Proceedings of the Emerging Technologies Conference (ETC) 2009

ETC-2009-0030

A PRELIMINARY INCONGRUENT MOVEMENT STUDY IN AN IMMERSIVE VIRTUAL REALITY SETTING

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ABSTRACT

The study of human-computer interaction requires an understanding of how humans handle sensory information. This paper presents the results of a preliminary research project that challenged users to process sensory data that violated normal expectations by using a Virtual Reality environment to horizontally invert the results of a participant's actions. By observing learning processes and measuring rates of improvement, the researchers found that users employ a variety of strategies to compensate for the change in visual stimuli. These preliminary results suggest that over time users can become as proficient with altered visual stimuli as with normal stimuli.

NOMENCLATURE

Virtual Reality, Sense-of Movement, Human Perception

INTRODUCTION

Human perception is a fundamental part of human-computer interaction. Studying perception can lead to a better understanding of the relationship between humans and systems and can inform our designs. Experimental psychology has shown that the human mind is extremely adaptable. From accommodation to inverted vision to the remapping of neural signals in order to control prostheses, most evidence shows that, given time, humans and other animals can adjust how they process sensory data. As humans become accustomed to atypical sensory information they may translate and use that information subconsciously.

Past research suggests that human perception adjusts to atypical stimuli in four stages (Kohler 1964). However, studies of such adjustments in virtual environments (VEs) are rare. This pilot study used an immersive Virtual Reality (VR) environment to present contradictory visual stimuli to research participants. The project explores an individual's performance and adaptation when placed in an environment that contradicts normal rules of vision and movement. We presented four study participants with a gross motor task and monitored their rate of accommodation in the contradictory VE. The preliminary results seem to indicate that further research is likely to help explain how users adapt to sensory data that contradicts their normal expectations. The study was designed to show how a VE is useful for exploring two research questions:

- How quickly do individuals learn to compensate for contradictory visual stimuli in 3D virtual environments?
- When do individuals compensate for contradictory perception with conscious effort, and when do they take on a “second nature?”

Answers to these questions may guide the design of more intuitive and immersive interfaces, and may increase knowledge about the relationship between human perception and human self-concept. While these questions focus on perceptual research in VR environments, answers to them are potentially of use to many disciplines related to perception. A partial list would include researchers designing immersive systems (accommodation), psychologists studying perception (incongruent visual stimuli), medical scientists studying physiology and rehabilitation techniques, and critics and philosophers studying self-concept in digital media/virtual environments.

A variety of prior research and experimentation in human perception forms the basis of the current project. These earlier experiments are briefly described below.

BACKGROUND

Philosophical Approaches

Philosophers have been closely influenced by cognitive psychology and speak directly to human perception of VEs. Alva Noë (2004) disagrees with the popular view that perception is input and action is output. He claims that perception is "a skillful activity on the part of the animal as a whole" and states "to be a perceiver is to understand, implicitly, the effects of movement on sensory stimulation." As evidence, he notes that blind creatures can think but thoughtless creatures can't see.

Physiological and Psychological Approaches

For many years, researchers have been interested in the human "sense-of-self," and the related topic of sense of movement. Indeed, as has been shown above, human perception and action are closely intertwined. Berthoz (2000) calls perception an internal simulation of action. A good place to start is the physical limitations of the human body. Movement is restricted by the joints and the physical proportions of the body. We must also take into account the limitations of the senses. The eyes, for example, have a 135-degree vertical and 200-degree horizontal field of view (Gibson, 1979).

Multiple sensory inputs combine to create bodily experience, including visual, vestibular, and proprioceptive inputs. The vestibular system includes semicircular canals within the ear that sense inertia, providing a Euclidian frame of reference. The proprioceptive system senses the position of body parts, allowing the body to receive feedback for its motor actions. Deviation between expected and actual sensory information causes rapid adjustment of movements. Since the brain tends to favor inputs with higher spatial acuity, it often trusts vision over proprioception. The perception of self-motion is called vection. The velocity of scenic motion, the spatial frequency of the scene, and the distance of the scene all influence vection (Giummarra et al. 2008, Berthoz 2000).

> “self-movement depends on perceptual modes of self-awareness, for example, proprioception and also 'perspectival self-consciousness' (i.e. the ability to keep track of one's relation to the world around one)” (Noë 2004)

One goal of virtual environments is to make the user "feel" like they are in a different place from where they are physically situated. This feeling is called presence—"a state of consciousness, the (psychological) sense of being in the VE," (Slater et al. 1996). Increasing the quality of sensory information increases the feeling of presence (Dinh et al. 1999). For example, a larger field-of-view (FOV) has been associated with an increase in presence (Tan et al. 2003). Dohse (2007) states, "Increasing the field of view increases the degree to which the participant's proprioception will be appropriately mapped." Finally, a user's level of involvement positively impacts presence (Witmer and Singer 1998).

Technical

Virtual reality using stereoscopic viewing and position tracking allows participants to use natural human motions to interact with computer models in a 3D space. VR has matured beyond providing a stereo view with the ability to fly through a scene—users can now become truly immersed in an interactive 3D environment. For example, today it is common to interact with 3D CAD models in VR. Advanced VR technology can provide a test bed for studying issues related to sense-of-self and sense-of-movement. The technology can benefit from such studies, too. For users to perform tasks in VR most efficiently, VR system designers need a detailed understanding of human perception.

The term "immersion" is used as a quantifiable description of technology (Slater et al., 1996). Display size, field-of-view, stereo graphics, and other factors affect the level of immersion in an environment. The level of immersion is important because it correlates with presence (Witmer and Singer 1998) and very large displays improve performance on spatial tasks (Tan 2003). Prothero and Hoffman (1995) found significantly higher presence levels with a wider FOV and Czerwinski et al. (2003) found that a wider FOV increases not only presence, but also performance in 3D navigation tasks (Tan 2003).

One reason for the performance increases associated with increased immersion is that users can treat rotation as egocentric when using large displays as opposed to exocentric on smaller displays (Tan 2003). When using egocentric rotation, the user rotates his or her body within the space. When using exocentric rotation, the user rotates the space around him or herself (Tan 2003).

A problem with modern VR systems is simulator sickness. The phenomenon is similar to motion sickness, in that both are caused by a visual/vestibular mismatch (Dohse 2007). Not only does a larger field-of-view increase immersion (and presence), but it also contributes to sickness. Interestingly, no correlation has been found between presence and simulator sickness (Seay et al. 2001).

Testing

Researchers began studying human perception long before the days of VR systems. In more recent years, researchers have begun to use VR to replicate studies and extend previous research. In one classic study, Ivo Kohler (1964) had subjects wear prism goggles that flipped visual input. Objects physically located on the right side of the body were appeared as if they were on the left side, and vice versa. Users adapted in four stages. At first the subject experienced experiential blindness, detecting light and color but making no sense of it. The subject could not "see." In the second stage, the subject saw objects and they would appear on the opposite side of the body from where they actually were. Other senses operated normally. If the subject snapped his fingers on his left hand, the sound would still "sound" like it came from the left even though the snapping appeared to occur on the right. In the third stage, vision "won". The snapping would now look, sound, and feel like it came from the right. Finally, everything reverted to normal. Objects on the left appeared to be on the left, even though the parts of the visual system receiving the light inputs were those normally associated with stimuli on the right. The same series of phenomena occurred when removing the goggles (Kohler 1964).

Berthoz (2000) created a trolley rig in his lab for studying human perception of motion. With the trolley, the user could be moved in one direction while a projector displayed a conflicting moving scene. Berthoz used the rig to study the interactions between visual and vestibular input. This study is a good example of an early attempt to use display technology to study these phenomena.

METHODOLOGY

Our team has designed an immersive virtual environment as a test bed for researching human perception involving incongruent visual stimuli using the C4 at Iowa State University. Descriptions of the test bed components follow.

1) **Virtual Environment**
   The virtual environment was designed to be simple enough not to distract the participants from their task but detailed enough to provide a rich perceptual experience. Colors and textures were chosen accordingly. Virtual walls are rendered with a layout similar to the physical C4 walls. A virtual ball is rendered and given a constant speed.
2) **User Tracking**
   The user's location is tracked continuously and the data is used to "flip" the environment and detect collisions. The user's movement is tracked along both horizontal axes. Visual cues indicate the bounds of the virtual environment to the user.
3) **Collision Detection**
   Collision detection determines when the ball should "bounce." A collision occurs the ball contacts any of the four vertical virtual walls or the front of the user. Collisions do not occur when the ball approaches the user from behind since the user always faces forward in the C4. To indicate a successful "hit," the ball changes color temporarily. When a collision is detected, the trajectory of the ball is altered accordingly.
4) **Log Data**
   A log file is created while the system is running. A time-stamp is recorded for each collision between the ball and the participant.

Experiment

The user was guided through the following protocol:

1) **First Trial**—The user spent 5 minutes using the application with normal visual stimuli. This provided a baseline for the rate of success for each user.
2) **Questionnaire 1**—Between trials, the user filled out a short questionnaire based on the Immersive Tendencies Questionnaire (See Appendix B) to gauge immersive tendency and prior experience with VR systems.
3) **Second Trial**—The user spent 5 minutes using the application with the horizontal axis inverted. Researchers used hit time-stamp data to compare the experience of the inverted environment to that of the unaltered environment. Test cases are explained further in Table 1.
4) **Questionnaire 2**—After the second trial, the user answered a short questionnaire to gauge their experience of presence, based on the Presence Questionnaire (Witmer and Singer 1998). They

were also briefly interviewed regarding their experience following the guidelines of an unstructured qualitative interview (Fontana and Frey 2007).

Since this was a preliminary study, the researchers were not certain which test cases would generate the clearest data, which prior experiences may influence test results, or how long trials may take to show significant results. Data from the initial study will guide changes to the experiment.

ANALYSIS

The researchers were primarily interested in two aspects of participant performance. One was the rate of success as user's attempted to intercept the virtual ball. The other was the learning process. The success rate was measured by the frequency of interceptions. Each time the ball hit the user's body a success was recorded. As the user became familiar with the system, we expected that the rate of successful interceptions would increase, indicating that the user had accommodated to the system. We also observed the strategies that the user employed during the learning process.

RESULTS

The initial study involved four participants. While this is not enough for statistical analysis, the initial data indicates possible avenues of further study. This data came from several sources, including

- Task success rates in the virtual environment
- Presence and immersive tendencies surveys
- Observations and interviews of participants

From these sources, we hoped to observe the initial stages of learning when a person is faced with visual information that contradicts their experience. We also hoped to examine any perceptual changes in how users process that visual information. In general, the data we have does not show perceptual changes, but it implies that such changes might be observable in longitudinal studies.

Task Success Rates in the Virtual Environment

Each participant was asked to block a moving ball with his or her body, first in a normal visual space and then in a horizontally inverted visual space. The system recorded the time between each hit. Based on this, we calculated a 3-member moving average of the task success rate, represented as number of hits per second. Each participant's data was normalized for comparison. Figure 1 (next page) displays the aggregated data for normal and inverted visual space for all participants. In general, the rate of success for each user in normal visual space was several times higher than their rate of success for the inverted space. Furthermore, the higher variability in the success rate for the inverted space indicates greater inconsistency of performance, as seen in the 10-member moving average displayed in Figure 1.

Aside from a gross comparison of success rates, Figure 1 also suggests a trend with respect to the changing rate of success. In both visual spaces, users improved slightly but noticeably during the 5-minute trials. This trend may continue over longer trials, warranting a larger study.

Digging deeper into individual participants' trials, further trends emerge. Some participants essentially maximized the theoretical rate of success in the normal space. Given that the ball's velocity and the dimensions of the visual space were fixed, users had a hard limit as to how many times they could successfully block the ball in 5 minutes. What remains to be seen is whether the success rate pattern for the inverted space would rise to similar levels as that of the normal space.

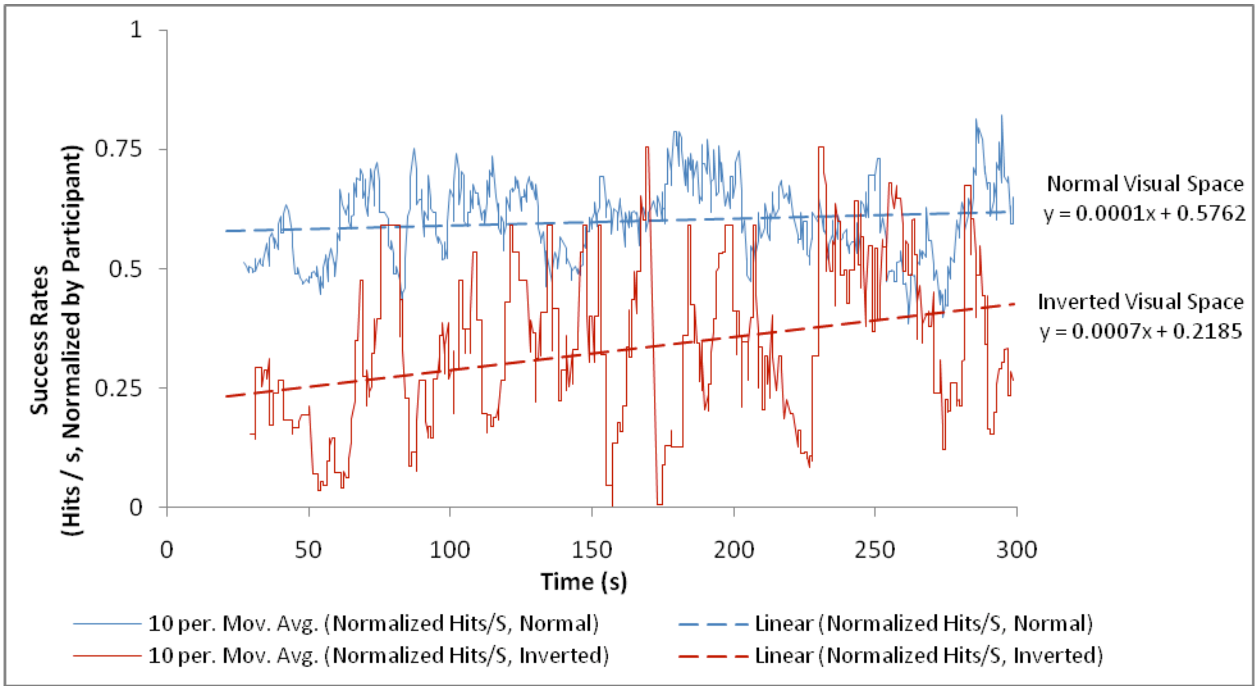

Figure 1: Over a 5 minute trial, participants in both normal (N) and inverted (S) visual spaces

We hypothesize that, given longer trials, at least some users are likely to achieve similar success rates in both spaces and will be able to dynamically switch between inverted and normal space. This is strongly indicated by the researchers' own experiences in the inverted virtual environment. In the course of testing, researchers spent significantly more time accommodating to the inverted visual space than indicated in the initial trails. By the end of the study, one researcher consistently scored similar rates of success blocking the ball in both inverted and normal visual space (see Figure 2). More study over longer periods will be required to verify that other participants can learn that skill.

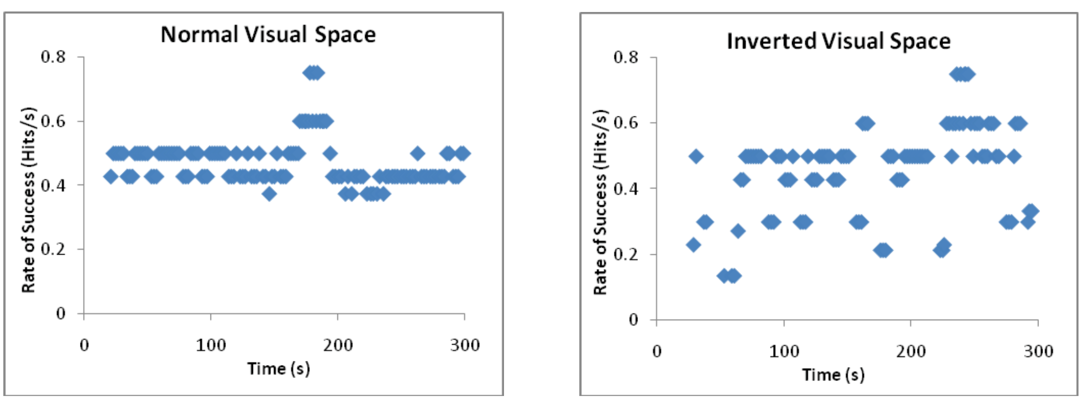

Figure 2: One researcher adjusted as well to the inverted visual space as to the normal space.

While the researcher in Figure 2 achieved a high rate of success in the inverted visual space, the hit rate still has more variance due to several instances of failure and subsequent recovery. The success rate in the normal visual space remained almost constant, except for one spike that represents a deliberate attempt at a more aggressive strategy by intercepting the ball closer to the front wall.

Presence and Immersive Tendencies

We collected survey data on participants' experience with technology, experience of presence in the virtual system, and the immersive tendency. This data helped handle outlier participants. In a larger study, this data may indicate a correlation between immersion and adjustment of perception. This correlation could exist anywhere on a continuum between two extremes. On one hand, users with a higher experience of immersion may be more prone to adjust to the system. On the other hand, immersive users may be less likely to override perceptual input. A larger study will be necessary to determine which pattern emerges in the virtual environment.

Observations and Interviews of Participants

Some of the most interesting conclusions from the study came from observations of the users as they attempted the inverted-vision task and from subsequent interviews, especially with the participants that had higher rates of success. These participants developed strategies to override their perceptual habits.

Some participants reported frustration at the inverted perception task. They could see the ball and elements of the environment, but they consistently moved towards the ball they were trying to catch. In the inverted space, this only resulted in the ball moving farther away, understandably producing some anger and frustration.

The participants who had higher rates of success actively developed strategies to override their perceptual habits. Some used a trial and error approach by moving a short distance, visually inspecting the results, and moving again. Others attempted to train themselves to move away from the ball, essentially reframing the task in a way that made it easier. Using these strategies, participants could string together several successful hits. The researcher who spent the most time in the inverted space reported that he deliberately ignored the walls of the system—the most prominent source of contradictory information—to always keep the ball directly in front of him. But with all of these strategies, a single miss tended to let visual habits take over, re-starting the adjustment process.

The level of conscious effort may suggest that, rather than perceiving the visual information differently, participants are learning to react to the information differently. This is similar to Kohler's prism goggles study, where users had to operate in a totally inverted visual space for days or weeks before experiencing a change in how they perceive vision. We think we are witnessing the initial stages of learning to compensate for inverted visual information. These results suggest that exploring that learning curve may produce important conclusions for the visual relationship between humans and virtual environments.

CONCLUSION

Future work will include changes to the protocol and the system. Since all trial users were members of the team, they knew about the shift in the horizontal axis before the trial. Users needed more time to show significant improvement or lack thereof. Users received a verbal or physical indication that they were close to the actual walls of the environment in order to prevent injury and damage.

Whatever patterns arise from the data collected in this study, it will increase knowledge of the accommodation process of humans using new virtual systems. This will have implications for several fields of inquiry, from the design of immersive systems and rehabilitation techniques to studies of perception, cognition, and philosophy of human nature. At the very least, this preliminary study will inform adjustments to the design of the planned full-scale study to generate the most useful findings.

Questions of human nature, whether approached philosophically, physiologically, or technically, encounter important challenges when human beings interact with virtual environments. Inspecting human beings in incongruent virtual environments will help advance our thinking on these matters.

ACKNOWLEDGMENTS

The authors would like to thank the Iowa State University's Virtual Reality Applications Center for the use of computational resources and hardware.

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