NaviChair: Evaluating an Embodied Interface Using a Pointing Task to Navigate Virtual Reality

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ABSTRACT

This research aims to investigate if using a more embodied interface that includes motion cueing can facilitate spatial updating compared to a more traditional non-embodied interface. The ultimate goal is to create a simple, elegant, and effective self-motion control interface. Using a pointing task, we quantify spatial updating in terms of mean pointing error to determine how two modes of locomotion compare: user powered motion cueing (use your body to swivel and tilt a joystick-like interface) and no-motion cueing (traditional joystick). Because the user-powered chair is a more embodied interface providing some minimal motion cueing, we hypothesized it should more effectively support spatial updating and, thus, increase task performance. Results showed, however, the user-powered chair did not significantly improve mean pointing performance in a virtual spatial orientation task (i.e., knowing where users are looking in the VE). Exit interviews revealed the control mechanism for the user-powered chair was not as accurate or easy to use as the joystick, although many felt more immersed. We discuss how user feedback can guide the design of more effective user-powered motion cueing to overcome usability issues and realize benefits of motion cueing.

Categories and Subject Descriptors

H.5.1 [Information interfaces and presentation]: Multimedia Information Systems - *Artificial, augmented, and virtual realities*

Keywords

Motion cueing; active locomotion; spatial updating; virtual reality; virtual locomotion

1. INTRODUCTION

Knowing where we are in a real environment is easy to determine and often automatic. Even when moving short distances with closed eyes, we can remain aware of where different objects are in the surrounding environment. In the case of virtual environments (VE), however, people often become lost and disoriented more easily. Why the discrepancy? And, how can we make navigation through VEs more effective, thus enabling real-world-like performance and ease-of-orientation?

Many researchers believe sensory cues from physical locomotion, such as proprioceptive and vestibular cues, are required to enable spatial updating - the largely automatized cognitive process that computes the spatial relationship between a person and their surrounding environment as they move based on perceptual information about their own movements [8,13,15,18]. Disorientation often causes unhappiness, anxiety, and discomfort [6]. And, this ultimately results in reduced usefulness, performance, and user acceptance. Being able to successfully orient in VR seems to be essential to completing many tasks, and it appears to be important to minimize sensory conflict to reduce negative side effects. Even though photorealistic immersive stimuli can under certain conditions be sufficient to enable automatic spatial updating when the visual scenery contains well-known landmarks [12], many still fail to update visually simulated self-motions [8]. A large body of literature (see [14] for review) has shown the availability of body-based information during movement in VR enables a better sense of direction compared to only visual information. That is, small physical motions seem to trigger automatic spatial updating and allow participants to more easily navigate in VR. Researchers have found using body rotations can lead to performance improvements in a navigational task compared to visual-only rotations [5,8]. There appears to be a disagreement in the literature as to what the minimum requirements are to enable spatial updating.

One factor to improve spatial updating is embodied, active locomotion (i.e., where users use their own body to move around). Motion cueing is an approach that simulates proprioceptive and vestibular cues as closely as possible when walking is not feasible. Smaller spaces often have constraints that do not allow 1:1 motion, so cheating the senses intelligibly is important in enabling the feeling of moving when actually stationary. Research has found motion cueing in VR can provide means of increasing self-motion or vection [7] (i.e., feeling like you are moving when you are actually not). Similar benefits can be gained using a modified force-feedback manual wheelchair [10] or gaming chair where participants control virtual locomotion by leaning into the direction they want to travel [1,11]. Studies of virtual and real travel have shown positive effects of motion cues on spatial orientation [8].

Motion cueing has been frequently used in industry for driving or flight simulation [2,16]. And, user-powered motion cueing has been shown to facilitate visually-induced vection [4,10,11]. Yet, it has not been determined if motion cueing can also help induce automatic spatial updating, ultimately giving the participant a better and more intuitive sense of orientation in the VE. One ecologically valid spatial updating measure is a pointing task, where participants travel along a pre-determined trajectory and point to previously-seen objects [8,18], and will be used in this study. We assess spatial updating because participants' mental spatial representation will have to be already automatically updated when they arrive at a new location or orientation in order to give a fast, intuitive, and accurate response.

SUI '15, August 08 - 09, 2015, Los Angeles, CA, USA
© 2015 ACM. ISBN 978-1-4503-3703-8/15/08…$15.00
DOI: http://dx.doi.org/10.1145/2788940.2788956

This research aims to investigate if using a more embodied interface that includes motion cueing (here: a NaviChair leaning stool interface) can facilitate spatial updating compared to a more traditional non-embodied interface (here: joystick). The ultimate goal is to create a simple, elegant, and effective self-motion control interface. Many VR systems can be very costly, sometimes millions of dollars. Intelligently cheating our senses through small, physical motions could have similar effects as full motion simulators without the cost.

2. STUDY METHODOLOGY

The goal was to determine if a more embodied locomotion interface (NaviChair) could help trigger spatial updating and thus increase performance in a virtual orientation task.

2.1 Participants and Environment

We recruited 30 (15 female) SFU students with an average age of 22.3 years. Participants had normal or corrected vision and reported they were not prone to motion sickness. Research was conducted under permission of the SFU Research Ethics Board (REB #2012c0022). VE paths were selected to ensure that participants would have to take left or right 60° and 120° turns at regular intervals. The lines of sight were blocked by fog and we removed all the structures and objects from the environment during the pointing tasks. The VE contained no global landmarks or other obvious directional cues. Participants were guided through the VE a female avatar that moved along a pre-defined path. Participants stopped at five different locations and pointed to all six previously memorized objects **(cf. 1)**.

2.2 Experimental Design, Stimulus, Apparatus, and Procedure

The experiment uses a within-subject design with two experimental conditions, defined by two locomotion interfaces **(cf. 2). (1)** User powered motion cueing interface used a swivel seat that acted like a joystick, which we call NaviChair – participants used their own body to move forward, e.g., tilting the chair forward moved yourself in the VE forward, and rotate the chair to rotate themselves in the VE (leaning left/right was disabled to ensure users rotated with the avatar). **(2)** Non-motion cueing locomotion interface was a stationary chair where participants moved with a normal joystick.

Each participant completed the spatial updating (pointing) task twice – first using NaviChair and then the joystick interface, or vice-versa. The order of interfaces and presentations for two variations of VEs (mirror images) were counter-balanced, creating four distinct experimental groups: NaviChair and VE layout 1 (N=8), NaviChair and VE layout 2 (N=7), joystick and VE layout 1 (N=7), and joystick and VE layout 2 (N=8). In all cases, participants viewed a 2.45 × 1.55m screen non-stereoscopically, which provided approximately 74° by 52° field of view. A single BenQ W1080ST (1920 × 1200). Whenever participants encountered a new location

they stopped and pointed, using a modified joystick, to all six target objects. This allowed us to test how participants' orientation in the environment evolved over time as task difficulty gradually increased.

To ensure sufficient control familiarity, each trial started with a practice run with an open environment. Next, participants were shown the scene with all the embedded objects, were asked to memorize their locations from one fixed vantage point, pointed to each object and were given on-screen feedback of pointing error, which needed to be within +/-23° to continue. Following were two

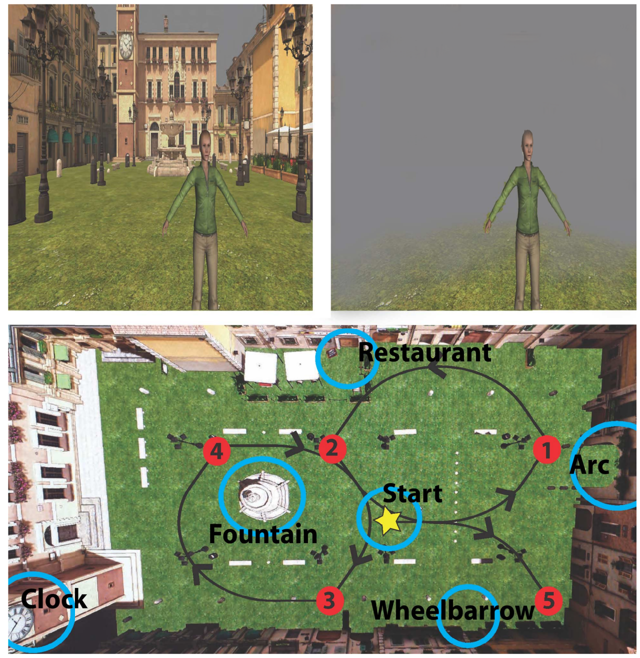

Figure 1: VE 1st-person POV (top) with (left) and without (right) landmarks, and top-down view (bottom) showing path (black), starting location (star), pointing locations (red dots), and target objects (cyan circles).

experimental blocks. Between blocks, participants filled out a short demographics questionnaire. Finally, after the second block, we completed a short semi-structured interview.

2.3 Data Collection and Analysis

Participants' spatial orientation performance was quantified using *mean absolute pointing error*, i.e., the arithmetic mean of absolute pointing errors for all targets at a given location and measures overall accuracy of the participants. We also assessed motion sickness, self-report orientation ability and task difficulty, and locomotion preference. To test if there was a difference in performance between joystick and NaviChair control, or the two variations of VEs, and if there was an interaction between input device and VE, we performed a within subject, repeated measures 2×2×6 ANOVA. A within subject design was conducted to account for individual differences, which are prevalent in spatial abilities [17]. The independent variables were interface (within), gender (between), and location of objects (within).

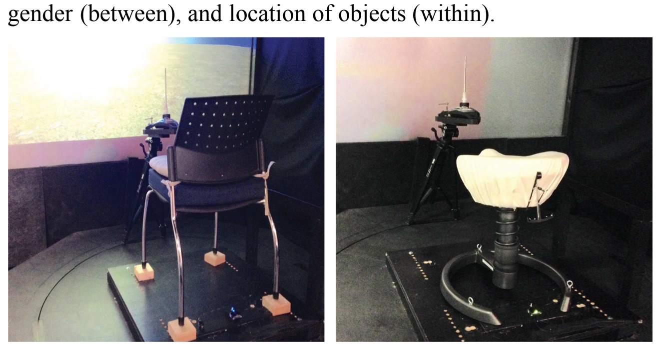

Figure 2: The locomotion interfaces: no motion cueing with joystick input (left) and motion cueing with NaviChair (swopper chair-based) input (right).

3. RESULTS

3.1 Mean Absolute Pointing Error

A significant main effect for interface was found, $F(1, 121) = 17.260$, $p < .001$, $\eta_p^2 = .125$, indicating the joystick interface ($M = 66.66$, $SE = 2.84$) resulted in a lower mean absolute pointing error compared to NaviChair ($M = 80.65$, $SE = 2.59$). The effect size η_p^2 is medium showing that the effect of interface accounts for 12.5% of the variance in mean absolute pointing error. This main effect was qualified by a significant interaction interface*gender, $F(1, 121) = 4.969$, $p = .028$, $\eta_p^2 = .028$, indicating that the effect of interface was stronger for males than females (**cf. 3**). That is, females had a lower mean absolute error with joystick interface ($M = 74.42$, $SE = 3.81$) compared to NaviChair ($M = 80.90$, $SE = 3.47$), and males had a lower mean absolute error with joystick interface ($M = 58.91$, $SE = 4.21$) compared to NaviChair ($M = 80.39$, $SE = 3.83$). Location showed a significant main effect, $F(4, 121) = 12.138$, $p < .001$, $\eta_p^2 = .286$, indicating that mean absolute pointing error was significantly different depending on the which object location the observer was at (**cf. 3**). Post hoc tests found location 1 had significantly lower mean absolute error than locations 2 ($p < .001$), 3 ($p < .001$) and 4 ($p = .005$), and location 2 had significantly lower mean absolute error than locations 4 ($p = .035$) and 5 ($p = .003$). All other effects, main effects and interactions, were non-significant.

3.2 Exit Interview

The majority of participants (21 out of 30) preferred the joystick interface. When asked why they preferred the joystick interface, many participants reported the joystick feeling more accurate, more in control, more familiar to use, mapped proportionally to the movement in the VE, and allowed some to use it as a strategy to remain oriented. Participants who preferred the joystick interface reported NaviChair was uncomfortable to use because of height issues or slipping off the chair, the controls were unfamiliar and hard to learn even after the training phase, NaviChair took a lot more concentration to remain balanced and control their movements, and sensitivity was either too much or too little depending on the participant. There were some participants who found NaviChair to be a more fun and interesting experience, though they ultimately preferred the joystick for familiarity reasons. A minority of participants (9 out of 30) preferred NaviChair for several reasons. Participants reported feeling more engaged with the VE, more oriented, and less motion sick with NaviChair. The main reason participants who preferred NaviChair did not like the joystick was because they felt the joystick was not as immersive. These participants felt as if they were actually moving through the VE with their own bodies, rather than looking at a screen and moving an avatar around.

4. DISCUSSION AND CONCLUSIONS

Contrary to our predictions, mean absolute pointing error **(cf. 3)** seems to indicate user powered motion cueing with NaviChair does not help orient participants in a VE, at least for the current methods used. Results show there are different factors having an influence on pointing performance. The interface*gender interaction for mean absolute error shows females on average seem to be worse than males at pointing to previously seen objects in a VE. This result is in keeping with previous research that found males exhibit better way finding performance than females (for a review see [3]). However, males were only significantly better than females with the joystick interface. Our result of the gender effect is inconsistent with a previous study, which found males benefitted from using physical rotations versus visual only rotations where females did not [5]. Our result of females having higher pointing error with the joystick interface compared to males is consistent with females using landmarks (not present in our experimental task) when navigating, and their performance decreases when none are present [9]. Additionally, Waller [17] suggests underlying individual differences in cognitive spatial abilities co-related with gender may explain gender gaps in navigation performance. And Coluccia and Louse [3] hypothesize, based on their literature review, that gender differences in orientation emerge only when tasks require a high load of Visuo-Spatial Working Memory. Here, males would show better orientation performance because of their larger Visuo-Spatial Working Memory span.

This study extends findings on the advantages and disadvantages of user-powered motion cueing for different interfaces including a Gyroxus gaming chair [11], a wheel-chair motion model [10], and the ChairIO gaming interface [1]. In Riecke and Feuereissen's study [11], active control reduced vection occurrence and increased vection onset latencies. Similarly, our study used active control for both NaviChair and joystick interfaces, so the effects of user powered motion cueing may be diminished. It remains to be investigated why and under what conditions active control reduces vection and spatial orientation performance. Moreover, our qualitative results are consistent with Riecke and Feuereissen's who also found that the usability and control issues of the gaming chair might have counteracted the benefit of motion cueing. Based on the insights gained from the current study and prior research (e.g., [1,4,5,11,14,15]), we are planning to study how these usability and control issues could be addressed.

Riecke [10] found that a simple locomotion paradigm like a wheelchair with user powered minimal motion cueing decreased vection onset latency and increased convincingness and vection intensity. While NaviChair did not help with pointing performance, participants did report in the qualitative exit interview that they felt NaviChair to be more immersive and allowed them to feel more a part of the virtual space. So, in terms of convincingness, NaviChair seems to be on the right path though its design needs improvement. Finally, Beckhaus and colleagues [1] designed a similar chair, called ChairIO, as an input device for gaming. They found this interface gives a novel experience for gamers and helped beginners play immediately. Extending these findings, we too found that participants who reported having high 3D game experience also found NaviChair

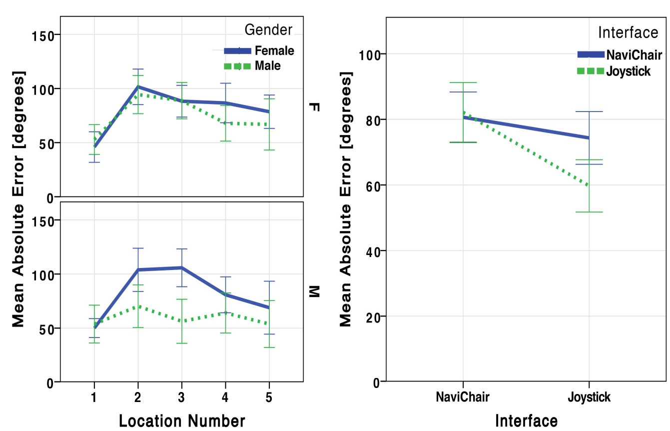

Figure 3: Mean absolute pointing error (degrees) as a function of location (left) for both females (top) and males (bottom), and gender and interface type (right) with 95% CIs.

to be a unique experience.

Exit interviews revealed many participants felt more immersed with NaviChair, though they reported better control and accuracy with the joystick. The control mechanism itself could be a contributing factor for why we found the joystick resulted in better pointing performance. NaviChair may have increased path integration errors and cognitive load and, thus, contributed to a worse pointing performance. For example, the need to actively control NaviChair that participants were not familiar with could have indirectly reduced attention to the visual stimulus or changed their viewing and fixation patterns, thus decreasing orientation. Alternatively, participants could have been fully focused on controlling and balancing NaviChair to pay sufficient attention to where they were going, thus increasing both path integration and spatial updating errors. It is feasible NaviChair facilitated automatic spatial updating, in the sense that it was relatively intuitive to remain oriented, but accumulating path integration errors counteracted such potential benefits.

There are several limitations in this study. First, participants are sitting down in both conditions, though they seem to be walking like the avatar in the VE, giving an obvious mismatch between what is real and what is virtual. Second, many of the participants reported in the exit interview they were already very familiar with the joystick, often for gaming, which may bias participants to do better with that mode of locomotion. Third, the design of NaviChair is still in its infancy. Adjustments and testing are an ongoing process in determining the ideal control parameters for the majority of users. Where the traditional joystick has well established control mechanisms, NaviChair still needs improvement. Ideally, the next step in this study will be to refine the controls of NaviChair to make controlling movement easier and fine-tuned to suit the user's needs.

Many factors including gender, location, and interface have an influence on a virtual pointing task. Our results suggest the presence or absence of user powered motion cueing may play a role in one's sense of orientation in VEs. When designing virtual systems, these individual factors should be kept in mind. Moreover, it seems user powered motion cueing with NaviChair in its current form may not be sufficient in helping people remain oriented in VEs. Exit interviews revealed NaviChair was difficult to control and make accurate movements, suggesting the control mechanism itself may have contributed to lower pointing performance. We aim to adjust NaviChair in order to make it as easy to control as a normal joystick.

5. ACKNOWLEDGMENTS

NSERC funded this research.

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