toad’s Factory
	3	Haptic	Koopa Cape
14	1	None	Coconut Mall
	2	Haptic	Koopa Cape
	3	Visual	Toad’s Factory
15	1	Haptic	Koopa Cape
	2	Visual	Coconut Mall
	3	None	Toad’s Factory
16	1	Visual	Koopa Cape
	2	Haptic	Toad’s Factory
	3	None	Coconut Mall
17	1	None	Toad’s Factory
	2	Visual	Coconut Mall
	3	Haptic	Koopa Cape
18	1	Haptic	Toad’s Factory
	2	None	Koopa Cape
	3	Visual	Coconut Mall
19	1	Haptic	Coconut Mall
	2	None	Toad’s Factory
	3	Visual	Koopa Cape
20	1	Visual	Coconut Mall
	2	None	Koopa Cape
	3	Haptic	Toad’s Factory
21	1	None	Koopa Cape
	2	Haptic	Coconut Mall
	3	Visual	Toad’s Factory
22	1	Haptic	Koopa Cape
	2	Visual	Toad’s Factory

	3	None	Coconut Mall
23	1	Visual	Toad’s Factory
	2	Haptic	Coconut Mall
	3	None	Koopa Cape
24	1	None	Toad’s Factory
	2	Visual	Koopa Cape
	3	Haptic	Coconut Mall
25	1	Haptic	Coconut Mall
	2	None	Toad’s Factory
	3	Visual	Koopa Cape
26	1	None	Coconut Mall
	2	Visual	Koopa Cape
	3	Haptic	Toad’s Factory
27	1	Haptic	Koopa Cape
	2	None	Coconut Mall
	3	Visual	Toad’s Factory
28	1	Haptic	Koopa Cape
	2	None	Toad’s Factory
	3	Visual	Coconut Mall
29	1	Haptic	Koopa Cape
	2	Visual	Toad’s Factory
	3	None	Coconut Mall
30	1	Visual	Toad’s Factory
	2	Haptic	Coconut Mall
	3	None	Koopa Cape