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Homing by triangle completion in consumer-oriented virtual reality environments

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ABSTRACT

Homing is a fundamental task which plays a vital role in spatial navigation. Its performance depends on the computation of a homing vector, where human beings can use simultaneously two different cognitive strategies: an online strategy based on the self-motion cues known as path integration (PI), and an offline strategy based on the spatial image of the path called piloting. Studies using virtual reality environments (VE) have shown that human being can perform homing tasks with acceptable performance. However, in these studies, subjects were able to walk naturally across large tracking areas, or researchers provided them with high-end large-immersive displays. Unfortunately, these configurations are far from current consumer-oriented devices, and very little is known about how their limitations can influence these cognitive processes. Using a triangle completion paradigm, we assessed homing tasks in two consumer-oriented displays (an HTC Vive and a GearVR) and two consumer-oriented interaction devices (a Virtuix Omni Treadmill and a Touchpad Control). Our results show that when locomotion is available (treadmill condition), there exist significant effects regarding display and path complexity. In contrast, when locomotion is restricted (touchpad condition), some effects on path complexity were found. Thus, some future research directions are therefore proposed.

1 INTRODUCTION

There are two cognitive strategies that human beings can use to move in the environment and find their way back home: *path integration (PI)* and *piloting*. In PI, subjects maintain track of their movement based on self-motion cues such as optic flow, vestibular, proprioceptive and efferent. During piloting, subjects create a mental representation of the path based on external references and their spatial relationships (usually known as "spatial image" [11]). Although both strategies are necessary to achieve an accurate performance, PI alone is enough to have an acceptable performance [12]. Studies in virtual environments (VEs) have shown the great plasticity of the human brain, where we can perform visual homing based only on the optic flow and in the absence of physical locomotion ([18], [4]). However, in these studies, subjects usually have conditions where they can either walk naturally or use room-dedicated large-displays, conditions that do not reflect the needs of current consumer-oriented VEs (COVEs). Hence, very little is known about how the devices interfacing our body influence these cognitive strategies.

The most used paradigm to study PI in VR is homing by triangle completion, where subjects start at a home location, moves between two points and he/she is asked to return using the most direct route [7] (Figure 1). To succeed, subjects must compute a homing vector

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with the perceived distance and direction of the home location, which accuracy depends on the integration of the PI and piloting processes. Thus, PI is usually described as an *online strategy* because the homing vector is computed continually based on the self-motion cues, and it does not require the formation of a spatial image. In contrast, piloting is usually described as an *offline strategy*, where the homing vector is computed once, and it requires the formation of a spatial image with the perceived directions and perceived distances of the different targets points [23]. Thus, we are interested in getting insights about how e cognitive strategies interact during a PI stimulus using COVEs.
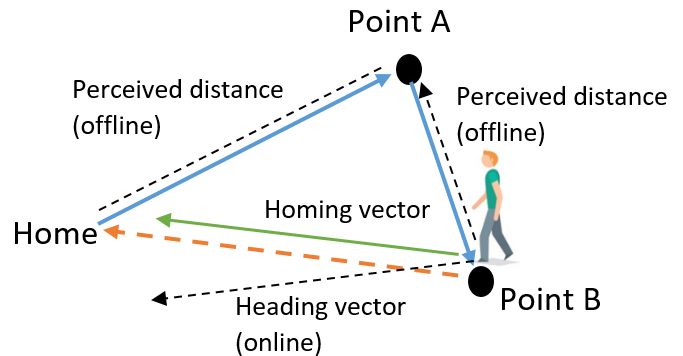

Figure 1: Homing by triangle completion. Subject starts at a home location, moves between two points and returns using the most direct route. To succeed, subjects must integrate the homing vector based on the self-motion cues and the spatial image.

PI and piloting are very different cognitive strategies, and studies suggest that a dissociation between both exists [23]. For example, fMRI studies indicated that different cortical systems are involved. While the online PI strategy involves low-level sensory-motor processes recruiting the human MT complex (hMT+) and intraparietal areas, the offline piloting strategy involves higher-level cognitive processes recruiting the hippocampus and the medial prefrontal cortex, regions associated with the spatial working memory ([24], [25]). Also, evidence suggests that both strategies use different reference frames. While PI uses egocentric spatial representations that are optimal for short-term sensory-motor integration, piloting uses allocentric representations that are more suitable for long-term memory [1]. Thus, we are interested in analyzing how the limitations of COVEs influence these different spatial representations.

Under natural conditions, both strategies cooperate to maintain accurate performance. The online strategy based only on self-motion cues is always affected by noise, where systematic errors occur in the computation of the homing vector according to the magnitude of displacements and turn required (also known as the *inherent noise*). The offline strategy supports the online by adjusting dynamically the state of the homing vector based on some external references (i.e., landmarks) ([3], [26]). When subjects had located themselves in the environment based on some external cues, the hippocampus can calculate subsequent positions based on the PI process, by analyzing

how far and what direction they had moved. Neurological evidence suggests that the hippocampus contains specialized cell types known as place cells and grid cells, where the former provides a dynamic allocentric representation of the space, and the second supports a sort of internal metric navigation system, which promotes activation in place cells [15]. Thus, some researchers suggest that the online PI strategy form the neural basis of the spatial image and the offline strategy ([11], [14]).

Neurological studies support the idea that locomotion is fundamental for the development of the spatial image, but this notion is challenged by studies of visual homing tasks, where physical movement is not necessary to have acceptable performance. This plasticity of the human brain presents an opportunity for navigation in COVEs, where locomotion is usually restricted. VEs allows the possibility of dissociating visual stimuli from physical motion, an advantage that we can use to understand how these cognitive strategies interact. We hypothesize that the interaction between these cognitive strategies changes depending on the quality of motor cues and visual cues provided by the VE and the number of sensory-motor conflicts induced. For example, a small FOV and resolution produce an optic flow field that is in disagreement with the motor cues. Mobile-based displays do not support head positional tracking affecting motion parallax, an important cue for spatial perception. Similarly, the perception of self-motion varies depending on the availability of motor cues provided by the interaction device [22]. Thus, the degree of sensory-motor immersion could be directly related to the performance during homing tasks.

In this study, we got insights about how COVEs influence the performance during homing tasks. In terms of displays, we selected two head-mounted displays (HMDs) that represents current trends in the market: a PC-based HTC Vive, which supports 110° FOV, 1.080 x 1.200-pixel resolution per eye and positional tracking capabilities, and a mobile-based Samsung S6-Edge GearVR which supports 96° FOV and around 1280 x 720-pixel resolution per eye. Regarding input devices, we selected two consumer technologies, a Virtuix Omni treadmill, which mimics locomotion by sliding the feet on a slightly concave surface, and a standard touchpad controller which supports classic joystick navigation. Thus, we were interested in understanding how both cognitive strategies interact depending on the availability and quality of the different motor cues and perceptual cues provided by these devices. Hence, we designed four VE setups that provide different immersion degrees, and we evaluate the subjects' responses under different homing stimuli.

2 RELATED WORK

2.1 Homing in the physical reality

The most extensive work for homing tasks have focused on PI, where triangle path completion is the most common method for assessing this spatial task (see [12], [9] for a complete review). Subjects are guided through a two-legs path in a physical environment and then asked to return to the origin under non-visual conditions. The typical experimental setup is composed of a set of triangles which shape is the factorial product of different target distance-to-origin and different turn-to-origin angles which represents different levels of spatial complexity. The results of these studies showed that subjects made systematic errors depending on the shape of the path, where large turns are underestimated and small turns are overestimated. Similarly, short distances are overestimated and long distances are underestimated. Although the performance is generally acceptable, researchers agreed that reliance on external landmarks and the offline strategy is necessary to have an accurate performance. In this study, we followed a similar experimental design to measure the performance in VEs with varying immersion degrees.

2.2 Homing in virtual reality

There are few studies about homing in VEs, but the evidence has shown that the human brain has great plasticity and subjects can perform homing tasks based only on the optic flow and in the absence of the other motor cues ([7], [18]). Subjects were asked to perform a homing task, and the contribution of the optic flow was isolated by navigating using a simple joystick inside a field with a noise pattern. Their results showed that subjects are not very sensitive to triangle shape when they must base their response only on the optic flow field (the online strategy). As more visual cues are introduced (visible landmarks and motion parallax), the performance improves and subjects respond differently to different triangles, a result that indicates that the offline strategy is more relevant when locomotion is restricted compared with studies in the physical reality.

Regarding the influence of the display, studies have shown that greater the physical display, better the performance and independently if locomotion is available or restricted [20]. This effects could be related with the direct relationship between display size, induced optic flow, and vection (or self motion perception). Studies have shown that the optic flow field induced by the display influences more the perceived amplitude of forwarding translations rather than the perceived amplitude of rotations ([16], [21]). As a consequence, the perception of speed tends to be underestimated, when the FOV and resolution decrease, affecting the online strategy. In contrast, a display with greater immersion (i.e a spherical stereo display with 180° horizontal FOV, 50° vertical FOV and 3500 x 1000 pixels resolution) can give to almost perfect performance when landmarks are available ([18], [4]). Hence, we designed a study to compare the effects of consumer-oriented displays with limited FOV and resolution on the performance during homing tasks.

The contribution of the motor cues has also been studied. When information from vestibular, proprioceptive and efferent cues is present, the online strategy becomes dominant ([7], [4]). Subject's responses are more consistent and more accurate when they can walk naturally, and the spatial image seems to be more reliable when landmarks are available, a behavior in agreement with the neurological evidence. In contrast, when locomotion is device-mediated, studies have shown that performance decreases and becomes more dependent on external references ([7], [18]. This result suggests that when locomotion is restricted, the influence of the offline strategy is stronger [7]. In this sense, this study provides insights into the interaction between the offline and online strategies during homing task using different consumer-oriented interaction devices.

The reliability of the spatial image depends on the subject's spatial perception, and VR displays suffer from distortions. For example, there exists a consensus that distances are generally underestimated, especially using HMDs. Before the advent of consumer-oriented devices, distances were generally underestimated by a mean of 75% (see [17] for a complete review). With the arrival of modern consumer-oriented displays with greater capabilities, the underestimation has become less stronger. Although several researchers suggested that the phenomenon was not associated to the display limitations, recent evidence suggests that the causes could be related to the nature of light stimulation and image resolution induced in the peripheral vision ([10], [6]). Thus, the display immersion degree can also impact the offline strategy, and this study tries to understand its influence in modern consumer-oriented displays.

2.3 Neural basis of homing in VEs

Studies in VEs using mice have shown that place cells and grid cells firing patterns reflects different inputs. While place cells patterns predominantly reflect the influence of external visual inputs, grid cells activity reflect the influence of physical motion [2]. These patterns also respond to environmental changes. For example, activation on grid cells tends to increase, compared with place cells activation, when landmarks are removed or replaced [15]. Thus, the

hippocampus can recalibrate the interaction between these cells as convenience. Recent evidence using human beings confirms the high plasticity of the human brain, where a persistent conflict between self-motion cues and visible landmarks induces a recalibration in the firing patterns in the hippocampal cells [5]. This recalibration effect is important because the *recalibration hypothesis* is one of the most accepted theories about the impact of VR in spatial cognition and the puzzling problem of underestimation of distances [8]. In this sense, we hypothesize that the limitations of COVEs induce a recalibration process in both cognitive strategies.

3 HOMING TEST

How precise subjects can develop homing tasks in COVEs with different degrees of sensory-motor immersion? In this test, we studied the performance when subjects compute the homing vector on the four VE setups. Figure 2 show our hypotheses of how both cognitive strategies will behave depending on each VE setup. Each setup was classified in immersion orders following Slater's (2009) definition of immersion [19]. As the availability of the motor cues increases (treadmill condition), the online strategy will become dominant, and the performance will rely on the quality of the optic flow field induced by the display, where the HTC Vive will surpass the GearVR. In contrast, as the availability of the motor cues decreases (touchpad condition), the offline strategy will become dominant, and the performance will rely on the number of distortions induced by the display in the spatial image, where again the HTC Vive will surpass the GearVR. Thus, the performance will depend on the amount of "noise" introduced in the system by the VE, either perceptual or motor, which is indirectly related with the immersion degree provided by the VE.
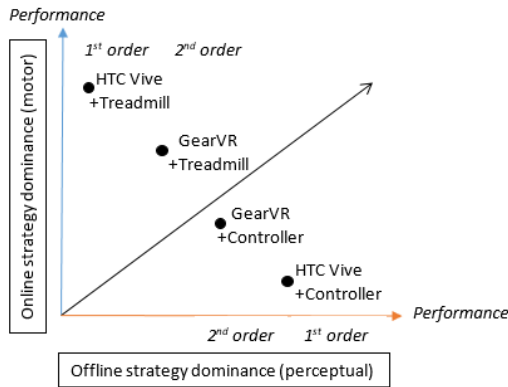
Figure 2: The expected behavior of the two cognitive strategies depending on the VE setup. As the quality and availability of the self-motion cues increases, the online strategy will be more influential in the performance. Otherwise, the offline strategy will be more influential.

To enhance the differences between VE setups, we designed a set of paths with different spatial complexity (inherent noise) and based on previous studies ([18], [7], [11]). The selected paths were composed of isosceles triangles whose shape corresponds to the 30°, 60° and 90° vertex angles (Figure 3). Independently of the path shape, subjects have to return the same target distance, so their performance will depend only on subject's ability to integrate the two-guided segments (solid arrows) and compute the homing vector, which magnitude is always the radius of the circumference (dashed arrow). The shape of the path is an indicator of the spatial complexity, where the 30° vertex triangle is usually the most difficult and more dependent on external references. Hence, we are interested in getting insights into how these two cognitive strategies interact depending on the path complexity.
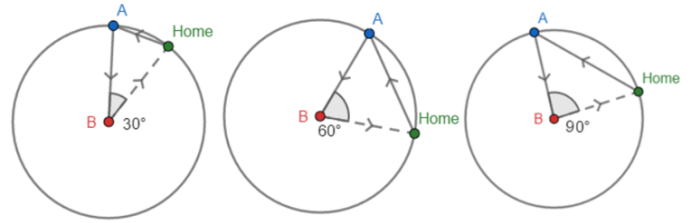
Figure 3: The selected path shapes. The shape represents the path spatial complexity, where 30° vertex triangle is the most complex and requires an active integration of both strategies.

3.1 Hypothesis

Our Hypothesis are as follows:

- H1: When locomotion is available (treadmill condition), the online strategy will be the most influential and there exist significant differences in spatial performance between both displays due to the differences in optic flow field induced.

- H2: When locomotion is mediated (touchpad condition), the offline strategy will be the most influential and there exist significant differences in spatial performance between both displays due to their effects in spatial perception and the formation of the spatial image.

- H3: There exist effects on path shape and display due to the influence of the display in both cognitive strategies.

4 METHOD

For each target VEs setup, we provided subjects with a VR controller and they followed the next procedure: First, subjects were located at the home position, which location was randomly selected inside a natural looking scene with visible landmarks (Figure 5). Then, they visualized the location of the target points (A, B) that were highlighted with a blue and red post respectively. We asked subjects to "visualize" the path in their minds first before starting to move. Then we guide them to move first to point A (blue post) and then towards point B (red post). After reaching point B, subjects had to return to the home location, which was not highlighted. Subjects selected the location where they considered was the starting point by pressing the trigger button, and we registered the chosen position. Then, a green post appears indicating the actual home location and subjects can visualize the precision of their homing vector. Finally, the subject's home location and point A are relocated aleatory around the circumference, and they performed the same steps with another path with a different shape.
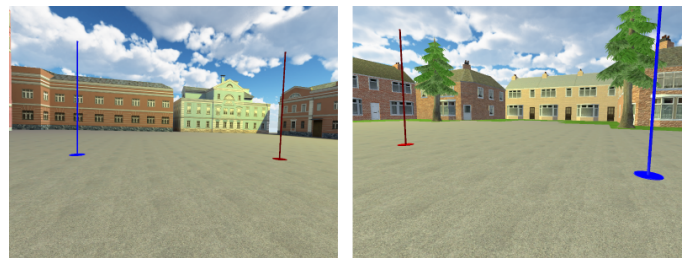
Figure 4: The natural looking scenes used in the test with the target points of the path highlighted.

Order	Display	Interaction	Group
1st	HTC Vive	Treadmill	Group 1
2nd	Gear VR	Treadmill	Group 2
1st	HTC Vive	Touchpad	Group 2
2nd	Gear VR	Touchpad	Group 1

Table 1: The classification of the VEs setups according to their immersion degree and the groups assigned at each setup.

The interaction was as follows: at every point, and independently of the interaction technique, we forced subjects to orientate their body first in the desired direction of motion and then move in straight line to the next point either by walking in the treadmill or by pressing the vertical axis in the touchpad. For the treadmill, we set the default max speed of 5 m/s and the default calibration parameters. Also, we used the coupled configuration, where the direction of gaze of the headset is used to determine the direction of motion (the configuration suggested for beginner users). Regarding the touchpad interaction, we implemented a constant speed mapping of 2 m/s for forwarding motion while we allowed subjects to turn their body to the desired direction. Thus, we maintain the same mechanism for the selection of the heading direction in both conditions.

Subjects performed the homing test in the four COVEs setups. We designed a between-subjects experiment, where subjects perform the test twice in two VEs setups without repeating the display and the interaction device. We classified the VEs setups according to their immersion degree (following Slater's (2009) definition of immersion [19]) and we assigned subjects in two groups (Table 1). We counterbalanced the order, so half of the subjects in the same group started with the first order VEs and the other half with the second order VE. Similarly, we alternate the natural looking scene presented in each VE. Thus, this configuration allows as to prevent bias due to learning effects and especially fatigue (mainly for the treadmill condition).

4.1 Participants

40 subjects participated in this experiment (28 M, 12 F) whose ages ranged from 19 to 21 years (mean: 19.36 years, SD:1.05). All participants had normal or corrected-to-normal vision. Participation was always voluntary, and they signed a consent form reporting good health at the moment of the experiment, with no previous history of relevant diseases. 8 of the 40 subjects were discarded because they manifested cybersickness symptoms or did not get used to walking in the treadmill after the training task.

4.2 Apparatus

Unity3D was used for the visualization where we applied the same rendering technique for both VR displays. We used forward-rendering lighting model with 2 pixels light count, and all materials used the optimized mobile-diffuse shader. The global illumination of the scene was baked with shadow mask support and the only real-time light calculated was applied over the posts that indicate the target points of the path. We measured the frame rate during a simple homing task using the treadmill: the HTC Vive condition had a higher framerate (88.96 ave, 2.18 SD) compared with the Gear VR condition (56.2 ave, 3.56 SD) without applying vertical sync. Also, we applied a texture with noise in the ground in both natural looking scenes to increase the optic flow below the horizon line.

We set the HTC Vive IPD to the same value of the GearVR IPD (62 mm according to Oculus specs). Also, we used the Lighthouse tracking system in the four VEs setups to support the integration with the treadmill in the GearVR and positional head tracking in the HTC Vive. We attached a Vive tracker to the GearVR headset to calibrate the subject height inside the VE. Also, we used this tracker to register the direction of heading, a vector that is used to compute the direction of motion in the treadmill for the coupled configuration. At the beginning of each homing task, we synchronized the orientation of the GearVR camera with the tracker orientation to ensure that both represents the heading direction. Also, we calibrate the Samsung S6 Edge sensors before connecting the mobile phone in the headset. Although the mobile sensors have an accumulative error, studies have shown that the average error in modern smartphones is under the 0.06 degrees [13], so we expected that this error is relatively smaller.
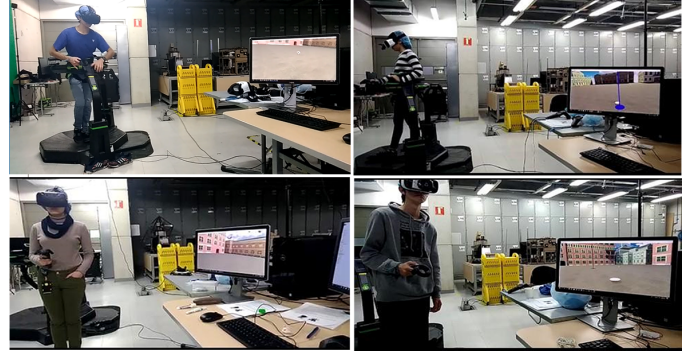

Figure 5: The four VE environment setups. Top. VEs setup with treadmill condition. Bottom. VE setups with touchpad condition.

4.3 Procedure

Before the actual experiment begins, we gave instructions to subjects of the different tests and how to use the equipment for each VE setup. First, we designed an adaptation task, where subjects had to locate and collect 6 soccer balls that appeared sequentially and randomly scattered in the scene. This task allowed subjects to get used to the interaction technique, either walking in the treadmill or using the touchpad controller. Then, subjects perform a training session, where subjects developed 4 homing tasks on 3 paths of different shape and size. This training allowed subjects to practice and understand better the nature of the test, and this task allowed us to discard those subjects who had difficulties to walk comfortably and collect the balls in a reasonable time. Also, we encouraged subjects to correct the homing vector by walking the distances that were underestimated so they can develop a better spatial impression. Thus, subjects performed 4 trials x 3 triangles x 2 VE setup training sets.

Finally, subjects performed the homing test in the target paths. We selected as target paths, 3 isosceles triangles with side-segments of 10m and vertex angles of 30°,60° and 90°. After the training session, each subject performed two trajectories for each triangle in clockwise and counterclockwise direction of motion (Figure 6). From these trials, we selected only the most optimal value as the performance for the target path and VE setup. In sum, subjects performed a configuration of 2 trials x 2 direction-of-motion x 3 triangles x 2 VE setups.
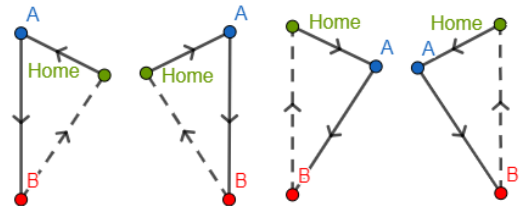

Figure 6: The two measured trajectories for the 30° path performed in clockwise and counterclockwise direction of motion.

5 RESULTS

Figure 7 presents the spatial performance of subjects after the homing test for the four VE setups. The scatter plot presents the best homing vector for each subject with the last position computed depending on the interaction technique and VR display. The results showed that subjects systematically tend to underestimate the direction and distance of the home location independently of the display, path-shape and interaction device.
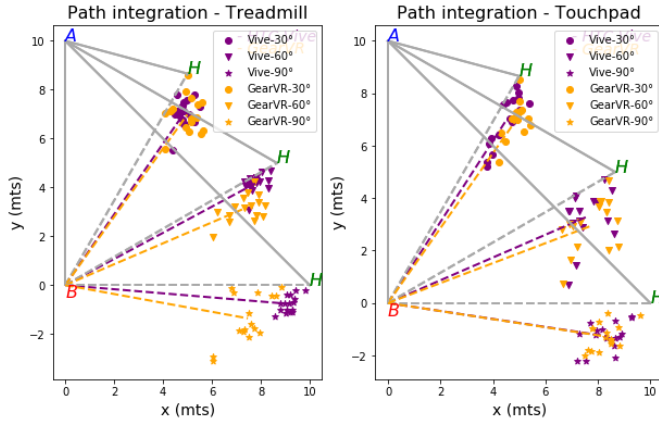

Figure 7: The performance for the homing test. Subjects tend to underestimate the direction and distance of the home location independently of the display, path shape and interaction device.

Figure 8 presents the mean trajectories and the confidence regions (defined as the covariance matrix) for the homing test. The ellipsoids represent the first and second standard deviations which center is the mean homing vector. The results show the influence of the VE setup in the spatial performance. When locomotion with the treadmill is available, subjects tend to compute more concise and more precise homing vectors in the HTC Vive than in the GearVR. This result implies that when locomotion is available, the online strategy is dominant and subjects can integrate paths more effectively in the display with the greater immersion degree, a result in agreement with previous studies about the influence of the display in the performance. In contrast, when subjects move with the touchpad, there are no differences between displays, but subjects have more difficulties in computing the homing vector.
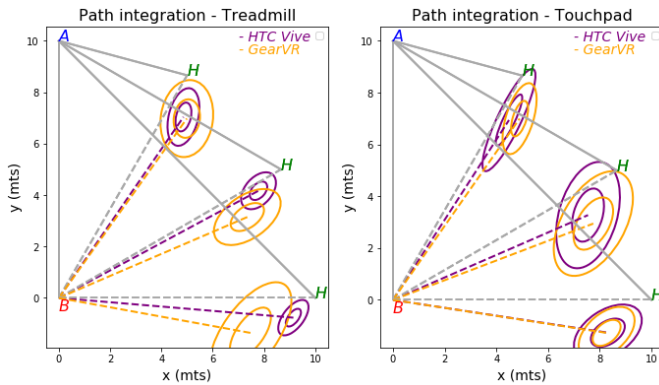

Figure 8: The spatial performance for the homing test described as confidence ellipses.

The confidence ellipses also show effects in path shape. In the Treadmill + HTC Vive condition, subjects have more difficulties

in computing the homing vector for the more complex path (30° vertex triangle). This performance is similar to the responses found in previous studies when locomotion is available, which implies that subjects have difficulties to use the landmarks to adjust their homing vector for this path and the influence of the offline strategy is smaller. In contrast, in the Treadmill + GearVR condition, there exist opposite effects in this path, a result that suggests that when the self-motion cues are severely affected by the display, the reliance on external landmarks and the offline strategy likely increases. The poor results in this condition could be related to the limited FOV and resolution, and the restricted motion parallax cue in this display.

Regarding the VE setups with the touchpad condition, both displays present similar variability, which implies that the offline strategy is more sensitive to the path complexity. Particularly, subjects tend to have more errors regarding distance for the most complex path, which indicates that the offline strategy is likely more influential. This performance suggests that despite subjects are actively using landmarks and the offline strategy in this condition; either both displays are affecting the perception of distances similarly, or the induced optic flow field is not enough to support the online strategy and build a reliable spatial image in absence of the other motor cues.

An analysis of variance was conducted to analyze the differences between the VE setups. Mauchly's Test of sphericity and Shapiro-Wilk test of normality indicated that sphericity and normality were violated for some of the target paths. Thus, a Friedman's non-parametric two-ways repeated measures ANOVA was conducted on the influence of the four VE setups on the spatial performance for all target paths. The non-parametric analysis of variance compared the differences in performance between two between-subjects factors (VE setup either with or without locomotion) and three within-subjects factors (30°, 60°, 90° path shapes). The main effect for display yielded a Chi-square $X_3^2 = 21.10, p < 0.01$ for distance-error and $X_3^2 = 22.37, p < 0.01$ for angle-error. A post-hoc comparison using a Dunn test with Bonferroni correction indicated that there are significant differences between VE setups but only in those with the treadmill condition, where the distance error of the HTC Vive + Treadmill setup ($M = 1.14, SD = 0.48$) is significantly smaller ($p < .01$) than the GearVR + Treadmill setup ($M = 1.911, SD = 0.79$), and the angle error of the HTC Vive + Treadmill ($M = 3.78, SD = 2.52$) is also significantly smaller ($p < .01$) than the GearVR + Treadmill setup ($M = 7.73, SD = 5.87$).

The results of the Dunn procedure shows that there exist significant differences between VE setups but only in those with the treadmill condition, where the performance of the HTC Vive + Treadmill setup is significantly higher compared with the GearVR + Treadmill setup. Hence, our hypothesis H1 holds, the display immersion degree has a powerful effect on the online strategy causing differences in the spatial performance between displays. In contrast, our hypothesis H2 did not hold. In the touchpad condition, we did not find significant differences between displays. Since the offline strategy relies mostly on the spatial image of the path, both display seems to affect the performance similarly.

To describe the interaction effects with path shape, a Wilcoxon signed-rank test was conducted for display, where the results are presented in Table 2. The analysis indicated that there exist significant effects on path shape for display in terms of angle and distance. The results suggest that independently of the interaction technique or which cognitive strategy becomes more influential, the spatial performance is highly sensitive to the noise introduced by the display, affecting either the effective integration of the path during PI or the reliability of the spatial image during piloting. Thus, our hypothesis H3 holds, the display immersion influences both cognitive strategies but in different ways.

Display	error	30°	60°	90°
Vive	dist.	M=1.58,SD=0.85	M=1.44,SD=0.66	M=1.19,SD=0.60
	angle	M=3.84,SD=2.21	M=4.35,SD=5.49	M=6.80,SD=3.79
GearVR	dist.	M=1.42,SD=0.68	M=1.83,SD=0.83	M=1.97,SD=0.68
	angle	M=5.37,SD=3.04	M=8.20,SD=4.94	M=9.75,SD=6.41
Post-hoc	dist.	Z=0.692, p=0.489	**Z=2.019, p=0.043**	**Z=3.403, p=0.001**
test	angle	**Z=2.861, p=0.004**	**Z=3.048, p=0.002**	**Z=1.982, p=0.047**

Table 2: Wilcoxon post-hoc analysis with the effects display and path shape in the performance for the four VE setups.

6 DISCUSSION

We develop a study about the effect of different COVEs with different degree of immersion on the performance during homing tasks. Our results show that subjects computes homing vectors more precise and concisely in the HTC Vive + Treadmill setup than in the GearVR + Treadmill setup when locomotion is available. These results confirm the influence of the display immersion degree in the online strategy when the motor cues are dominant, results which are in agreement with previous studies. However, the results suggest also that the influence of the offline strategy increases as the quality of the optic flow field induced by the display is reduced. Thus, the differences between both displays could be due to the limited FOV, resolution and the restricted motion parallax cue in the GearVR.

Regarding the conditions when locomotion is restricted (touchpad condition), there are no significant differences between the HTC Vive + Touchpad setup and the GearVR + Touchpad. However, the performance in the most complex path could mean that the influence of the online strategy is stronger. This result suggests that when the offline strategy becomes dominant, the reliability of the spatial image is severely affected by the display. Since consumer-oriented displays have display sizes smaller than large-immersive-displays, this could cause that either (1) the induced optic flow field is not enough to form a reliable spatial image (in the absence of the other motor cues), or (2) the subject's spatial perception is severely affected.

In sum, the display has a significant impact on the normal interaction between the online PI strategy and the offline piloting strategy. We believe that the quality of the optic flow field induced by the display is an essential in building reliable spatial images, following the neurological evidence and the studies about visual homing without locomotion. However, the results shows that locomotion is still important to developing homing tasks in COVEs.

7 FUTURE WORK

The interaction between the offline and online strategies in COVEs is more complicated than we expected. In this sense, it is necessary to develop further studies about what is the contribution of each cognitive strategies independently, for example by isolating the optic flow contribution, by presenting the target points sequentially, by changing the reliability of different landmarks or influencing different spatial perception cues. Understanding the plasticity of the human brain to develop homing task in VEs with different degrees of immersion is a crucial step to improve navigation in COVEs.

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