Virtual Exploration: Seated versus Standing

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Abstract: Virtual environments are often explored standing up. The purpose of this work is to understand if standing exploration has an advantage over seated exploration. Thus, we present an experiment that directly compares subjects' spatial awareness when locomoting with a joystick when they are physically standing up versus sitting down. In both conditions, virtual rotations matched the physical rotations of the subject and the joystick was only used for translations through the virtual environment. In the seated condition, users sat in an armless swivel office chair. Our results indicated that there was no difference between the two conditions, sitting and standing. However, this result is interesting and might compel more virtual environment developers to encourage their users to sit in a comfortable swivel chair. As an additional finding to our study, we find a significant difference between the performance of males versus females and gamers versus non–gamers.

1 INTRODUCTION

With the introduction of low cost commodity level immersive virtual systems (like the Oculus Rift, HTC Vive, and GearVR), the use of virtual reality (VR) has become more widespread. With these systems, users wear a head-mounted displays (HMDs) to view a 3D computer generated world. Exciting, new research involving this equipment has been published such as analyzing the effectiveness of directional signage (Huang et al., 2016), visiting a historical Selimiye mosque in Turkey (Kersten et al., 2017), allowing doctors to visualize 3D MRI slices (Duncan et al., 2017), and treating spider phobia (Miloff et al., 2016). When playing video games, HMDs have been shown to produce stronger, more immersive experiences than desktops and televisions (Pallavicini et al., 2017). Given the relatively low–cost of these immersive virtual systems and their potential to produce more meaningful experiences, VR might have a huge impact on learning, social interaction, medical care, training workers, entertainment, and so on. However, much is still unknown about how humans learn in a virtual environment (VE) and how this learning is different than the real world.

Humans reason about space in a VE in a way that is functionally similar to the real world (Williams et al., 2007). That is, they update their spatial knowledge or spatial orientation with respect to their environment as their relationship to objects in the environment change much like the real world. However, humans are more disoriented in VEs (Darken and Peterson, 2014; Kelly et al., 2013). Thus, navigation, the most common way people interact with a VE (Bowman et al., 2004), causes people to feel disorientated. Exploring a VE by physically walking seems to result in the best spatial awareness (Darken and Peterson, 2014), but the size of the space that can be explored using a tracking system is limited without alternate interventions such as teleporting. Much work has looked at how best to explore a VE larger than the tracked space while maintaining spatial awareness (Kitson et al., 2017; Riecke et al., 2010; Suma et al., 2012; Wilson et al., 2016; Zielasko et al., 2016). Much of the more recent navigation work has focused on engaging the user in physical movement as it seems to result in better spatial awareness of the VE as compared to using a joystick (Wilson et al., 2016; Waller and Hodgson, 2013). Alternatively, (Riecke et al., 2010) found that when the joystick was combined with physical rotations that performance compared to actual walking was similar in terms of search efficiency and time.

Many of the proposed methods of locomotion used by researchers (Kitson et al., 2017; Suma et al., 2012; Wilson et al., 2016; Zielasko et al., 2016) and in industry (such as a tracked system with teleporting (Bozgeyikli et al., 2016)) involve the user standing up to explore the VE. Standing can be tiring to VR users, especially while wearing a helmet that can get warm. Sedentary behaviors such as sitting in front of a television or computer, and riding in an auto-

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Figure 1: This picture shows the two conditions, standing and seated exploration in a VE.

mobile typically are in the energy-expenditure range of 1.0 to 1.5 METs (multiples of the basal metabolic rate)(Ainsworth et al., 2000). Thus, behaviors that involve sitting involve low energy expenditure and might be more natural to encourage the widespread adoption of VR for a variety of applications, especially entertainment.

In this work, we examine what happens to spatial orientation when subjects explore a VE with a joystick seated as compared to standing. Subjects used the joystick for translating in the VE while rotations matched that of the real world. Thus, similar to (Riecke et al., 2010), subjects in our experiment translate in the direction that their head is facing by pushing the joystick forward. It is important to note that the major difference between the two conditions was that in one condition the subjects were standing and the other condition the subjects were seated on a swivel chair. Eye height for two conditions matched the physical eye height of the participant. In this work we could have studied distance perception or looked at different locomotion interfaces to compare seated versus standing. However, for our own purposes we were interested in what happens when people move and navigate through environments while seated. Thus, we decided to run an experiment that examines spatial awareness as subjects move through a VE. Most video games involve some sort of haptic devices that allows the user to move around in the environment. Joystick translations plus physical rotations can easily be achieved while sitting or standing.

In the real world there has been some evidence of difference between sitting and standing observations. (Carello et al., 1989) conducted four real world experiments and found different effects for reaching when people stood versus sat down. While sitting, subjects had a tendency to overestimate the reaching range of their arm while imagining picking up a target object placed at different distances in front of them. While standing, there was an underestimation of perceived reachability when participants were standing upright. In the virtual world, not much is known about seated versus standing observations. Much work has studied the issue of the similarities and differences in distance estimation between real and virtual environments (Loomis and Knapp, 2003; Willemsen and Gooch, 2002; Li et al., 2016). These works all find that subjects underestimate distances in VEs.

2 BACKGROUND

Haptic devices, such as joystick or keyboard, have been used to explore environments for many years (Ruddle et al., 1999; Bowman et al., 1999; Waller et al., 1998). However, studies have consistently shown that physically walking rather than using a haptic device produces significantly better spatial orientation (Ruddle and Lessels, 2006; Lathrop and Kaiser, 2002). Suma et al. (Suma et al., 2007) show that using position and orientation tracking with an HMD is significantly better than using a system that combines the orientation tracking and a haptic device for translations. However, (Riecke et al., 2010) found that joystick translations and physical rotations led to better performance than joystick navigation, and yielded almost comparable performance to actual walking in terms of search efficiency and time. Thus, in our experiment, the users' orientation in the VE matched their physical head orientation.

(Nybakke et al., 2012) preform a within subjects experiment similar to (Riecke et al., 2010) where subjects search the contents of 16 randomly positioned and oriented boxes to find 8 hidden target using four locomotion modes: real walking, joystick translation with real rotation while standing, joystick translation while sitting, and motorized wheel chair. They find a marginal effect of condition for number of revisits to the same hidden target, but pairwise comparisons did not reveal differences. They found that that the distance traveled was smaller in the walking condition and it took less time to complete the trial when users physically walked. The spatial orientation task in our experiment is similar to (Williams et al., 2006) where they find a significant advantage of walking over joystick plus physical rotation exploration. We suggest that it could be that the task outlined in (Nybakke et al., 2012) and (Riecke et al., 2010) is not hard enough to yield differences and could explain why Riecke et al. found results that are somewhat inconsistent with the literature. (Waller et al., 2003) found that people who received the motion cues from riding in a car were no better at learning the spatial layout of the environment over people who were provided with only the visual optical flow of the same experience. However, in both of these conditions, the participant passively experienced both the motion and visual stimuli, and did not actively control the process. (Waller and Greenauer, 2007) presented a study intended to contrast the effects of visual, proprioceptive, and inertial information to acquire spatial knowledge in a large-scale environment. Using a variety of measures, such as pointing, distance estimation, and map drawing, they observed very few differences among groups of participants who had access to various combinations of visual, priopriocetive and interracial information. Proprioceptive information did produce a small effect. They found that pointing accuracy was better in people who had proprioceptive cues.

In our everyday lives, we humans constantly change our viewing perspective by sitting, standing, etc., yet the perceived size of objects remains the same. As (Wraga, 1999) points out, this may be because of familiar size or previous knowledge about size and shape (Gogel, 1977; Rock, 1975). (Gibson, 1950) showed that the ground plane provides crucial information about an object's location in an environment. Gibson explained that there were two reasons why the ground plane played such a crucial role in our understanding of space. First, humans rely on ground surfaces for locomotion and second, that ground planes are universal whereas ceilings are mostly human created. Thus, the ground or horizon is important for perceiving the distance and size of objects. More specifically, the angle of declination from the horizon line to an object is an important source of information. The angle of declination is defined as the vertical viewing angle from a target object to the horizon. In nature, the horizon is always at the observer's eyelevel. Therefore, the higher the object appears on the horizon, the further its distance appears to the observer. In the experiment presented in this work, users experience a 50m by 50m outdoors environment. Other studies have shown the importance of eye height. (Wraga, 1999) compare seated, standing and ground–level prone observations and find that seated and standing observations are similar, but prone observations are significantly less accurate. (Warren, 1984) found that people judged whether they could sit on a surface according to whether the surface height exceeded 88% of their leg length. Moreover, people choose to climb or sit on a surface according to the relationship between the surface's height and their eye height (Mark, 1987). Prior work has shown manipulating eye height can produce a predictable effect on judged distances measured with verbal estimates, and, thus, could be a promising candidate to reduce or even eliminate distance underestimation in a similar way across different measures (Leyrer et al., 2015). Additionally, prior work found that eye height manipulation not only affects perceived distances, but also judgments of single room dimensions, suggesting a change in perceived scale rather than a cognitive correction in distance judgments (Leyrer et al., 2011).

3 EXPERIMENTAL EVALUATION

We compare seated joystick and standing joystick exploration in this experiment. We tested 24 subjects (12 female, 12 male) on their spatial orientation in the environment using a within-subjects design. After a user finished both navigation methods, we asked them a series of questions. In both conditions, pushing all the way forward on the joystick resulted in translating through the VE a rate of 1 m/s, which is approximately normal walking speed. Participants moved with the joystick in the yaw-direction of gaze for both conditions. Eye height in the VE matched the physical eye height of the participant. Thus, seated exploration was at a lower eye height than standing. In both conditions, the subjects memorized a set of objects, locomoted to various positions and then turned to face these remembered target objects.

3.1 Materials

The experiment was conducted in a 3m by 3m room that only contained the head-mounted display. The immersive VE was viewed through a HTC Vive head-mounted display (HMD) which had a resolution of 1080x1200 per eye, a field-of-view of 110° diagonally, a weight of 0.47 kg and an optical frame rate of 90Hz. Orientation was updated using the orientation from the sensor found on the Vive. The joystick used in this experiment was a Logitech Extreme 3D Pro. Graphics were rendered using the Unity. The swivel desk chair used in the experiment was a HON Volt Series 5701 Task Chair.

The immersive VE used in the experiment was a circular shaped grassy plane (50m diameter) with a generic dome backdrop depicting the sky as seen in Figure 2. For each condition, the user would memorize the positions of 6 objects placed around the environment on columns (Figure 2). The heights of the columns varied so that the top of the objects were always at the same level. After the user had memorized the locations of the objects, the tests would begin. These six target objects were arranged in a particular configuration, such that the configuration in both conditions varied only by a rotation about the center axis. In this manner, the angles of correct yaw-

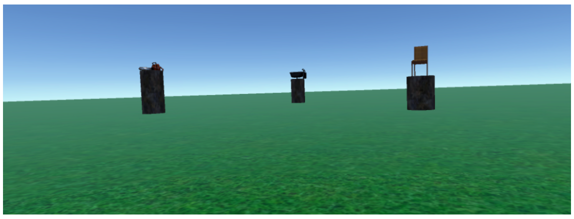

Figure 2: A view of the virtual environment.

angle responses were preserved across all conditions. The random order of trials and the different objects concealed the fact that the arrangement was the same throughout the experiment. Objects were similar in size and height and were placed on pillars. We used a red cylinder and a red floating sphere to indicate the position and orientation, respectively, of the testing location for a particular trial. The red cylinder was used to indicate the position of the subject that was needed for that particular turn-to-face trial. The correct orientation was facing the red sphere at the red cylinder. In this manner, the cylinder and sphere were used to control the exact testing location and orientations of the subjects.

In both conditions, the target objects and testing locations where located with a radius of 8m from the center of the plane. Subjects were instructed to remain relatively close to the center and the experimenter told the participants to move more towards the center of the environment if they were venturing too far from the space. In this manner, the explored space was roughly the same in both conditions.

3.2 Procedure

Each of the 24 participants explored each of the environments under the two different translational locomotion conditions, seated joystick and standing joystick. Half of the subjects performed the seated experiment first and half of the subjects performed the standing experiment first. Order was also counterbalanced for gender. The experimental procedure was verbally explained to the subjects using physical props prior to seeing the VEs. Before the subject saw the target objects in each condition, the participant was shown two objects on pillars that did not appear in our test set. Participants performed several practice trials in this environment so that they were familiar with the setup and the experimental design. After the subject understood the task and the condition, the practice target objects disappeared. The participant then practiced the locomotion condition by moving to various targets in the environment for 2 minutes. Once the participants were comfortable with this, they were asked to memorize the set of target objects. During the learning phase, subjects were asked to learn the positions of the six target objects while freely moving around the VE according to the condition that they were in. After about five minutes of study, the experimenter tested the subject by having them close their eyes, and point to randomly selected targets. This testing and learning procedure was repeated until the subject felt confident that the configuration had been learned and the experimenter agreed.

Participants' spatial knowledge was tested from six different locations. A given testing position and orientation was indicated to the subject by the appearance of a red cylinder and a red sphere in the environment. Participants were instructed to locomote to the cylinder until it turned green and then turn to face the floating sphere until it turned green. When both the cylinder and sphere were green, the participants were in an appropriate position. When the subject reached this position, the objects were hidden so that the participant only saw the cylinder and the sphere on a black background. After the participant was told which object to turn to face, the cylinder and sphere disappeared and the participant briefly saw the name of the target object. Specifically the subjects were told "turn to face the <target name>". Once the participant indicated that they had turned to face the object, the angle turned, the angle of correct response and the latency associated with turning to face the object were recorded. The cylinder and sphere reappeared and the participant then turned back to face the sphere until it turned green again. Then, the subject was instructed to face another target object. At each location, the subject completed three trials by turning to face three different target objects in the environment, making 18 trials per condition. After completing three trials at a particular testing location, the participant was asked to face the sphere until it turned green before the environment and objects were displayed again so that the participant would not receive any feedback. After the environment and objects were shown again, the cylinder and sphere were moved to the next target location. Subjects were encouraged to re–orient themselves after completing a testing location.

To compare the angles of correct responses across conditions, the same trials were used for each condition. The testing location and target locations were analogous in both conditions, and targets varied randomly across the environments. The trials were designed so that the disparity was evenly distributed in the range of 20–180°. That is, the correct angle of response for each trial was evenly distributed in the range of 20–180°. Also the testing locations were positioned in such a way that they would never turn to face a target object closer than 0.8m.

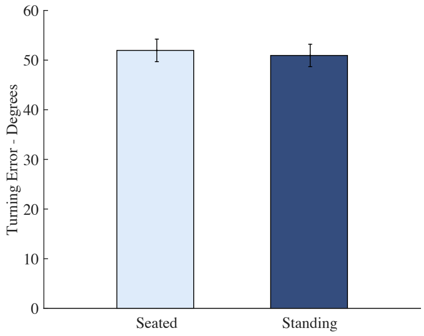

Figure 3: Mean turning error for the seated and standing conditions. Error bars show the standard error of the mean.

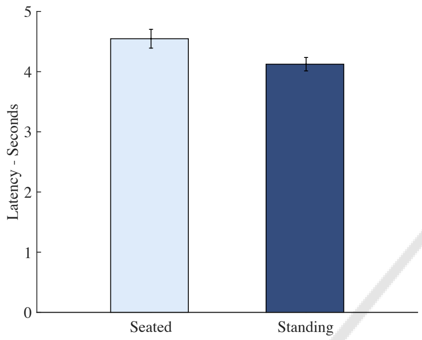

Figure 4: Mean latency for the seated and standing conditions. Error bars indicate the standard error of the mean.

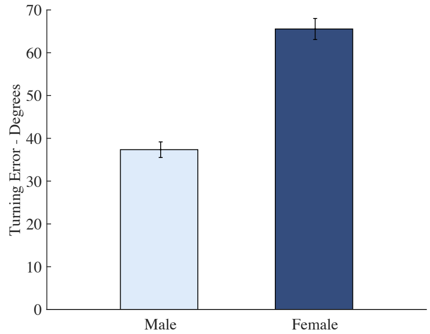

Figure 5: Mean turning error collapsed by gender. Error bars indicate the standard error of the mean.

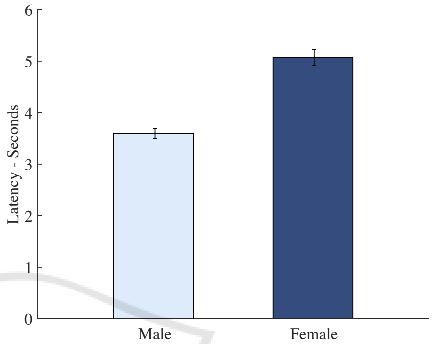

Figure 6: Mean latency collapsed by gender. Error bars indicate the standard error of the mean.

To assess the degree of difficulty of updating orientation relative to objects in the VE, latencies and errors were recorded. Latencies were measured from the time when the target was identified until subjects said they had completed their turning movement and were facing the target. Unsigned turning errors were measured as the absolute value of the difference in initial facing direction (toward the sphere) minus the correct facing direction. The subjects indicated to the experimenter that they were facing the target by verbal instruction, and the experimenter recorded their time and orientation. The time was recorded by computer, and the rotational position was recorded using the orientation sensor on the HTC Vive HMD. Subjects were encouraged to respond as rapidly as possible, while maintaining accuracy.

After the experiment, subjects were asked a few questions. They rated both conditions on a scale of 1 to 5 on how well they thought they did. They were also asked to choose which method they liked better, seated or standing exploration. They also indicated if they regularly play 1st person video games and if they had ever experienced an immersive VE.

3.3 Results

Figures 3 and 4 show the subjects' mean turning errors and latencies by locomotion condition in the VE. 9 out of 24 of our subjects regularly play video games. Also, 9 out of 24 of our subjects had experienced a VE. Only a few subjects were both a gamer and had prior experience in an immersive VE. Subjects were asked to report how well they did on a 5 point Likert scale from 1 to 5. 1 indicating that they felt their performance was bad and 5 indicating that they felt their performance was good. For the seated condition this average was 2.875 across the participants. For the standing task this value was a little lower at 2.79. 11 subjects prefered the seated condition while 13 subjects preferred the standing condition.

We compared mean turning error between the conditions using a repeated measures ANOVA and did not find any significant differences between the two conditions. Thus, subjects were similarly accurate when turning to face the location of target objects in both conditions. We ran a similar analysis for latency and found a marginal difference for the seated and standing conditions, $F(1,23) = 3.621, p = 0.07$. We also ran repeated measures ANOVA using the turning errors with order between groups and we did not find

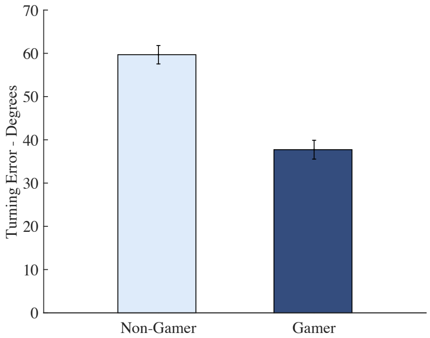

Figure 7: Mean turning error collapsed by video game experience. Error bars indicate the standard error of the mean.

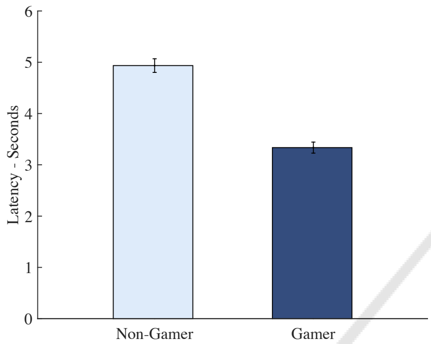

Figure 8: Mean latency collapsed by video game experience. Error bars indicate the standard error of the mean.

an effect of condition, order, or an interaction of condition and order. An analysis on latency with order between groups also did not reveal any effects. Thus, subjects did not seem to get more accurate or faster over the course of the experiment.

We analyzed mean turning error between the conditions using a repeated measures ANOVA with gender between groups. The analysis not reveal an effect of condition or a two way interaction between condition and gender for turning errors. However, we found a significant effect of gender for turning errors, $F(1,22) = 11.72, p = .002$. Running a similar analysis with latency yielded similar results with only a significant effect of gender, $F(1,22) = 7.26, p = .013$. Figures 5 and 6 show the mean turning errors and latencies collapsed across gender. The differences between these two groups is considerable. Males respond faster and more accurately than females.

Within our pool of 24 subjects, we had 9 gamers and 15 non–gamers. Gamers identified themselves as those who self reported that they regularly play video games. We ran a repeated measures ANOVA on turning error and latency with gamers and non-gamers as a between group factor. There were no significant effects of condition or the interaction of condition and gamer for turning error and latency. However, there was an effect of gamer for turning errors ($F(1,22) = 4.67, p = 0.04$) and for latency ($F(1,22) = 28.77, p = 0.009$). Turning errors and latency collapsed across gamers versus non-games can be seen in Figures 7 and 8, respectively.Video gamers made fewer errors than non–gamers and responded more quickly. We did not find any effects as to whether or not someone has had prior experience exploring an immersive VE.

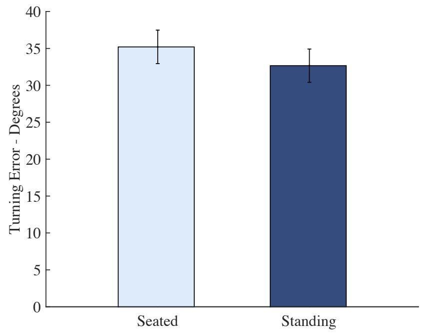

Figure 9: Median turning error for the seated and standing conditions. Error bars show the standard error of the mean.

Figure 9 shows the subjects' median turning errors by locomotion condition. The related median latency figure was omitted because it is similar to Figure 4. Although the trends are similar to Figure 3, the turning errors are lower. The reason for the difference between the median and mean data was mainly due to the existence of large outliers. We completely reran all of the statistical analyses outlined above and found similar results using the median turning errors and median latency. The only difference was that the repeated measures ANOVA for latency did not reveal any significant differences between the two conditions (seated and standing).

4 DISCUSSION

We presented a within–subjects experiment with 24 participants to examine whether seated exploration or standing exploration has any effect on navigation through a VE. Before running this experiment, we hypothesized that subjects would be better at standing to explore the VE. Standing seemed more natural to us and eye height changes have been shown to have an effect on distance judgements in VR (Leyrer et al., 2011; Leyrer et al., 2015). In our studies eye height always matched the physical eye height of the participant. The carefully designed experiment presented here revealed that subjects update their spatial awareness while navigating through a VE with a joystick similarly when they are seated versus standing up. It is important to note that in both conditions users were able to freely rotate around the VE using their own physical rotations. In the seated condition users sat in a swivel office chair. We think that these results are interesting and that more techniques should be implemented that allow the user to fully explore a VE while sitting down.

From the results, our turning errors are sizable, but are consistent with similar experiments (Wilson et al., 2016). Other works have presented virtual exploration techniques that are not limited in size by the bounds of the tracking system and outperform the joystick (Kitson et al., 2017; Suma et al., 2012; Wilson et al., 2016; Zielasko et al., 2016). It will be interesting to see other techniques adapted for seated exploration and possibly be better than the joystick. This work lays the groundwork for this future direction. One idea that we had to move this work forward is to look at manipulating rotations while seated to explore a VE. Turning around in a swivel chair does require some effort and it could be possible to scale the rotational gain of the turning so that less physical turning is required to turn. (Kuhl et al., 2008) showed that people can recalibrate their rotational gain. That is, people can adapt to amplified visual rotation and calibrate their physical turning to adjust accordingly.

After the experiment we asked subjects to comment on their experiences. Some subjects felt strongly about sitting down to explore the VE while other subjects felt strongly about standing up. The preference for one method over the other was almost evenly split, with 11 subjects preferring seated exploration and 13 preferring standing. One subject commented that "standing made me feel like I got lost. I liked the swivel aspect of sitting, it also felt more like a video game." Another subject cited that they preferred sitting because "sitting felt like [they were] in a vehicle." Two subjects specifically commented about the swivel aspect of sitting being positive. Another subject explained that "standing felt much more realistic than sitting, felt like I had better knowledge of the objects around me." The results indicate no clear winner of the two conditions in terms of latencies, turning errors, and user preference. Thus, we feel like seated virtual exploration is a good option that needs further exploration.

We found huge gender differences in this experiment. Mean turning error for females in this experiment was almost double that of males. Moreover, males were around a second and a half faster than females. There was only one female game player in our dataset which could explain some of the large differences. There have been many studies that report males outperforming females in spatial orientation tasks over the last few decades (Masters and Sanders, 1993; Coluccia and Louse, 2004; Kitson et al., 2016; Nori et al., 2015). Studies suggest that the females are more likely to adopt an egocentric strategy as opposed to males who are more likely to adopt an allocentric strategy when exploring a VE(Kitson et al., 2016; Chen et al., 2009). These gender differences suggest the possible need for interface designs of navigational support systems taking into consideration gender differences.

Finally, we find a between subjects effect of gamers versus non-gamers. Previous studies have shown that gamers perform spatial task better in VR (Murias et al., 2016). These works suggest that people who play video games regularly have better navigation and topographical orientation skills because they consistently practice these skills while playing for the purpose of entertainment. As VR games become more and more prevalent, it will be important for researcher to understand the effects of video game exposure on performance of navigation tasks in VEs.

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