Navigating ADHD: Using VR to Explore ADHD Group Navigational Differences

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Introduction

Whether navigating a familiar space or a new city, our brains rely on a series of complex cognitive processes to support our wayfinding goals and spatial learning such as spatial working memory (SWM), attention, and cognitive flexibility (Hegarty et al., 2006; Montello, 2005; Nazareth et al., 2019). However, individuals with ADHD demonstrate impairments with these cognitive processes because of broad executive dysfunction stemming from impairments in the pre-frontal cortex (Alderson et al., 2013; Barkley, 1997; de la Paz et al., 2025; Rapport et al., 2008). Prior research shows that deficits in these cognitive processes have a negative impact on wayfinding ability (Blacker et al., 2017; Hegarty et al., 2006) and the development of spatial knowledge in ADHD individuals (Gitten et al., 2006; Luo et al., 2019).

Del Lucchese et al., (2021) and Luo et al., (2019) showed that ADHD children demonstrate differences in geospatial navigation behavior and strategy (egocentric vs. allocentric), negatively impacting their wayfinding abilities because of executive function impairments, particularly in the SWM attentional control mechanisms that underpin wayfinding skills. Gitten et al. (2006) showed that ADHD individuals experience impaired general spatial learning abilities due to attentional executive dysfunction. These executive control functions are critical for the requisite processing of spatial information and development of spatial knowledge (Credé et al., 2020; McAfoose & Baune, 2009; Wen et al., 2012) and may lead to struggles with route planning and spatial updating of cognitive maps when impaired (He et al., 2021; Ruginski et al., 2019; Uresti-Cabrera et al., 2015).

Immersive virtual reality (VR) has emerged over the past decade as a valuable tool in cognitive science research and research on spatial cognition. Compared to other VR tools, immersive VR provides enhanced ecological validity and spatial embodiment (Riva et al., 2019). These advantages are critical in the study of geospatial navigation as it allows researchers to control environmental variables while mitigating loss to the environmental and scenario validity for real-world contexts. In addition to this increased environmental presence, immersive virtual environments can be used for assessing the impacts of impaired cognitive functions (Belger, 2021). As such, immersive VR is a useful tool to study the impacts of impaired executive cognitive functions in ADHD adults on spatial navigation.

Prior research has focused on spatial navigation in the general population, noting the influence of individual differences, particularly in executive functions, on navigational ability (Ishikawa, 2018; Ishikawa & Montello, 2006). However, current literature has not focused on the impacts of executive function impairment present in ADHD on navigational abilities. This study sought to examine how ADHD-related executive function impairments impact navigational abilities, spatial learning, and cognitive load. Using a virtual environment, we compared the geospatial navigation performance of adults with ADHD to control adults, exploring how task complexity affects spatial learning and wayfinding abilities. The findings from this work will inform the development of neuro-adaptive geospatial navigation tools and interventions to enhance spatial skills and address spatial deskilling.

Methods

Apparatus/Materials

We developed a virtual experiment in unity for the Apple Vision Pro headset. Participants controlled their navigation using hand gestures and eye gaze control. The participants' perspective view changed according to their head direction allowing them to adjust navigation direction. City models used for the environment were adapted from a study conducted by the GIVA lab (Cheng et al., 2023).

To assess navigational self-efficacy and executive function capacities participants completed the Santa Barbara Sense of Direction (SBSOD) survey, NASA TLX (perceived cognitive load), spatial-span memory test (working memory), and trail making test (visual attention and cognitive flexibility).

Participants and Recruitment

This study recruited 46 participants in total between the ages 18 to 57, 23 clinically and self-diagnosed ADHD adults and 23 control adults. From the ADHD group 5 people were excluded and from the control group 6 participants were excluded due to technical issues and incomplete results. The final count was 17 control and 18 ADHD participants.

To account for the broad individual variability of symptom for ADHD and the admission of self-diagnosis we used the Adult ADHD Self-Report Scale (ASRS-v1.1) in our recruitment procedures. Recruitment was conducted through the on-campus UW-Madison Research Email Service, reaching a distribution pool of approximately 78,000 email addresses.

Wayfinding Assessment

For the VR component of this study participants were placed into an virtual urban environment (Figure 1). For the wayfinding task they were tasked with locating waypoints in a prescribed order. The waypoints were marked on a digital map (Figure 2) of the virtual environment accessible to participants. They were asked to complete one training round and three trial blocks that consisted of two experimental wayfinding conditions. The first condition consisted of three waypoints and the second condition consisted of seven waypoints. The increase in the number of waypoints and the route complexity increased the demands on an individual's cognitive load and spatial working memory. The data collected from this task were waypoint order accuracy, time taken to complete the task stages, the virtual distance travelled within the environment, and the frequency and duration of map referencing.

Figure 1: A participant perspective of the virtual environment.

Figure 2: A mock-up map with the path that the participant is to travel for an experimental trial condition.

Spatial Learning Assessment

To assess the participant's spatial survey knowledge acquisition, they were asked to complete the judgment of relative direction task and a return to start task. After they located the final waypoint in each of the experimental conditions rounds, they are then asked to orient themselves in the direction of the starting location. Participants were no longer able to access the map once starting this stage, and thus they were required to rely on their current knowledge of the environment. The accuracy of the participants' heading was measured by the angle of error from the true starting point. After they completed this task, they were then asked to navigate back to the starting location. The data collected from this task were time to completion and heading accuracy.

Results

Preliminary results for this study reveal a significant difference between ADHD adults and control participants when comparing sense of direction, perceived cognitive load and map access count.

Sense of Direction

A Mann-Whitney U test revealed that participants in the experimental group rated themselves significantly higher on the Santa Barbra Sense of Direction survey (*Mean = 51.50, SD = 17.01)* compared to those in the control group *(Mean = 41.06, SD = 14.93),* **p = 0.041.**

Executive Function

The preliminary findings of this study did not reveal that there was a significant difference between the control and ADHD groups when examining results for the spatial-span memory test (working memory), $p = 0.86$, and trail making test (visual attention and cognitive flexibility), $p = 0.11$, using the Mann-Whitney U test.

VR Wayfinding + Spatial Learning

Preliminary analysis did not show a statistical difference between groups for wayfinding performance (measured as time to completion), or across two measures of spatial learning: judgement of relative direction and return to start. These preliminary findings applied to both easy and hard experimental conditions.

VR Map Use

VR map use was measured by how many times a participant accessed the map and how long they accessed during each level. Mann-Whiteny U tests revelated a significant difference in map access between groups on hard levels (*control: Mean = 24.50, SD = 9.38; ADHD: Mean = 36.56, SD = 15.34***; p = 0.006***)* but not in easy levels nor in map accesses duration.

Perceived Cognitive Load

Preliminary analysis revealed a significant difference between ADHD adult and control participants perceived cognitive load as measured by the NASA Task Load Index (TLX) **$p = 0.05$.**

Discussion

Prior research has demonstrated that SWM, attention, and cognitive and strategic flexibility are key to geospatial navigational success (Hegarty et al., 2006; Montello, 2005; Nazareth et al., 2019). Impairment in each of these cognitive processes demonstrate significant individual variability and is thus hard to parse out their influence more acutely. Research shows ADHD impairs these cognitive processes (SWM, attention, and cognitive and strategic flexibility) (Alderson et al., 2013; Barkley, 1997; de la Paz et al., 2025; Rapport et al., 2008).

However, our preliminary findings reveal an interesting contrast to prior work. We see a noteworthy difference between ADHD self-rated navigational ability and cognitive load demands during navigation. Interestingly, participants with ADHD reported a significantly higher self-rated sense of direction, yet this elevated self-assessment was accompanied by higher perceived and inferred cognitive load. This divergence suggests that strong navigational self-efficacy does not necessarily reflect lower task demands. Crucially, despite the higher perceived cognitive load, these preliminary findings do not demonstrate a difference in wayfinding performance or spatial learning between the groups. This tentatively indicates that individuals with ADHD successfully employ compensatory strategies such as exerting extra cognitive effort and utilizing map aids—to achieve typical navigational outcomes. Additionally, these results indicate that there is not a statically significant difference between the groups when the examining the measures of executive functions. There are two likely reasons for this within group differences that need further analysis at this time and that these measures (spatial span memory and trail making) are not appropriate measures of executive functions required for large scale navigational task. Further analysis is needed for a more comprehensive interpretation of the results.

Conclusion

Navigation is a cognitively complex process that demonstrates broad individual variability. This variability makes it difficult to model navigational abilities in the development of neuro-adaptive navigation aids. This research has sought to understand further group variations by comparing wayfinding performance between ADHD and control adults. In pursuit of this, we conducted a VR experiment that test wayfinding ability and spatial learning. Our findings indicate that though those with ADHD experienced higher cognitive demands they performed comparably. Indicating an underlying compensation. Further analysis is needed, but these results propose an interesting component of navigation for further research into adaptive navigational aids.

Disclosure

The study (UW agreement AGR00010027) used Apple Vision Pro and Apple Watch devices provided by Apple Inc. through an Investigator Support Program (researchandcare.org) grant. Apple was not involved in the design of the research, nor was it involved in the collection, analysis, or interpretation of the research data, or the content of this or any related publication.

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