Development and Evaluation of a Hands-Free Motion Cueing Interface for Ground-Based Navigation

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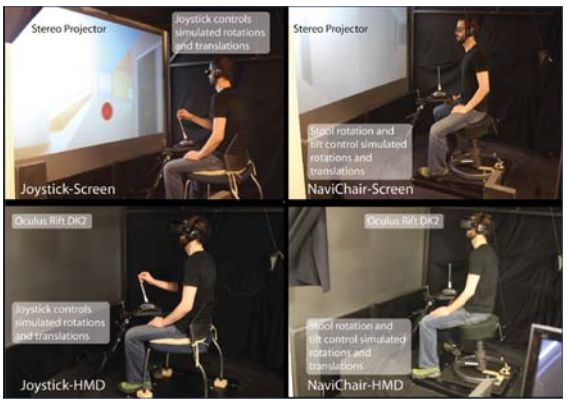
Abstract

With affordable high performance VR displays becoming commonplace, users are becoming increasingly aware of the need for well-designed locomotion interfaces that support these displays. After considering the needs of users, we quantitatively evaluated an embodied locomotion interface called the NaviChair (see figure 1) according to usability needs and fulfillment of system requirements. Specifically, we investigated influences of locomotion interfaces (joystick vs. an embodied motion cueing chair) and display type (HMD vs. projection screen) on a spatial updating pointing task. Our findings indicate that the NaviChair provided users with an immersive experience of a space regardless of display type, without requiring a costly interface that requires complex transport and setup limitations.

Figure 1: NaviChair locomotion interface (above)

Figure 2: Experimental setup (below)



Methods

In a balanced mixed-factorial design, participants evaluated both the NaviChair interface and a joystick interface (within-subjects), in combination with either an HMD display or 3D a projection screen (between-subjects). We assessed 32 students (17 female), aged 19-34 (M = 23.9) for usability and experience within a virtual environment (VE) of a proposed Student Union Building project. See figure 2 on the left for photos describing the experiment.

Our evaluation sought to answer these questions:
1) How do the NaviChair and joystick locomotion interfaces compare on measures of *spatial orientation*, pointing task *response time*, and ratings of *motion sickness*, *immersion*, *intuitiveness*, and *controllability*?
2) How do the HMD and 3D projector display compare in terms of user performance on measures of *spatial orientation*, and ratings of *motion sickness* and *immersion*?
3) What feedback do users have on the NaviChair locomotion interface and how might it be improved?

During the experiment, participants used each locomotion interface to follow a guiding sphere to 5 object locations along a path in the VE. At each location, the participant was asked to point to each previously encountered location. After using each interface participants were asked to rate motion sickness, and at the end of the experiment they were asked to rate immersion, intuitiveness and controllability.

Results & Discussion

We analyzed mean absolute pointing errors to investigate potential effects or interactions of the factors locomotion interface (within), display (between), gender (between), and pointing location (within) using a mixed-design 2x2x2x5 ANOVA.

As illustrated in figure 3, absolute pointing errors increased over the 5 locations of the traveled path $F(4, 140) = 3.523$, $p = .009$, $\eta 2 = .091$. This suggests that the task got successively harder and participants got increasingly disoriented the more pointing objects they had to update along their path.

Figure 3: Mean absolute pointing error per location

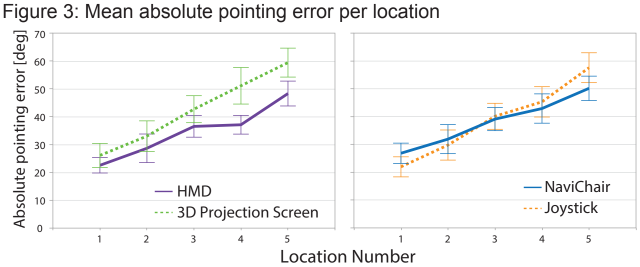
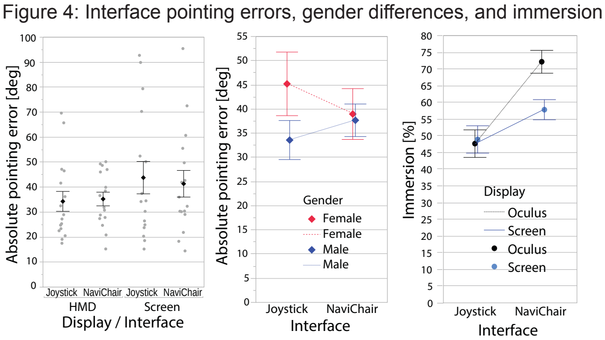


Figure 4: Interface pointing errors, gender differences, and immersion



Presented on the left of figure 4, a significant main effect of display was found, with a finding of lower overall pointing errors for the Oculus Rift HMD (M = 34.78, SE = 2.58) compared to the 3D projection screen (M = 42.46, SE = 2.54), $F(1, 139) = 4.500$, $p = .036$, $\eta 2 = .031$.

Displayed in the middle of figure 4, females had a lower pointing error using the NaviChair (M = 38.39, SE = 3.04) compared to the joystick (M = 44.97, SE = 3.24), and males had a higher pointing error using the NaviChair (M = 37.57, SE = 2.83) compared to the joystick (M = 33.58, SE = 3.01), $F(1, 139) = 5.280$, $p = .023$, $\eta 2 = .037$. This difference might suggest gender differences in their familiarity with the joystick.

Shown on the right of figure 4, the joystick resulted in lower mean immersion ratings (M = 48.13, SE = 2.91) compared to the NaviChair (M = 64.83, SE = 2.28), $F(1, 30) = 25.854$, $p < .001$, $\eta 2 = .463$.

When using the joystick, participants reported higher mean controllability ratings (M = 83.61, SE = 2.76) compared to the NaviChair (M = 57.56, SE = 3.21), $F(1, 30) = 50.610$, $p < .001$, $\eta 2 = .628$. Similarly, the joystick yielded higher intuitiveness ratings (M = 79.10, SE = 13.96) compared to the Navi- Chair (M = 64.88, SE = 16.88), $F(1, 30) = 23.065$, $p < .001$, $\eta 2 = .435$. Using the HMD increased mean motion sickness ratings (M = 22.45, SE = 3.60) compared to the projection screen (M = 6.19, SE = 3.60), $F(1, 30) = 10.189$, $p = .003$, $\eta 2 = .254$. The locomotion interface did not significantly affect motion sickness.

Users reported the NaviChair was a fun and attractive locomotion interface, and with more practice it could potentially grant a similar level of controllability as the joystick. The main advantage with the NaviChair appears to lie in the enhanced sense of immersion, specifically when used with the HMD. Still, the appropriateness of the display depends on whether users wish to engage with others (projection screen) or be more immersed (HMD). Interviews yielded ideas for future development and improvement of the chair, which we plan to implement in future design iterations.