Evaluating Joystick Control for View Rotation in Virtual Reality with Continuous Turning, Discrete Turning, and Field-of-view Reduction

Shyam Prathish Sargunam
Texas A&M University
United States
shyam.prathish@tamu.edu

Eric D. Ragan
Texas A&M University
United States
eragan@tamu.edu

ABSTRACT

Head tracking is commonly used in virtual reality applications to allow users to naturally view 3D content using physical head movement, but many applications also support joystick control to allow additional turning. Joystick control is convenient for practical settings where full 360-degree physical rotation is not possible or preferred, such as when the user is lying on a couch or sitting at a desk. Though joystick control provides the benefit of convenience, previous research and development projects have demonstrated joystick-controlled view rotation to have drawbacks of sickness and disorientation compared to more natural physical turning. To combat such issues, researchers have considered various technique configurations such as speed adjustments or reduced field of view, but empirical data is limited on how different design variations for joystick rotation influences sickness and ability to maintain spatial orientation. Our research compares three common joystick rotation techniques: (1) traditional smooth, continuous rotation, (2) continuous rotation with a reduced field of view, and (3) discrete rotation with fixed intervals. In a controlled experiment, participants traveled through a sequence of rooms and were tested on spatial orientation. Results showed no evidence of differences in orientation, but the results of sickness ratings found discrete rotations to be significantly better than field-of-view reduction.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **Mixed / augmented reality**;

ACM Reference Format:
Shyam Prathish Sargunam and Eric D. Ragan. 2018. Evaluating Joystick Control for View Rotation in Virtual Reality with Continuous Turning, Discrete Turning, and Field-of-view Reduction. In *IWISC 2018: 3rd International Workshop on Interactive and Spatial Computing, April 12–13, 2018, Richardson, TX, USA.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3191801.3191815

IWISC 2018, April 12–13, 2018, Richardson, TX, USA

ACM ISBN 978-1-4503-5439-4/18/04…$15.00
https://doi.org/10.1145/3191801.3191815

1 INTRODUCTION

Head tracking is commonly used in virtual reality (VR) applications to allow users to naturally view 3D content using physical head movement. Supporting natural physical interaction is often seen as one of the greatest benefits of VR technology, and prior research has demonstrated that realistic physical forms of travel and view control offer significant benefits for navigation (e.g., [5, 15]), presence (e.g., [17, 18]) and 3D spatial judgment tasks (e.g., [1, 7, 11]).

However, many VR applications do not rely solely on physical interaction, and many applications also support joystick control to allow additional turning. Joystick control is convenient for practical settings where full 360-degree physical rotation is not possible or preferred, such as when the user is lying on a couch or sitting at a desk. Though joystick control provides the benefit of convenience, previous research and development projects have demonstrated joystick-controlled view rotation to have drawbacks of sickness (e.g., [12]) and disorientation (e.g. [3]) compared to more natural physical turning. To combat such issues, developers often considered various technique configurations such as speed adjustments, and researchers have also explored reduced field of view (FOV) [6, 9], but empirical data is limited on how different design variations for joystick rotation controls compare to each other.

Our research contributes to this area through a study that compares three common joystick rotation techniques: traditional *continuous rotation*, continuous rotation with *reduced FOV*, and *discrete rotation* with fixed intervals for turning. The goal of our research is to investigate whether there are tradeoffs for different joystick rotation techniques in terms of sickness, preferences for home entertainment and the ability to maintain spatial orientation in a 3D environment. In a controlled experiment, participants traveled through a sequence of rooms and tested on spatial orientation, and we also collected subjective measures of sickness and preference.

2 RELATED WORK

Many travel and viewing techniques for VR have been studied in terms of effects on outcomes such as speed, accuracy, spatial awareness, and presence. Techniques generally vary in how users control movement. Usoh et al. [18] found that physical walking is the most natural and believable travel method in virtual reality, where the changes in user's tracked movements in the real world are applied directly to the virtual camera. However, physical walking usually requires large tracking space for the users to walk. Our research focuses on scenarios and real world setups where physical walking is not practical or not preferred. Researchers have explored many alternative techniques for such situations. Some examples

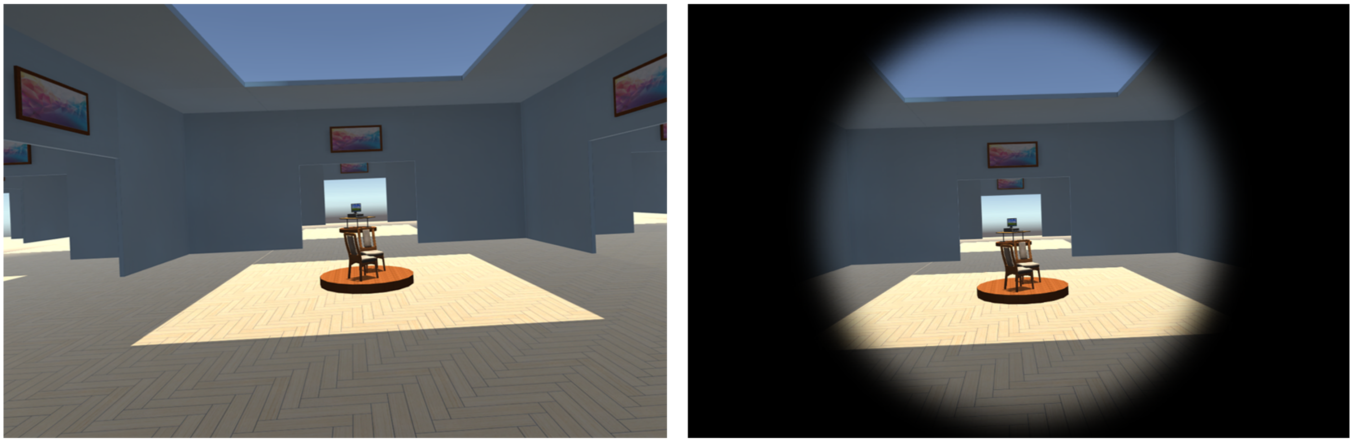

Figure 1: Screenshots showing perspective views of the virtual environment without FOV reduction on the left and with FOV reduction on the right

include: *walking in place* (e.g., [13, 18]), *leaning metaphor* (e.g., [14, 21]), or *guided head rotation* [16].

However, the most common approach for real applications is to use less natural techniques like *steering* (or *flying*) [3, 19] or *teleportation* [2, 4] using a hand-held controller. Studies have found that *teleportation* can cause disorientation while jumping from one place to another, since the positional changes are discrete and instantaneous [3]. In the presented research, we chose to avoid teleportation because we focus on studying techniques that support maintenance of spatial orientation during travel. Thus, our study uses ground-constrained steering, as this is the one of the most common options for travel in commercial applications.

Many other studies have included joystick rotation as part of their research. For example, Chance et al. [5] studied physical rotation to *visual turning* in which the virtual camera is rotated based on the joystick input. In other work, Riecke et al. [14] compared joystick controlled travel and rotations with a gaming chair setup where controls are based on the leaning metaphors. Generally, joystick controlled travel has been found to have problems when compared to more natural or physically-based techniques.

As one approach to these problems, researchers have considered limiting the FOV to reduce simulator sickness (eg., [9, 20]). For example, Fernandes et al. [6] studied subtle and dynamic FOV reduction for reducing sickness during virtual travel. Despite the prior research involving travel techniques and joystick control, the body of research specifically focusing on comparisons of different joystick-based travel techniques is limited.

3 EVALUATION

We ran a controlled experiment to investigate how the techniques being compared affect the spatial orientation of the users and to find out the preference of the users in terms of comfort, sickness and naturalness.

3.1 Techniques

Our study compared three types of joystick rotation techniques, which we will refer to as: *continuous rotation*, *discrete rotation*, and *reduced FOV*. The three techniques were designed to be controlled with an analog joystick on a common controller, as is common for many VR applications and 3D games.

The *continuous rotation* technique was implemented as the standard for how joystick rotation is usually used in virtual environments and games. Moving the joystick to the right or left rotates the camera heading relative to the vertical axis. The implementation for the study used a constant speed of 30 degrees/second. We found this speed to cause comparatively lesser sickness effects while not being too slow during our pilot studies.

In contrast, the *discrete rotation* joystick technique only allows turning in discrete increments of 30 degrees. This technique still uses the analog joystick, but the magnitude of discrete rotation was constant (the user could not control or adjust the angular amount for each discrete rotation). We chose 30 degrees because during pilot studies, we found that the change in virtual environment (VE) after a 30 degree turn is minimal when compared with greater angles. With this interval, some part of the VE is still within the virtual view before and after a turn, making the users feel less disoriented. This technique was chosen for our comparison because it reduces visual updating and limits optical flow during turning. Users can control a sequence of rotational "jumps" to achieve a new view orientation. However, with this *discrete rotation* technique, the user could not precisely control the amount of virtual rotation.

Lastly, the *reduced FOV* joystick technique used continuous rotation with the analog stick in the same way as in the *continuous rotation* technique. The difference is that the *reduced FOV* technique applied a visual mask on top of the virtual view that limited the user's FOV to only a small circular region that reduced the Rift's normal FOV of approximately 200x135 degrees. The FOV reduction used a radial-falloff effect to give the effect of blurred edges around the view (see Figure 1, right) for an FOV of approximate 95x95 degrees. This FOV mask was applied whenever the user used the joystick to rotate. Note that the FOV reduction was not gradual, but rather was enabled in an all-or-nothing fashion. The *reduced FOV* allows continuous viewing of the rotational movement to allow the user to view the entire turn. However, the drawback is that the

Figure 2: Perspective view showing a 3D landmark in the environment with a blue marker above it to indicate the path.

FOV mask hides considerable amount of visual content and might be expected to reduce spatial awareness while turning.

For all three techniques, 6 degree-of-freedom head-tracked rendering was enabled. So, in addition to using the joystick technique, participants could also physically turn their heads to view more of the virtual environment. Participants could also move their heads positionally to adjust their view position. However, to reduce variability due to physical movement, the joystick techniques were tested in the context of seated VR. Participants sat in a standard non-rotating chair to limit the range of comfortable physical turning. For virtual travel (translational movement), all techniques made use of the thumbstick moved in the forward or backwards direction to control movement based on the direction of virtual gaze.

3.2 Hypotheses

Since the *continuous rotation* technique adjusts the view gradually without any break in presence, we hypothesized that it might suffer lower penalties to spatial orientation as compared to the other joystick techniques. Reducing the FOV has been found to negatively affect performance during spatial search tasks [20]. So we hypothesized that the *reduced FOV* condition will deteriorate user performance in the spatial orientation tasks. We also hypothesized that the discrete rotations would make it more difficult to maintain spatial orientation because of the more sudden changes to the view.

In terms of sickness, based on the results from pilot testing, we hypothesized that the continuous camera rotations would make most users nauseous. Since reducing FOV during translational movements has been found to cause less sickness effects [6], we hypothesized that the *reduced FOV* technique would cause less sickness compared to the *continuous rotation* condition. Since the *discrete rotation* does not involve continuous camera turns, we hypothesized that this condition would cause the least sickness effects of the three.

3.3 Environment and Task

To test the techniques, we designed a virtual environment consisting of cubical rooms with identical dimensions of 13.25 meters in length and width. The rooms were arranged in a 10x10 regular grid with doorways connecting to adjacent rooms. We placed 3D objects at the center of every room to serve as navigational landmarks. The landmark were 3D models, with examples including a car, a desk, a couch, and a piano. Users could use the orientation of the objects to get an idea of their direction after turning. However, to make the environment more challenging for a navigation task, the models were repeated throughout the rooms. Landmarks were chosen such that for any particular room with its four adjacent neighbors, their five landmarks were unique. But once the user steps out of these five rooms, one of the five landmarks from the previous set of rooms could be seen again.

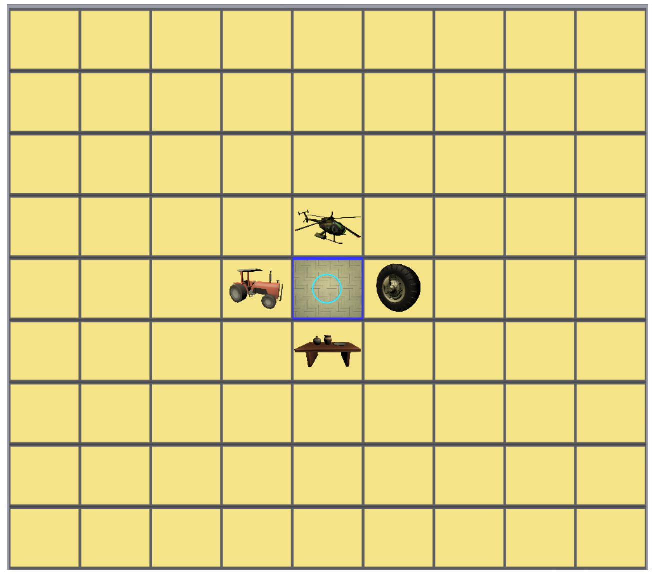

Figure 3: The exocentric plotting task used a top-down view showing the neighbors of the end room with the cursor initially located at the ending room's position.

Using these environments, participants completed a VR navigation task that consisted of three sub-tasks: (1) virtual travel along a path, (2) an egocentric pointing task, and (3) an exocentric plotting task. The virtual travel subtask involved participants moving from one room to another following a path indicated by blue rings that appear over the 3D landmarks in the adjacent rooms. Only one ring was visible at a time; once a ring was collected, the next ring would appear in one of the four rooms adjacent to the current location. The last ring was shown as orange instead of blue to indicate the end of the path. The room paths were manually pre-determined based on three simple rules: (1) each path consists of exactly seven rooms including the starting and ending rooms; (2) each path will have one 180-degree virtual turn where the user travels to the center of the room and then immediately returns to the previous room; (3) travel involves a minimum of 90-degree virtual turn at each room along a path (i.e., after moving to a room, the next room will never be straight ahead). Following these criteria, 15 unique paths were created, and each participant completed the task 12 times using a random subset of 12 paths from the 15 total paths.

After following the path and reaching the end point, users were asked to do an egocentric pointing task where they had to turn and face towards the room where the virtual travel started. The participants were asked to push a button in the controller while facing towards the initial room in the path. A difference in the angle between the direction pointed by the user and the direction towards the actual starting room was recorded as the angular error. This error was one of the two metrics used to determine the spatial awareness of the users. Immediately following the pointing task, the users completed an exocentric plotting task using a 2D grid that represented a top-down view of the environment (see Figure 3). The 2D grid only displayed the landmarks for the four neighbors of the end room (where the orange ring was found), and all the other cells were blank. Based on the arrangement of these landmarks on the grid, the users were asked to select the cell corresponding to the initial room where the path started. Users made this selection by using a controller to move a cursor to the indicated cell. From this task, an error metric was calculated as the difference in the number of cells in both vertical and horizontal directions from the actual starting point to the selected cell.

The environment and the sub-tasks were designed specifically to understand the tradeoffs for the three techniques in terms of the ability to maintain spatial orientation, sickness and home entertainment preferences. The environment is designed in a way that maintaining spatial orientation during travel is challenging. But at the same time, it supports virtual travel similar to a typical virtual environment that has doorways and navigational landmarks.

3.4 Experimental Design

We ran a controlled experiment to evaluate the three techniques. The experiment followed a within-subjects design with each participant testing all three techniques. Each participant completed the navigation task 12 times split into three blocks corresponded to the three techniques. That is, participants completed the task four times for each technique, where the first was considered a familiarity trial with the technique. Technique order was counter-balanced across the participants.

The dependent variables of this experiment were the errors from egocentric pointing task, errors from the exocentric plotting task, subjective responses given in the post-experiment questionnaire, and responses on a simulator sickness questionnaire (SSQ)[8]. The post-experiment questionnaire consisted of eighteen questions based on ease of use, sickness, comfort, and preference for home entertainment. These questions were presented in the form of Likert scales with ratings ranging from 1 to 10.

3.5 Apparatus

The experiments were run in a lab environment and a non-rotating chair was used for the trials. A Windows PC with a 3.4 GHz Quad Core processor and a 16GB GeForce GTX 1070 graphics card was used to run the experiments. An Oculus CV1 headset was used with the default positional and orientation head tracking enabled. The study application was developed using the Unity game engine. The application ran with the frame rate ranging between 128 and 134 frames per second. An Xbox One controller was used for user inputs during the trials.

3.6 Procedure

The study was approved by our organization's institutional review board (IRB). On arrival, participants were given an overview of the study and asked to provide signed consent before proceeding. They were then asked to complete a brief background questionnaire with questions about age, gender, education, computer knowledge, gaming experience, and VR experience. After this, the participants were asked to complete a SSQ questionnaire based on how they felt before starting the experiments. Next, they were given an explanation of the VR application and experimental tasks.

Next, they started doing the trials with the navigation tasks split into three blocks with four trials in each. In each technique block, the first trial was a practice trial for the participant to gain familiarity with the techniques, then three main trials followed whose data was considered for analysis. Participants were told they can use the controller's analog thumbstick to adjust the view whenever needed, but the experimenter intentionally did not explain the details for the three techniques.

Participants were asked to complete another SSQ after each technique block. After the SSQ at the end of each block, participants took a three-minute break where they were asked to walk casually in the lab space without the headset before starting the next session. This was done to reduce carry-over effects related to any sickness.

After completing all three technique blocks, participants were asked to complete an experience questionnaire. Finally, there was a semi-structured interview about the overall experience, general preference and thoughts about the techniques, and use of the techniques for spatial navigation. The procedure took approximately 65 minutes for each participant.

3.7 Participants

Eighteen participants (eleven males and seven females) participated in the user studies. All the participants were university students aged between 20 and 24 years. All the participants reported having good knowledge on computers and technology. Twelve of the eighteen participants reported playing some 3D video game every week. And eight participants reported not having any prior experience with VR before taking part in the study.

4 RESULTS

We analyzed our results to compare the three joystick techniques in terms of spatial orientation, sickness, and preference.

4.1 Spatial Orientation Results

Despite the travel paths involving seven rooms with varied turning, the spatial orientation measures indicate that participants were able to maintain their sense of spatial awareness fairly well. The error results for the egocentric pointing task are shown in Figure 4. The pointing data were skewed right, so it was corrected with log transformation to meet the assumptions for parametric testing. A repeated measures ANOVA failed to detect any differences in pointing errors due to the techniques, with the test showing $F(2,34) = 0.45$.

Similarly, no differences were detected for the exocentric plotting errors, with $F(2,34) = 0.53$. Overall error was low. For many trials, participants were able to exactly select the position of the starting room from the top-down grid view in the exocentric plotting task.

With these results, we are unable to identify any differences in the extent to which the three techniques affect spatial orientation. However, the results also demonstrate that all variations can be

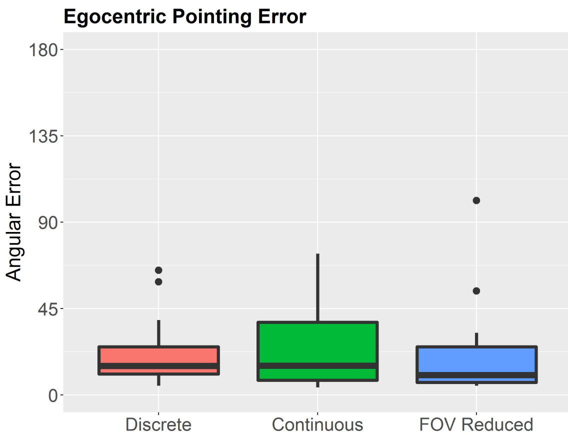

Figure 4: Error from the egocentric pointing task. Lower error is better.

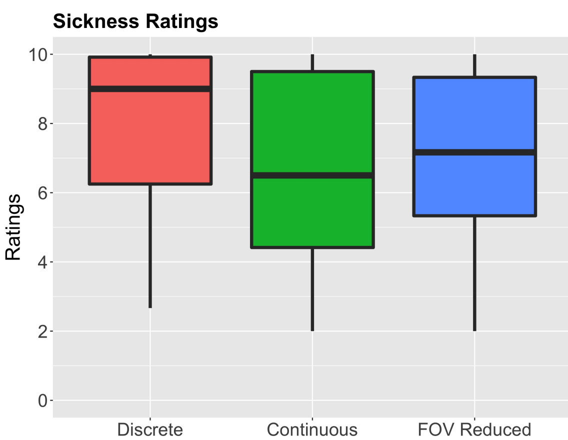

Figure 5: Comparative ratings based on sickness. Higher ratings indicate higher preference and lower sickness.

used to travel while maintaining awareness of travel path. It may be that the presence of the landmarks made the task easy, but on the other hand, landmarks are common in many types of virtual experiences. Thus, these results demonstrate general usability and conclude that all three techniques can support spatial awareness during travel—at least in certain types of environments.

4.2 Sickness Results

Our assessment of sickness effects considered both relative ratings and SSQ results for the techniques. The relative sickness ratings are summarized in Figure 5. Because the sickness ratings were ordinal and relative, we tested for differences in sickness ratings using a Friedman test. The test found a significant difference from the techniques with $\chi^2(2) = 9.93$ and $p < 0.01$. A post-hoc Nemenyi test found *discrete rotation* technique to be rated significantly better than *reduced FOV* with $p = 0.03$, and *discrete rotation* was nearly significantly rated over continuous rotation with $p = 0.06$.

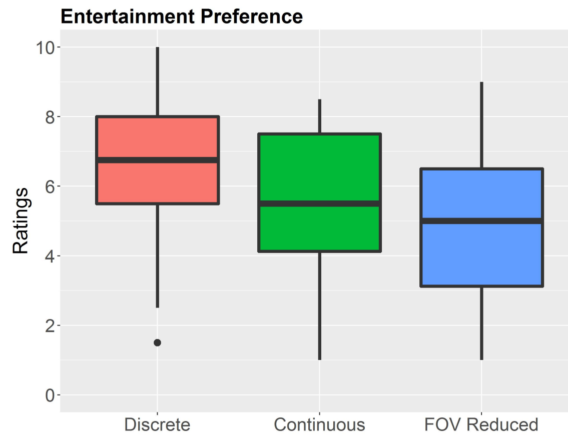

Figure 6: Comparative ratings based on preference for home entertainment. Higher ratings are better.

Overall, the SSQ results had $M = 38.92$ and $SD = 33.36$. For the analysis of the SSQ results, we were interested in the resultant effects from each technique rather than in the overall cumulative sickness over the duration of the study. Since participants took an initial SSQ test before beginning and another SSQ test after trying each technique, we were able to calculate the difference in SSQ from the previous sickness state. We analyzed this SSQ change for each technique. We note that it was possible to achieve negative score changes, meaning a decrease in perceived sickness. SSQ changes were relatively low across conditions with moderate variance ($M = 9.97$, $SD = 19.15$). For statistical comparison of SSQ changes for the techniques, we conducted a non-parametric Friedman test because the data failed to meet the assumption of normality, and we were unable to correct with transformations. The test failed to find a significant effect with $\chi^2(2) = 3.97$.

Thus, the SSQ results found relatively low overall sickness scores, but the relative sickness ratings showed the *discrete rotation* technique to be significantly preferred. Due to the repeated measures design of the study and the compounding experiences in VR, we find the ratings to be a more meaningful metric for the study.

4.3 Preferences and Feedback

For home entertainment preferences, ratings given by the participants to a set of questions were grouped together. The questions were based on how much fun the techniques were, how comfortable they were, how frustrating they were and how interested participants would be to use them for home entertainment. We tested for differences in preferences for home entertainment using a Friedman test. The test failed to detect a significant effect with $\chi^2(2) = 4.46$ and $p = 0.11$. Preferences varied greatly with no clear consensus on preferred technique (see Figure 6). In general, these results allow us to be confident that there was no clear “best” joystick technique from our group. Although the *discrete rotation* technique was the top preferred technique more than the others, individual differences and opinions make a strong impact in preference or interest using any given technique for real applications.

All three techniques received mixed qualitative feedback during the post-study interview. Three participants reported that the *continuous rotation* felt the most natural among the three techniques and five participants reported *continuous rotation* causing sickness. In contrast, we did not identify any complaints about sickness for the *discrete rotation* technique, and two participants reported that it helped them turn quickly.

Six out of eighteen participants reported that they did not like the continuous rotation with *reduced FOV*. Three of them reported that the view was frustrating due to the limited visibility. Example comments about this technique are:

> "The tunnel view made it frustrating to complete the tasks. It's one more obstacle that I had to tackle."
> "I really hated the tunnel view. I didn't like that it blocked my view."
> "The mask was very off-putting—felt weird while using it and looking around."

5 DISCUSSION AND CONCLUSION

Our study revealed few important characteristics of the three variations of joystick-controlled turning. With respect to spatial awareness, there was no clear "winner", and the overall errors from the two spatial tasks were low. This indicates that the three techniques did not substantially affect the spatial understanding in environments. It is likely that the complexity of the navigation task was too easy due to the presence of the landmarks objects, and it may be necessary to conducting testing with a more difficult task to assess technique differences. However, we felt it important to include such landmarks to make the task more comparable to more realistic environments, which often include numerous landmarks. We contend that the task and environmental complexity was appropriate for assessment of common travel needs; thus, the orientation results demonstrate reasonably high usability for all three techniques.

In terms of sickness, *discrete rotation* was considered the best technique in terms of comparative ratings, and the preference based on sickness was significantly better than the *reduced FOV* variation. We note that the FOV reduction may be less problematic or noticeable if applied gradually (as in [6]) rather than via the all-or-nothing method used in our study. We suspect more participants would have shown *discrete rotation* to also be significantly better than *continuous rotation* due to the $p = 0.06$ post-hoc result.

In general, this result reveals an important finding about how simple alterations to rotational control can have positive effects for sickness without noticeably influencing orientation. Discrete rotational adjustments may be preferred over continuous rotation when sickness is a concern, which has been shown to be a greater issue for users with less experience with VR or gaming (e.g., [10, 12, 16]).

Though joystick-controlled travel is a well-known and commonly used technique, further study would be beneficial for understanding alterations for practical use. Understanding the effects and trade-offs of different configurations is perhaps even more important due to the rise in popularity of mobile VR and home VR systems, as empirical data from studies can help developers make simple yet critical decisions for implementation of travel and view control.

REFERENCES

[1] Felipe Bacim, Eric Ragan, Siroberto Scerbo, Nicholas F Polys, Mehdi Setareh, and Brett D Jones. 2013. The effects of display fidelity, visual complexity, and task scope on spatial understanding of 3D graphs. In *Proceedings of Graphics Interface 2013*. Canadian Information Processing Society, 25–32.
[2] Benjamin Bolte, Frank Steinicke, and Gerd Bruder. 2011. The jumper metaphor: an effective navigation technique for immersive display setups. In *Proceedings of Virtual Reality International Conference*.
[3] Doug A Bowman, David Koller, and Larry F Hodges. 1997. Travel in immersive virtual environments: An evaluation of viewpoint motion control techniques. In *Virtual Reality Annual International Symposium, 1997., IEEE 1997*. IEEE, 45–52.
[4] Evren Bozgeyikli, Andrew Raij, Srinivas Katkoori, and Rajiv Dubey. 2016. Point & teleport locomotion technique for virtual reality. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play*. ACM, 205–216.
[5] Sarah S Chance, Florence Gaunet, Andrew C Beall, and Jack M Loomis. 1998. Locomotion mode affects the updating of objects encountered during travel: The contribution of vestibular and proprioceptive inputs to path integration. *Presence: Teleoperators and Virtual Environments* 7, 2 (1998), 168–178.
[6] Ajoy S Fernandes and Steven K Feiner. 2016. Combating VR sickness through subtle dynamic field-of-view modification. In *3D User Interfaces (3DUI), 2016 IEEE Symposium on*. IEEE, 201–210.
[7] Andrew Forsberg, Michael Katzourin, Kristi Wharton, Mel Slater, et al. 2008. A comparative study of desktop, fishtank, and cave systems for the exploration of volume rendered confocal data sets. *IEEE Transactions on Visualization and Computer Graphics* 14, 3 (2008), 551–563.
[8] Robert S Kennedy, Norman E Lane, Kevin S Berbaum, and Michael G Lilienthal. 1993. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology* 3, 3 (1993), 203–220.
[9] JJ-W Lin, Henry Been-Lirn Duh, Donald E Parker, Habib Abi-Rached, and Thomas A Furness. 2002. Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment. In *Virtual Reality, 2002. Proceedings. IEEE*. IEEE, 164–171.
[10] Michael E McCauley and Thomas J Sharkey. 1992. Cybersickness: Perception of self-motion in virtual environments. *Presence: Teleoperators & Virtual Environments* 1, 3 (1992), 311–318.
[11] Eric D Ragan, Regis Kopper, Philip Schuchardt, and Doug A Bowman. 2013. Studying the effects of stereo, head tracking, and field of regard on a small-scale spatial judgment task. *IEEE transactions on visualization and computer graphics* 19, 5 (2013), 886–896.
[12] Eric D Ragan, Andrew Wood, Ryan P McMahan, and Doug A Bowman. 2012. Trade-Offs Related to Travel Techniques and Level of Display Fidelity in Virtual Data-Analysis Environments.. In *ICAT/EGVE/EuroVR*. 81–84.
[13] Sharif Razzaque, David Swapp, Mel Slater, Mary C Whitton, and Anthony Steed. 2002. Redirected walking in place. In *EGVE*, Vol. 2. 123–130.
[14] Bernhard E Riecke and Daniel Feuereissen. 2012. To move or not to move: can active control and user-driven motion cueing enhance self-motion perception (vection) in virtual reality?. In *Proceedings of the ACM Symposium on Applied Perception*. ACM, 17–24.
[15] Roy A Ruddle, Stephen J Payne, and Dylan M Jones. 1999. Navigating large-scale virtual environments: what differences occur between helmet-mounted and desk-top displays? *Presence: Teleoperators and Virtual Environments* 8, 2 (1999), 157–168.
[16] Shyam Prathish Sargunam, Kasra Rahimi Moghadam, Mohamed Suhail, and Eric D Ragan. 2017. Guided head rotation and amplified head rotation: Evaluating semi-natural travel and viewing techniques in virtual reality. In *Virtual Reality (VR), 2017 IEEE*. IEEE, 19–28.
[17] Mel Slater, Martin Usoh, and Anthony Steed. 1995. Taking steps: the influence of a walking technique on presence in virtual reality. *ACM Transactions on Computer-Human Interaction (TOCHI)* 2, 3 (1995), 201–219.
[18] Martin Usoh, Kevin Arthur, Mary C Whitton, Rui Bastos, Anthony Steed, Mel Slater, and Frederick P Brooks Jr. 1999. Walking> walking-in-place> flying, in virtual environments. In *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*. ACM Press/Addison-Wesley Publishing Co., 359–364.
[19] Colin Ware and Steven Osborne. 1990. Exploration and virtual camera control in virtual three dimensional environments. In *ACM SIGGRAPH Computer Graphics*, Vol. 24. ACM, 175–183.
[20] Maxwell J Wells and Michael Venturino. 1990. Performance and head movements using a helmet-mounted display with different sized fields-of-view. *Optical Engineering* 29, 8 (1990), 870–878.
[21] Daniel Zielasko, Benjamin Weyers, Martin Bellgardt, Sebastian Pick, Alexander Meibner, Tom Vierjahn, and Torsten W Kuhlen. 2017. Remain seated: towards fully-immersive desktop VR. In *Everyday Virtual Reality (WEVR), 2017 IEEE 3rd Workshop on*. IEEE, 1–6.