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Differences in navigation behavior between head-mounted display and desktop presentation

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Abstract:
Cartographic visualizations play a crucial role in conveying spatial information. They help users familiarize themselves with the spatial conditions of a particular area before or while encountering the real environment. Cartographic visualizations must be accurate and tailored to the user's needs to represent spatial environments effectively. Beyond traditional maps, 3D visualizations have gained popularity in both geographical data visualization (Keil, Edler, Schmitt, and Dickmann, 2021) and in scientific experiments (Hepperle and Wölfel, 2023), as various restrictions of real-world experiments, such as a limited space, no longer apply. Research across various fields has already explored different aspects of presenting 3D environments using head-mounted displays (HMDs) or desktop screens (e.g. Hruby et al., 2020; Shu et al., 2019). Some studies also compared the 3D visualization via HMD with an analog presentation in the real world (e.g. Auer et al., 2021). Most studies show a higher degree of immersion when an HMD is used to display a 3D environment compared to a desktop presentation (Hepperle and Wölfel, 2023; Hruby et al., 2020; Shu et al., 2019). However, the influence of presentation type on navigation performance in 3D environments remains unclear. This aspect was meant to be investigated in this experimental setup. We also wanted to find out whether varying arrangements of distal landmarks in connection with presentation type (HMD/desktop) affect the navigation performance of participants. The identification of visual cues is necessary to design maps supporting the construction of a mental spatial map. Findings on the effectiveness of environmental cues form an important basis for deriving links to different neuronal processes in the brain, which might support the construction of a mental representation of space (cf. Dickmann et al., 2024; Korte et al., 2024).

We examined the influence of using an HMD versus a desktop screen presentation during a spatial navigation task within a between-subject design. Participants were divided into two groups: one performed a path integration task on a computer desktop, while the other used a standalone HMD (PICO 4 Ultra VR-Headset). The sample size was 97 (desktop: 46 subjects; HMD: 51 subjects; M_{age} = 24,27, SD_{age} = 4,76, 48% males). We used a circular spatial 3D environment with a grassy plane without any visual boundaries. Additionally, four distal cues in two distinct colors were positioned on the blue sky within the participants' field of view. These cues indicated two axes (30°/60°) to facilitate spatial orientation without providing distance estimation (see Fig. 1).

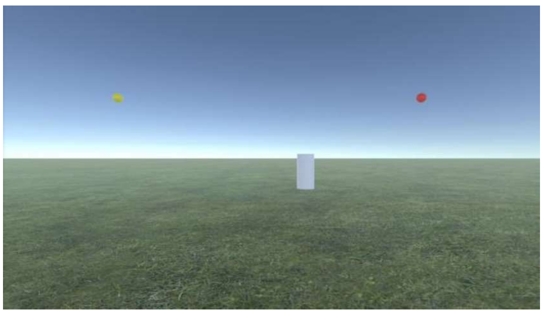

Figure 1. Exemplary participant's view in the virtual environment (desktop and HMD presentation).

The forward movement was controller-based in both groups. Rotation in the HMD group was performed by head movement, whereas in the desktop condition, it was controlled via the joystick. The task required participants to

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navigate to various locations within the environment. Starting from the center, they were instructed to move towards different locations marked by cylinders, which disappeared upon approach. Once the participants reached the target, they had to return to the location of the first cylinder and indicate the location by pressing a controller button. Participants conducted up to 36 trials in total. We investigated various distance measurements, participants' performance in the path integration task, the influence of the angle between axes indicated by the distal cues, and navigation behavior between the two groups. Path integration performance was operationalized by the Euclidean distance between the correct and indicated location of the first cylinder. After testing for normal distribution, t-tests to detect possible differences between the two groups, a general linear model, and several post hoc tests were conducted.

Age, gender distribution, and average time spent playing computer games per week did not differ significantly between groups. Moreover, the analyses showed no significant effect of any distance measure concerning the experimental locations. This indicates that all other differences are not based on differences between the two groups, such as distances between the locations. Path integration performance showed no significant difference. Participants in both groups performed the task equally well. We also found no main effect of the angle between axes, nor an interaction between presentation type and angle between axes. However, differences in navigation behavior were observed. Participants performing the task with an HMD covered (travelled) a shorter distance on average than participants using the desktop for the task ($T(95) = 1.661$, $p = 0.050$). Moreover, subjects in the HMD group showed a significantly higher difference between the ideal expected walking distance and the distance travelled in comparison to the group conducting the experiment via desktop ($T(95) = 1.699$, $p = 0.046$). The path integration performance of the HMD group was similar to the desktop group, even though the HMD group travelled shorter distances than expected. This might lead to the conclusion that the participants in the HMD group walked in a straighter line between the locations in the virtual environment than participants in the desktop group. It seems likely that the test subjects in the HMD group perceive directions (angles) better than participants in the desktop group and therefore show better orientation behavior. The shorter travelled distances in HMD could be attributed to the artificial locomotion and rotation used in this experiment. For future studies, it might be useful to add a short training in distance estimation to improve navigation performance (Keil, Edler, O'Meara, et al., 2021). Our findings suggest that HMDs may offer advantages in navigation efficiency and spatial orientation over desktop presentations, even though path integration performance remains comparable. This emphasizes the importance of considering presentation type in the design of virtual navigation tasks.

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