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Perceived Space and Spatial Performance during Path-Integration Tasks in Consumer-Oriented Virtual Reality Environments

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ABSTRACT

Studies using virtual reality environments (VE) have shown that subjects can perform path integration tasks with acceptable performance. However, in these studies, subjects could walk naturally across large tracking areas, or researchers provided them with large-immersive displays. Unfortunately, these configurations are far from current consumer-oriented VEs (COVEs), and little is known about how their limitations influence this task. Using a triangle completion paradigm, we assessed the subjects' spatial performance when developing path integration 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 the display and the path. In contrast, when locomotion is mediated no effect was found. Some future research directions are therefore proposed.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality

1 INTRODUCTION

Path integration (PI) allows human beings to explore the environment and find their way back home based on their self-motion cues and a mental representation of the path known as ”spatial image” [4]. The most used paradigm to study PI is triangle completion, where subjects start at a home location, move between two points and return using the most direct route [3] (Fig. 1 left). However, we use two different cognitive strategies to solve this problem, known as the online and offline strategies [8]. In the *online* strategy, the homing vector is computed continually based on self-motion cues (optic flow, vestibular, proprioceptive and efferent). In contrast, in the *offline* strategy, the homing vector is computed once, based on the perceived directions and perceived distances of the different points (spatial image). Studies in VEs usually have conditions where subjects can either walk naturally or use large immersive displays, conditions that do not reflect current COVEs.

Under natural conditions both strategies cooperate to maintain an accurate spatial performance. PI based only on self-motion cues is affected by noise, where systematic errors occur in the computation of the homing vector. The offline strategy supports the online one by dynamically adjusting the homing vector based on external references (i.e., landmarks) [1]. In contrast, the limitations of COVEs cause that self-motion cues and spatial perception become non-reliable and contradictory, conflicting these strategies. In this study, we got insights about how COVEs influence these cognitive strategies during a PI task. We selected two head-mounted displays (HMDs) that represents current trends in the market: an HTC Vive (110° FOV, 1080 x 1200 resolution), and a Samsung S6 GearVR (96° FOV, around 1280 x 720 resolution and no positional tracking). Also, we selected two consumer interaction devices, a Virtuix Omni treadmill and a standard Touchpad controller (Fig. 2). Thus, we designed four VE setups that provide different immersion levels and we evaluated the subjects' performance under different PI stimuli.

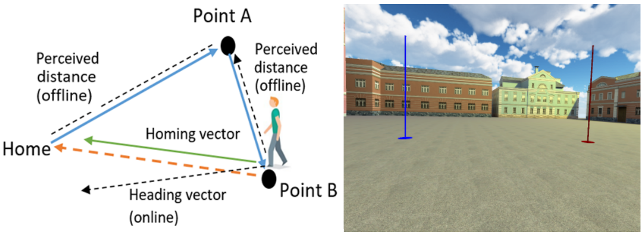

Figure 1: Left. PI task: the homing vector is based on the motor cues and the spatial image. Right: Natural looking scene used in the test.

2 RELATED WORK

Most of past work about PI has been done in physical reality using the triangle completion paradigm [5]. Typically, researchers test a set of triangles with different spatial complexity (a factorial product of different distances-to-origin and turns-to-origin). Results showed that subjects make systematic errors depending on the path shape. Large turns/distances are slightly underestimated and small turns/distances are overestimated. Studies in VEs showed that subjects can perform PI based only on the optic flow and without any physical locomotion [2, 3, 6]. The optic flow contribution was isolated while navigating inside a field with noise and using a joystick. Subjects were not very sensitive to the triangle shape when they based their response only on the optic flow (online strategy). As more visual cues were introduced (i.e., landmarks), performance improves and subjects responded differently to different paths (offline strategy) [2, 6]. Thus, we took into consideration these effects in our experimental design providing visible landmarks and various paths with different complexities.

Regarding immersion, the greater the display, the better the performance no matter whether locomotion is available [6, 7]. In terms of interaction, subject's responses are more accurate when they can walk naturally [2, 3]. In contrast, when locomotion is restricted, performance decreases and becomes dependent on external cues [3].

3 PATH INTEGRATION TEST

How precise subjects can develop PI tasks in COVEs? In this test, we studied how well subjects perform PI tasks on the four VE setups described above. We designed a set of paths with different spatial complexities based on previous studies [3, 4, 6]. The paths were composed of 10m-side-segment isosceles triangles with apex angles of 30°, 60° and 90°. Independently of the path, subjects returned the same target distance so their performance depended only on subjects' ability to integrate the two-guided segments (blue lines in Fig. 1 left) and compute the homing vector, whose magnitude is the circumference radius (green line in Fig. 1 left). Thus, we analyzed how both cognitive strategies interact depending on the path and the VE setup.

3.1 Experiment

The procedure was as follows. First, subjects were located at the home position (randomly selected) inside a natural looking scene with visible landmarks (Fig. 1 right). Then, they visualized the target

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points (A, B), highlighted with a blue and red post respectively. We guided them to move to point A and then towards point B. After reaching B, subjects returned to the home location (not highlighted). Subjects selected the position where they considered to be back home by pressing a button and we registered it. Finally, the subjects' home location was relocated aleatory around the circumference and they repeated the steps with a different path.

We designed a between-subject experiment, where subjects performed the test twice in two VEs with different displays and interaction devices. We assigned them in two groups in counterbalanced order: half in the same group started with the first VE and the other half with the second. After a training session, each subject performed two trajectories for each triangle in the clockwise and counterclockwise directions. From these trials, we selected only the most optimal value for the target path and VE setup. In sum, subjects performed 2 trials x 2 directions x 3 triangles x 2 VEs, giving a total of 24 trials.

40 subjects participated in this experiment (28 M, 12 F, ages $M = 19.36$, $SD = 1.05$ years). All participants had normal or corrected-to-normal vision. Participation was voluntary, and they signed a consent form reporting good health with no history of relevant diseases. 8 of the 40 subjects were discarded because they manifested cybersickness or did not get used to the treadmill.

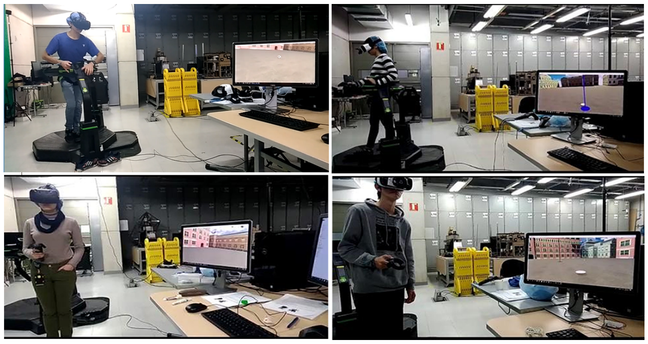

Figure 2: The four VE environment setups. Top. VE setups with the treamdill. Bottom. VE setups with the touchpad.

3.2 Hypotheses

Our hypotheses were as follows. H1: When locomotion is available (treadmill condition), the online strategy will be dominant and there exist significant differences in spatial performance between both displays. H2: When locomotion is mediated (touchpad condition), the offline strategy will be dominant and there exist significant differences in spatial performance between both displays.

4 RESULTS AND DISCUSSION

Figure 3 shows the spatial performance represented by the confidence regions (defined as the covariance matrix) for the PI tests. The ellipsoids represent standard deviations with mean homing vector as the center. Subjects systematically underestimated the direction and distance of the home location independently of the display, path and interaction device. When locomotion is available (treadmill condition), subjects tended to compute more concise and precise homing vectors in the HTC Vive than in the GearVR. This implies that when locomotion is available, the online strategy is dominant and subjects can integrate paths more effectively in displays with greater immersion, which is in agreement with previous studies (except for the most difficult triangles). However, its seems that the influence of the offline strategy is considerable and the differences between displays could be due to the restricted motion parallax cue in the GearVR, an important spatial perception cue. On the other hand, in the touchpad condition, no differences between displays exist and subjects were less sensitive to the path shape, which implies that the dominance of the offline strategy is limited or severely affected by the display.

A Friedman's non-parametric two-way repeated measures ANOVA was conducted on the influence of the four VE setups on the spatial performance for all target paths. The ANOVA compared the differences in performance between two between-subject factors (VE setup) and three within-subject factors (30°, 60°, 90° paths). The main effect for the display yielded a Chi-square $\chi^2_3 = 21.10, p < .01$ for distance-error and $\chi^2_3 = 22.37, p < .01$ 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, where the distance error of the HTC Vive + Treadmill setup ($M = 1.911, SD = 0.79$) is significantly smaller ($p < .01$) than the GearVR + Treadmill setup ($M = 1.14, SD = 0.48$), and the angle error of the HTC Vive + Treadmill setup ($M = 3.78, SD = 2.52$) is also significantly smaller ($p < .01$) than the GearVR + Treadmill setup ($M = 7.73, SD = 5.87$).

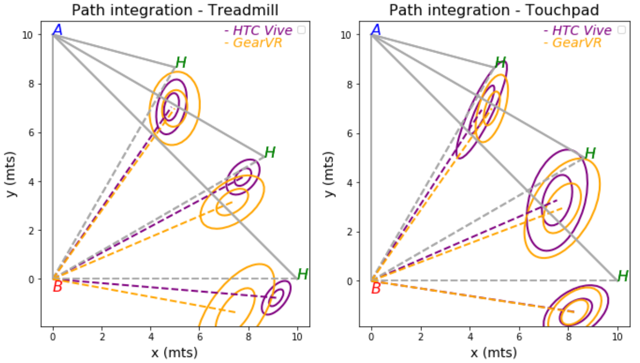

Figure 3: Results of the PI test. Subjects tend to underestimate the direction and the distance independently of the display, path and interaction.

Based on the results, our hypothesis H1 holds, the display immersion has a powerful effect on the online strategy causing differences in spatial performance, confirming the importance of the display immersion when motor cues are dominant. However, performance can be severely affected by the quality of the cues used in the offline strategy. On the other hand, our hypothesis H2 did not hold, in the Touchpad condition we did not find any significant differences between displays. Since the offline strategy relies mostly on the spatial image, either its dominance is severely affected or both displays seem to affect subjects' spatial perception similarly. Thus, interaction between the offline and online strategies in COVEs is more complex than we expected. In this sense, it is necessary to develop further studies about what are the effects of the treadmill's walking metaphor and analyze the contribution of each strategy independently, for example by isolating the optic flow contribution, by presenting the target points sequentially or by influencing different spatial perception cues.

REFERENCES

[1] A. S. Etienne and K. J. Jeffery. Path integration in mammals. *Hippocampus*, 14(2):180–192, 2004.

[2] P. Foo, W. H. Warren, A. Duchon, and M. J. Tarr. Do humans integrate routes into a cognitive map? map-versus landmark-based navigation of novel shortcuts. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31(2):195, 2005.

[3] M. J. Kearns, W. H. Warren, A. P. Duchon, and M. J. Tarr. Path integration from optic flow and body senses in a homing task. *Perception*, 31(3):349–374, 2002.

[4] J. M. Loomis, R. L. Klatzky, and N. A. Giudice. Representing 3d space in working memory: Spatial images from vision, hearing, touch, and language. In *Multisensory imagery*, pp. 131–155. Springer, 2013.

[5] J. M. Loomis, R. L. Klatzky, R. G. Golledge, and J. W. Philbeck. Human navigation by path integration. *Wayfinding behavior: Cognitive mapping and other spatial processes*, pp. 125–151, 1999.

[6] B. E. Riecke, H. van Veen, and H. H. Bülthoff. Visual homing is possible without landmarks. Technical report, Tech. Rep, 2000.

[7] D. S. Tan, D. Gergle, P. G. Scupelli, and R. Pausch. Physically large displays improve path integration in 3d virtual navigation tasks. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pp. 439–446. ACM, 2004.

[8] J. M. Wiener, A. Berthoz, and T. Wolbers. Dissociable cognitive mechanisms underlying human path integration. *Experimental brain research*, 208(1):61–71, 2011.