WHEN THE INNER EYE FAILS: A CASE STUDY EXAMINING SPATIAL MEMORY AND NAVIGATION IN THE ABSENCE OF VISUAL IMAGERY

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Abstract

Spatial memory and navigation rely on multiple cognitive mechanisms including visual imagery and episodic memory. Aphantasia, the inability to generate voluntary visual imagery, provides a unique opportunity to examine how individuals navigate without visual mental maps. This case study investigates how the absence of visual imagery affects spatial memory across both recent and remote environments. Using a framework of topographical disorientation, we examine SD, an individual with aphantasia who has lived in multiple environments. We assessed how environmental familiarity impacts recall of coarse spatial layouts and fine-grained spatial details. A mixed-methods approach was used, combining the *Sea Hero Quest* (SHQ) task of spatial learning, with a battery of ecologically valid spatial memory tests. SD demonstrated preserved navigation abilities but exhibited difficulties with tasks that require fine-grained spatial details for flexible wayfinding. These findings suggest that visual imagery supports flexible, detailed spatial representations, offering insights into individual differences in navigation.

Keywords: spatial memory, spatial navigation, aphantasia, imagery, episodic memory, prosopagnosia, landmark recognition

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When the Inner Eye Fails: A Case Study Examining Spatial Memory and Navigation in the Absence of Visual Imagery

How do you get from your home to your neighbourhood grocery store? How about from your home to a restaurant near the grocery store that you have never visited? To answer these questions, you might draw on your memory of the neighbourhood and visualize a potential route in your mind's eye (Bocchi et al., 2017). Wayfinding often depends on a range of mnemonic and visual processes, including spatial memory, imagery, and scene recognition (Aguirre & D'Esposito, 1999; Li et al., 2025; Palermo et al., 2008; Shelton et al., 2021). Some aspects of navigation may require recollection of specific experiences navigating and may involve visual imagery of familiar trips or sequences of turns, while others involve a more abstract, schematic representation of their neighbourhood to plan out their movements. These spatial representations engage distinct cognitive processes, such as landmark recognition, directional orientation, and frame-of-reference transformations from allocentric (object-centred) to egocentric (person-centred), all of which can aid performance based on environmental characteristics, such as the density of landmarks and whether the environment is familiar or recently encountered.

To better understand dissociations within spatial representations of different environments and how these representations may be disrupted following neural compromise, Aguirre and D'Esposito (1999) proposed a taxonomy of topographical orientation that classifies different aspects of typical and atypical navigation based on the specific perceptual-cognitive mechanism involved (e.g., landmark recognition, egocentric and allocentric processing, new spatial learning). This framework continues to provide a valuable lens through which to examine how the demands of the environment interact with mechanisms underlying spatial navigation, and how disruption of a mechanism manifests in cases of impaired navigation. This taxonomy

has proven successful in predicting some but not all dissociable aspects of spatial memory and navigation; discussion of visual imagery was relatively limited to egocentric processing, even though it is likely that visual imagery intersects with allocentric processing and landmark recognition. Greater consideration of familiarity with the environment that is navigated and the level of detail contained within the memory of that environment might provide additional insight into how spatial memory is organized and how it changes over time. The current study investigates lacunae in this and related models of spatial navigation by investigating the effects of impaired visual imagery on detailed vs. gist-like representations of recently vs. remotely experienced environments.

Visual processes play a central role in human spatial memory and navigation, reflected in findings that visual information often guides one's selection of navigational strategies (Ekstrom, 2015). When we visually imagine familiar routes, we are internally re-experiencing our representations of those familiar scenes and elements (Aydin, 2018). Palermo et al. (2008) investigated how visual imagery ability contributes to the ability to navigate based on a "cognitive map," which refers to an internal representation of the allocentric spatial relations amongst objects/landmarks in an environment that a person has physically navigated at an earlier time (Ekstrom et al., 2018; O'Keefe & Nadel, 1978). The researchers asked participants to complete a navigational test where they had to move around a virtual environment to learn its spatial layout. During a subsequent retrieval task, participants were asked to use their mental representations of the environment to navigate from one location to another. They found that the ability to form a cognitive map (inferred from the duration of participants' navigation) was strongly related to their ability to navigate around the map (accuracy of their navigation). Yet, despite how heavily it seems that humans rely on visual imagery for spatial memory and

navigation, the nature of its contribution to navigation remains poorly understood (Fan et al., 2023).

Familiarity also shapes our choice and use of navigational strategies (Maguire et al., 1998; Terao et al., 2025). For instance, navigating within a familiar grocery store, where you instinctively know the locations of each item, contrasts with navigating within an unfamiliar supermarket for the first time, where you may have a general schema of item categories but may need to rely on aisle signs and external cues to find specific items (see Farzanfar et al., 2023). The ability to form effective spatial representations in unfamiliar environments may involve greater attentional processes and working memory (Boumenir et al. 2010). In this context, individuals who lack visual imagery – such as SD, a person with aphantasia – present a unique opportunity to examine the role of visual imagery in spatial memory and navigation in newly learned and pre-experimentally learned environments, including places learned within the past few years (recent) and places learned long ago (remote).

Aguirre and D'Esposito's Taxonomy

In the late 20th century, reports of patients with selective impairments in spatial navigation challenged the idea that topographical disorientation was a singular, homogeneous condition. In response, Aguirre and D'Esposito (1999) proposed a taxonomy that classifies disorientation based on the underlying spatial representation or cognitive mechanism affected. Their taxonomy includes: 1. egocentric disorientation, difficulties representing the positions of objects relative to oneself, 2. allocentric disorientation (referred to as heading disorientation), difficulties representing spatial relationships between objects independent of the self, 3. landmark agnosia, an inability to recognize or use familiar visual landmarks to aid navigation,

and 4. anterograde disorientation, an inability to form new spatial memories in unfamiliar environments.

While visual imagery was most linked to egocentric disorientation – understood as a failure to generate person-centred representations of space – it is possible that imagery processes may also influence allocentric spatial representations, landmark recognition, and the acquisition of spatial knowledge in unfamiliar environments. These relationships remain underexamined and may offer insight into how visual imagery contributes to spatial processing across both familiar and unfamiliar environments.

Aguirre and D'Esposito also noted that familiarity plays a mediating role in navigation, as repeated exposure can strengthen or shift one's internal spatial representations. More recent research (e.g., Evensmoen et al., 2013; Farzanfar et al., 2023; Winocur & Moscovitch, 2011) has shown that spatial memories themselves evolve over time, often transitioning from detailed to coarser, gist-like representations. How visual imagery interacts with these time-dependent transformations in memory – particularly in distinguishing recent from remote spatial environments – remains an open and important question.

Egocentric and Allocentric Perspectives

A foundational distinction in spatial memory research is between allocentric and egocentric representations. Allocentric representations are thought to rely heavily on the hippocampus, as described in Cognitive Map Theory (CMT; Ekstrom et al., 2018; Ekstrom & Hill, 2023; O'Keefe & Nadel, 1978; Tolman, 1948), while egocentric representations are associated with regions such as the posterior parietal cortex (Burgess et al., 1999; Colby & Goldberg, 1999). CMT gained empirical support from the discovery of place cells, neurons in the hippocampus that fire in response to an animal's position in space (Redish & Ekstrom, 2013),

providing evidence for an allocentric coding system. Patient studies further support this division: individuals with hippocampal lesions often exhibit impaired allocentric spatial memory, while retaining intact egocentric spatial memory (cf. Ciaramelli et al., 2010; Holdstock et al., 2000; but see Gomez et al., 2014).

Aguirre and D'Esposito (1999) distinguished between egocentric disorientation and heading disorientation (considered to rely on allocentric spatial representations), suggesting that they may be supported by visual imagery via distinct mechanisms. Visual imagery has been shown to support egocentric spatial processing via the precuneus (Duan et al., 2025; Fletcher et al., 1995; Gardini et al., 2006; Hebscher et al., 2018; Zaehle et al., 2007). Allocentric spatial processing may also rely on visual imagery, however, as suggested in O'Keefe and Nadel's (1978) proposal that in humans' allocentric spatial maps – anchored in hippocampal representations of space – form the scaffolding upon which episodic memories are constructed. That is, to mentally relive an event, one often begins by reinstating the spatial context in which the episode occurred. Supporting this idea, research has shown that episodic memory draws heavily on visual imagery (Fan et al., 2023), especially for constructing coherent, spatially detailed scenes.

At the same time, episodic memory is not solely allocentric. It frequently takes on egocentric characteristics as individuals often remember events from a field perspective, as if re-experiencing them through their own eyes – an egocentric vantage point associated with richer sensory and emotional detail (Bernsten and Rubin, 2006; St. Jacques et al., 2017). Lesion studies further underscore this link: for example, a case of representational neglect (Bisiach & Luzzati, 1978) demonstrates how damage to the right parietal cortex may also result in neglect of the left side of imagined environments, demonstrating that deficits in egocentric spatial memory may

extend to visual imagery. This duality suggests that both allocentric and egocentric spatial representations rely on visual imagery, though perhaps via distinct cognitive and neural mechanisms. So, although heavily implicated in the development of spatial memory elements, it remains unclear whether visual imagery supports both egocentric and allocentric representations through a shared mechanism, or if it operates independently within each system.

Landmark Recognition and Scene Construction

Aguirre and D'Esposito (1999) also outlined cases of individuals with "landmark agnosia" who are unable to recognize familiar landmarks despite having intact perception and recognition of non-landmark objects. Indeed, landmark agnosia has also been found to be dissociable from prosopagnosia (face recognition difficulties) and object agnosia (Piccardi et al., 2019; Van der Ham et al., 2017). This is a selective deficit in recognizing familiar landmarks despite intact spatial knowledge – typically resulting from damage to the lingual gyrus along the ventral visual stream (Aguirre & D'Esposito, 1999; Palejwala et al., 2021). Affected individuals may describe a landmark's features but fail to recognize it when standing in front of it. To compensate, they often rely on verbal labels, building numbers, or schematic representations to navigate (Whitely & Warrington, 1978).

Although often discussed in the context of object perception, visual imagery might also play a critical role in the recognition of landmarks during navigation. Landmarks cue the spatial behaviour required to reach one's desired destination. Landmark recognition supports wayfinding by providing stable environmental cues (Newman & McNamara, 2022; Pazzaglia & De Beni, 2001; Yesiltepe et al., 2021). For instance, a student might know to turn right at the Student Union building to reach the Food Court. Interestingly, such strategies often remain effective even when superficial features change (e.g., a building is repainted), suggesting that

spatial context is more critical than detailed visual features (Rosenbaum et al., 2024; Shelton & Yamamoto, 2021).

In the case of SD, who also presents with prosopagnosia, it is important to consider whether her deficits extend beyond face recognition to include landmark recognition, a key component of topographical orientation as described by Aguirre and D'Esposito (1999). Face and landmark recognition have been associated with adjacent and sometimes overlapping regions in the ventral visual stream, suggesting that damage affecting one domain may also impact the other (Haxby et al., 2001). Furthermore, neuroimaging research shows that visual recognition and visual imagery share category-specific cortical regions: imagining a face or a place activates the fusiform face area (FFA) and parahippocampal place area (PPA), respectively (O'Craven & Kanwisher, 2000). This overlap raises the possibility that SD's deficits in visual imagery may extend to faces, landmarks, and potentially other object categories – though this remains an open question.

Although cases like that of K.S., an individual with landmark agnosia, demonstrate that landmark recognition can be selectively impaired while certain aspects of route knowledge are spared (Van der Ham et al., 2017), it is unclear whether such cases retain the ability to conjure up vivid visual details of these environments. This uncertainty underscores the distinction between the structural knowledge of spatial layouts and the phenomenological quality of spatial re-experiencing, particularly in individuals with imagery deficits. It is therefore important to clarify whether SD's prosopagnosia co-occurs with landmark agnosia and whether her visual imagery impairments are category specific. Separately, while there are documented cases of individuals with impaired landmark recognition but preserved landmark imagery (Pallis, 1955;

Whitely & Warrington, 1978), it remains unclear whether the opposite dissociation – impaired landmark imagery with intact landmark recognition – can occur.

New Spatial Learning and Anterograde Disorientation

Landmark agnosia applies to both newly encountered and familiar landmarks. Early case studies have documented other individuals with striking impairments in forming spatial representations of new environments despite preserved recognition of familiar spaces. In a 1987 report, Habib and Sirigu described two individuals who were able to identify familiar landmarks but were unable to construct mental maps of newly encountered environments. When asked about their navigational strategies, both individuals reported relying heavily on verbal cues such as street names and storefront labels, suggesting a compensatory shift away from visuospatial processing. Similarly, Ross (1980) described an individual who exhibited severe spatial disorientation and prosopagnosia. Although he could navigate his childhood home with ease, he was unable to form a mental map of the hospital's neurology wing and struggled to identify non-verbalizable objects from visually similar foils. Ross attributed these deficits to a selective impairment in recent visual memory. For example, when presented with non-verbalizable objects, the patient struggled to distinguish them from visually similar alternatives.

One possibility is that visual imagery might facilitate the formation of detail-rich spatial memories of newly encountered environments, but it might not be needed for representing the gist-like representations of coarse spatial relations such as directions and distances, particularly as an environment becomes highly familiar (Farzanfar et al., 2023). Preliminary evidence suggests that spatial memory for gist remains intact in individuals with aphantasia (Fan et al., 2021), but this has not been systematically investigated using real-world tasks based on both recently and remotely experienced environments. Additionally, research from Bainbridge et al.

(2021) evaluated how object and spatial representations differ in individuals with aphantasia. Participants were initially asked to study images of scenes and were then asked to draw the scene from memory afterward. Their findings show that participants with aphantasia remember and produce more accurate spatial layouts than controls but provide drawings with fewer objects and less colour, taking less time to complete overall. This finding may be taken to suggest that the ability to visualize mental images plays a crucial role in how detailed and vivid their spatial representations are for newly encountered environments, affecting the richness of the spatial memory that is formed.

Visual Imagery and Spatial Representations

The strength of a memory trace often depends on the richness of the encoded experience, including features like visual detail, spatial layout, and contextual cues (Olton, 1977). One mechanism thought to support the encoding of such features –particularly in the spatial domain – is visual imagery. Borst and Kosslyn (2010) assessed the correlation between classic spatial test scores and participants' ability to mentally imagine spaces. They administered standardized paper-and-pencil tests such as the: 1) Paper Folding test, b) Paper Form Board test, c) Raven's Advanced Progressive Matrices, d) Object-Spatial Imagery Questionnaire (OSIQ), and e) Vividness of Visual Imagery Questionnaire (VVIQ). Participants also completed an image-scanning task in which they first viewed an image containing a pattern of dots. After drawing the dot pattern from memory to confirm encoding, they were shown arrows and asked to judge whether each arrow pointed to the location of a previously seen dot. They found that participants with higher self-reported use of mental spatial imagery in their everyday lives created the most accurate representations of the dot patterns (for an argument on the utility of self-report measures for assessing spatial abilities, see Sas & Noor, 2009). Findings from the Borst and Kosslyn study

underscore the importance of visual imagery in tests of spatial memory and navigation. However, the stationary, table-top nature of the spatial tests and reliance on self-report in assessing actual spatial navigation suggests that further investigation into how visual imagery facilitates accurate and efficient wayfinding in large-scale, real-world environments may be needed.

The ability to bring mental representations to mind was previously believed to be innate and common, but it is now estimated that over 4% of the global population experience aphantasia – a phenomenon characterized by either dim or absent visual imagery (Dance et al., 2022). Aphantasia can be acquired via a neurological event (Keogh et al., 2021), but most individuals with aphantasia have experienced an absence of visual imagery since birth, referred to as congenital aphantasia. Recent research has examined the neural basis of visual imagery, and the lack thereof, to further understand its role as it relates to other cognitive processes (Kosslyn et al., 2005; Milton et al., 2021). An early case of acquired aphantasia shows how instrumental the process is to the retention of detail. In 1883, two French scientists, Charcot and Bernard, reported the case of Monsieur X, a multilingual entrepreneur, with an appreciation for visual imagery. He especially enjoyed his ability to recall colours of objects and shapes, as well as the faces of his loved ones. However, after the loss of a large sum of money, he began to exhibit marked and persistent mood disturbance whereby he felt agitated and restless. Monsieur X realized that he could no longer recognize or visualize shapes or colours. He was unable to discern the features of his wife and children, nor could he draw with the same meticulous detail as before. His sketches transformed into technical drawings, emphasizing geometry and schematics. The aspects of his cognition that were once filled with vibrant visual information had now been bombarded with verbal information; the words even dominated his dreams. Although Charcot

and Bernard did not investigate how Monsieur X's loss of visual imagery affected his navigation, his case underscores the broader questions of how the absence of visual imagery impact spatial memory components – a topic that contemporary research is now examining more systematically.

The Role of Environmental Familiarity

While visual imagery appears to support the formation of spatial representations, it is not the only factor influencing how environments are mentally represented. Familiarity – whether an environment is recently or remotely learned – is proposed to play a mediating role, particularly in how fine-grained spatial details transform to coarse gist-like details. It follows that individuals with impoverished visual imagery may differ in how they mentally represent recently versus remotely learned environments, particularly in terms of coarse elements versus fine-grained spatial details. Familiarity likely plays a moderating role in this process. To investigate how familiarity influences spatial representations across time and space, Jafarpour and Spiers (2017) asked university students to draw sketch maps of their campus. Participants then estimated travel paths and times between pairs of locations, varying in familiarity. Their findings revealed that familiar routes were associated with expanded spatial estimates but compressed temporal estimates, suggesting that familiarity warps both spatial and temporal perception.

Separate work by Li et al. (2025) provides further insight into how familiarity may interact with visual imagery. In a study comparing individuals with aphantasia and controls, participants were asked to describe both frequently and infrequently travelled routes. While aphantasic participants showed reduced sensory detail for less familiar routes, their descriptions of familiar routes were comparable to controls, suggesting that with repeated exposure,

individuals with aphantasia may develop compensatory strategies that support spatial recall in the absence of visual imagery.

The Present Study

The current study seeks to investigate the influence of visual imagery on spatial memory and navigation by testing a unique individual, SD, with aphantasia. SD represents an extreme subtype of aphantasia, with a prevalence of just 0.8% according to Dance et al. (2022). In addition to aphantasia, she experiences stereoblindness (impaired depth perception), prosopagnosia (impaired face perception), and severely deficient autobiographical memory (SDAM), which we verify with the use of the Autobiographical Interview (AI; Levine et al., 2002). These areas of difficulty have been confirmed with objective tests of visual imagery, object recognition, and autobiographical memory, administered across multiple independent labs (Bone et al., 2025; DeGutis et al., 2024; Palsamudram et al., 2024; Kirsch et al., 2024). SD's unique pattern of preservation and impairment offers a unique opportunity to investigate how visual imagery differentially affects the components of spatial orientation outlined by Aguirre and D'Esposito (1999).

As mentioned above, work by Bainbridge et al. (2021) and Li et al. (2025) suggests that the ability to visualize mental images may affect memory for objects and possibly fine-grained visuospatial details that may be incidental to navigation (e.g., mailbox, fence). However, the impact of visual imagery on spatial memory may differ depending on the familiarity and novelty of the environment. To assess SD's new spatial learning abilities, we administered the video game *Sea Hero Quest* (SHQ), which evaluates spatial memory for newly learned environments, and includes levels that differentially engage egocentric and allocentric representations. In addition, SD completed a sensitive battery of tasks based on naturalistic environments

experienced in both the recent and remote past, some of which target specific components of spatial orientation (e.g., landmark recognition, spatial perspective-taking). Based on this approach and prior findings, we hypothesize that:

1) SD will show some difficulties on tasks that rely on egocentric and allocentric spatial representations, as visual imagery may differentially contribute to the two types of representations.
2) Due to the aforementioned difficulties, SD is expected to have less vivid and/or detailed spatial representations of *all* environments she has lived in (regardless of familiarity).
3) SD's recollection of coarse spatial details about the landmarks (e.g., distances, directions, landmark order) will be comparable to or better than controls', especially when based on very familiar environments.
4) SD is expected to demonstrate impairments in new spatial learning, as visual imagery may be critical for forming detail-rich representations of novel environments.
5) SD will have intact landmark recognition despite her prosopagnosia, given evidence of a dissociation between face and landmark recognition (Van der Ham et al., 2017), and between landmark perception and imagery (Pallis, 1955; Whitely & Warrington, 1978).

Methods

Participants (Recent and Remote Spatial Memory Tasks)

SD was 43 years old at time of testing. She is a right-handed woman with 16 years of education. She has lived in 3 U.S. states at different time periods of her life: Tampa, Florida from

ages 0 to 21 years, Washington D.C. from ages 21 to 41 years, and West Virginia (W.V.) since age 41 years. Tampa and Washington D.C. serve as remote environments, while West Virginia is considered to be a recently learned environment. In addition to aphantasia, stereoblindness, prosopagnosia, and SDAM, SD self-reports frequent moments of spatial disorientation. She mentioned that she is often surprised if she can make it to her destination without making any navigational errors. SD's autobiographical memory was compared to that of control participants from Rosenbaum et al. (2008) for the Autobiographical Interview (AI). All controls (n = 12) were right-handed, native English speakers who were recruited from the Baycrest older adult database. The control mean age was 52.7 years (SD = 4.07; range = 40-53; demographic information presented in Table 1). SD's data were compared to that of two groups of controls for task of new spatial learning (SHQ): age- and sex-matched controls and controls with comparable gaming ability. This was done to control for the effects of gaming ability. Control participants for the recent and remote tasks include BD, SD's 38-year-old brother who also has aphantasia, JD, SD's 67-year-old father, both familiar with Tampa, and HD, SD's 46-year-old husband who is familiar with Washington D.C. and West Virginia – see Table 3. This study was approved by institutional REBs and all participants provided informed consent.

Table 1.
Demographic Information for SD and AI Controls (Rosenbaum et al., 2008)

	SD	Controls (SD)
Age (yrs)	43	52.7 (4.07)
Sex	female	6 male/6 female
Education	16	15.6 (1.97)

Aphantasia Assessment

The Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973), a 16-item, self-report measure rated on a five-point Likert scale, is a well-established task used to assess visual imagery integrity. The measure asks participants to imagine a series of images and to then select the option that describes their image best, such as (*5) – perfectly clear and as vivid as normal vision, (4) – clear and reasonably vivid, (3) – moderately clear and vivid, (2) – vague and dim, or (1) – no image at all, you only 'know' that you're thinking of an object*. The VVIQ has been widely used in previous studies to identify individuals with aphantasia (Pounder et al., 2022; Wicken et al., 2021; Zeman et al., 2010). Scores range from 16 to 80 points, with lower scores reflecting reduced vividness of visual imagery. In their investigation of aphantasia prevalence among over 1000 participants, Dance et al., (2022) used a VVIQ score range of 16 –32 to classify individuals with dim or absent visual imagery. This study adopts the same criterion to determine participants' aphantasia status.

The Autobiographical Interview

The Autobiographical Interview (AI; Levine et al., 2002) was used to assess SD's autobiographical memory. The AI is a reliable method that has been used to assess memory deficits in various aging and developmental populations (Acevedo et al., 2023; Hernandez et al., 2024; Horner et al., 2023). The AI distinguishes between internal (episodic) details and external (non-episodic details). In accordance with the protocol, SD described events specific in time and place from different timepoints in her life (Free Recall). She was subsequently probed with non-specific questions (General probe: "Is there anything else you can tell me about that?") followed by specific questions about the event (Specific probe: "When was that exactly").

SD and controls recalled five events from the following ranges: 5-10 days ago, 2-6 weeks ago, the previous year, 5 years ago, and in early childhood, and all were recorded for transcription and scoring. To score the interview, the event description is segmented into chunks of internal or external details. Internal details include categories such as event, time, place, perceptual, and emotion/thought) whereas external details include other categories such as: semantic facts, autobiographical events that occurred at a different time, repetitions, or other metacognitive statements.

New Spatial Learning Task

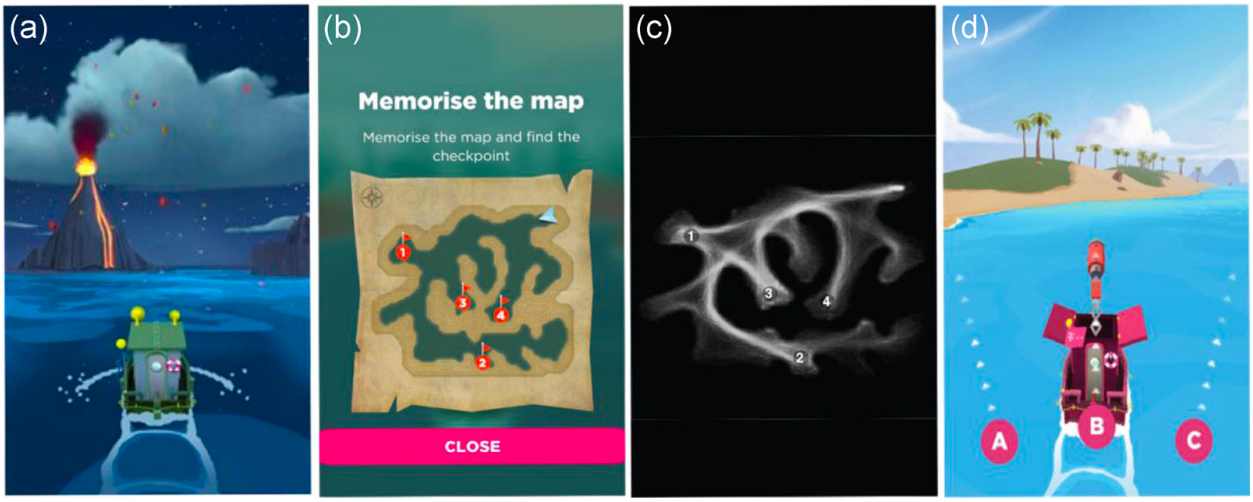
Bainbridge et al. (2021) demonstrated that individuals with aphantasia may struggle to recall fine-grained details of newly encountered environments. To assess SD's new spatial learning, we utilized the mobile video game *Sea Hero Quest* (SHQ), a widely used tool downloaded over 4 million times globally. The game prompts players to steer their boat through oceans and islands in search of sea creatures. Before navigating their boat to the destination, participants are shown a map of the route – see Fig. 1b. They receive points based on how quickly they can reach the checkpoints provided on the map. Performance is measured by trajectory length or the distance travelled by players, as the shorter their distance (or length of their trajectory) to the goal, the more optimal their navigation. While trajectory length or distance was used the calculate performance, navigational ability can be affected by other factors such as:

1. *Difficulty:* Level difficulty was determined using entropy and geometric path measures from Yesiltepe et al. (2023), where environments with greater complexity and unpredictability were classified as more challenging, while more structured and direct environments were considered easier. The difficulty does not align with the order of the levels as level 56 is considered more difficult than level 68.

2. *Weather*: The visibility of the route can vary, being either clear or obscured by fog. When fog is present, it simulates challenging weather conditions, increasing the complexity of the level.
3. *Decision points*: Decision points along the route are key turning points where participants must choose which direction to take.

Figure 1.

SHQ Task Design



Note. (a-b) Wayfinding task: The map depicts the ordered set of checkpoints that is presented and disappears at the beginning of the game. (c) Overlay of 1000 individual trajectories randomly sampled from Level 32. (d) Path integration task: After completion of the level, players launch a flare in the direction of where they began. Reproduced from Coutrot et al., (2018).

SHQ has demonstrated strong test-retest reliability, providing a robust dataset for comparison (Coughlan et al., 2020; Spiers et al., 2023). Serving as an interactive measure of new spatial learning and path integration, SHQ has been shown to predict real-world navigation (Coutrot et al., 2019; Goodroe et al., 2025), identify individuals with heightened genetic risk for Alzheimer's Disease (Coughlan et al., 2019), and detect those with traumatic brain injuries (Seton et al., 2023). By comparing SD's results to both normative data and players with comparable gaming ability, we are able to gain insight into how the absence of mental imagery uniquely affects her spatial cognition. This approach allows us to examine the extent to which

SD's performance deviates from population-level performance and identify specific compensatory mechanisms reflected in her gameplay data. Her performance is reported in percentiles across the 8 levels she played (i.e., 1, 2, 11, 16, 32, 42, 56, 68), all of which assess allocentric wayfinding due to the map provided before navigation begins (Coughlan et al., 2019). Data from levels designed to assess egocentric processing (i.e., those involving flare accuracy) are not reported here.

Tasks for Recent and Remote Environments

To assess spatial memory for recent and remote environments, SD and controls completed a series of tasks virtually via Zoom. They completed the following battery of tests of spatial memory based on highly familiar locations within the target neighbourhoods:

1) *Proximity Judgments*: Participants select the landmark that is closest in proximity to the reference landmark.
2) *Distance Judgments*: Participants estimate the distance between pairs of locations.
3) *Landmark Sequencing*: Participants place a list of landmarks in the order that they would be passed if they were commuting from North to South.
4) *Landmark Recognition and Identification*: Participants identify landmarks from target neighbourhoods amidst foil landmarks from other unfamiliar locations.
5) *Route Description*: Participants are asked to describe a frequently travelled route, providing as many details as possible.

Proximity judgments, distance judgments, and landmark sequencing are used as tasks of coarse spatial detail, as they tap into our knowledge of general spatial layouts, distances, and directions. Proximity judgement accuracy was quantified as the percentage of trials in which participants correctly identified the closest landmark to the reference landmark. For the distance

judgments task, the mean distance error was calculated as the absolute difference between the estimated and actual distance, with lower values indicating greater accuracy. Sequence accuracy was calculated as the percentage of landmarks placed in the correct order. The aforementioned tasks align with the measures of coarse, global detail used in Evensmoen et al. (2013): (a) multiple distance test: participants indicate landmark furthest away from the target and (b) spatial sequence test: participants place landmarks in the correct order when moving from one location to another. The landmark recognition task is used as a measure of fine detail recollection of spatial memories as successfully distinguishing between target landmarks and foils relies on participants recalling unique, context-rich features of the landmarks, such as their appearance, associated memories, or surrounding environment. Performance on the task was classified using signal detection theory, where "hits" refer to correctly identifying the familiar landmark, "misses" refer to not identifying the familiar landmark, "correct rejections" refer to correctly identifying unfamiliar landmarks, and "false alarms" refer to misidentifying unfamiliar landmarks.

In line with Ciaramelli et al. (2010), tasks such as proximity and distance judgments are considered to rely primarily on allocentric representations, while tasks such as landmark sequencing and route description are more reliant on egocentric representations. While these distinctions are based on standard definitions and geometric properties of spatial reference frames (Aguirre & D'Esposito, 1999), it is acknowledged that these tasks are not process-pure and may draw on both systems to varying degrees depending on strategy (see Table 2 for task descriptions and spatial reference labels).

Route Description Scoring. Each description was divided into a set of statements according to the scoring protocol used in other studies investigating recall of spatial details

(Hassabis et al., 2007; Herdman et al., 2015). Each statement was classified into four categories: spatial reference (SPA), entity presence (EP), sensory description (SEN), and thought/emotion/action (TEA). For the purpose of this study, we further categorize SPAs and TEAs as coarse spatial details, and EPs and SDs as fine spatial details as they aid with vivid re-experiencing of the event. To evaluate navigational accuracy, route descriptions were compared against directions available in Google Maps.

Table 2.
Recent and Remote Spatial Memory Tasks

Task	Description	Dominant Reference Frame	Dominant Detail Type
Proximity Judgments	Select one of the two landmarks that is closest in proximity to the reference landmark.	A	Coarse
Distance Judgments	Estimate the distance between pairs of locations.	A	Coarse
Landmark Sequencing	List landmarks in the order that they would be passed if they were commuting from North to South.	E	Coarse
Landmark Recognition	Identify landmarks from target neighbourhoods amidst foil landmarks from other unfamiliar locations.	N/A	Fine
Route Description	Describe the route between two landmarks with as many details as possible.	E	Coarse/Fine

Note. A = allocentric, E = egocentric

Results

VVIQ Criteria

The VVIQ scores from participants align with self-reports of visual imagery ability. Participants who reported low visual imagery have VVIQ scores in the 16-32 range, with SD having the most extreme score of 16. Her brother's (BD) score also aligns with the aphantasia cut-off with a score of 21. SD's father (JD) and husband (HD) achieved scores of 60 and 58, respectively. Table 3 presents the demographic information of SD and controls (i.e., age, aphantasia status, and VVIQ scores).

Table 3.
Participant Demographic Information

Participant	Sex	Age	Education	VVIQ Score
SD	F	43	16	16*
BD	M	38	18	21*
HD	M	46	18	58
JD	M	67	19	60

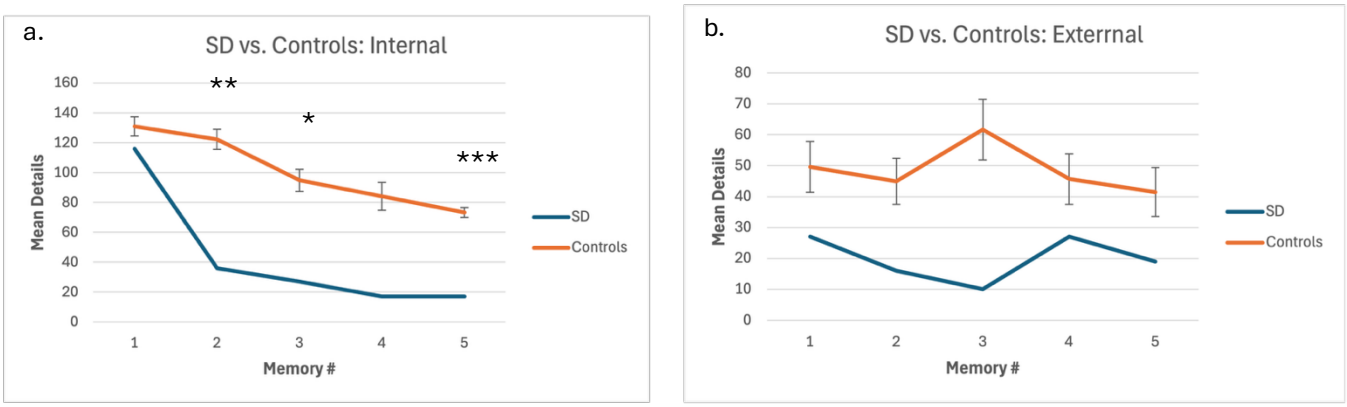
*indicates aphantasia

Autobiographical Interview

Using a modified t-test for single-case studies (Crawford et al., 2010), we compared SD's internal and external detail recall to that of controls. Significant differences were found for internal details across multiple life periods, whereas external details did not differ significantly. Specifically, SD recalled significantly fewer internal details than controls from the previous year, $t(11) = -3.52$, $p = .0048$; five years ago, $t(11) = -2.56$, $p = .027$; and from childhood, $t(11) = -4.72$, $p = .00063$ (see Figure 2).

Figure 2.

Mean details of internal and external details for SD and controls



Note.

(a) Mean number of internal details retrieved by SD and controls. (b) Mean number of external details retrieved by SD and controls. M1: 5-10 days ago, M2: 2-6 weeks ago, M3: the previous year, M4: 5 years ago, M5: early childhood. Error bars indicate standard error. * $p < .05$; ** $p < .01$; *** $p < .001$.

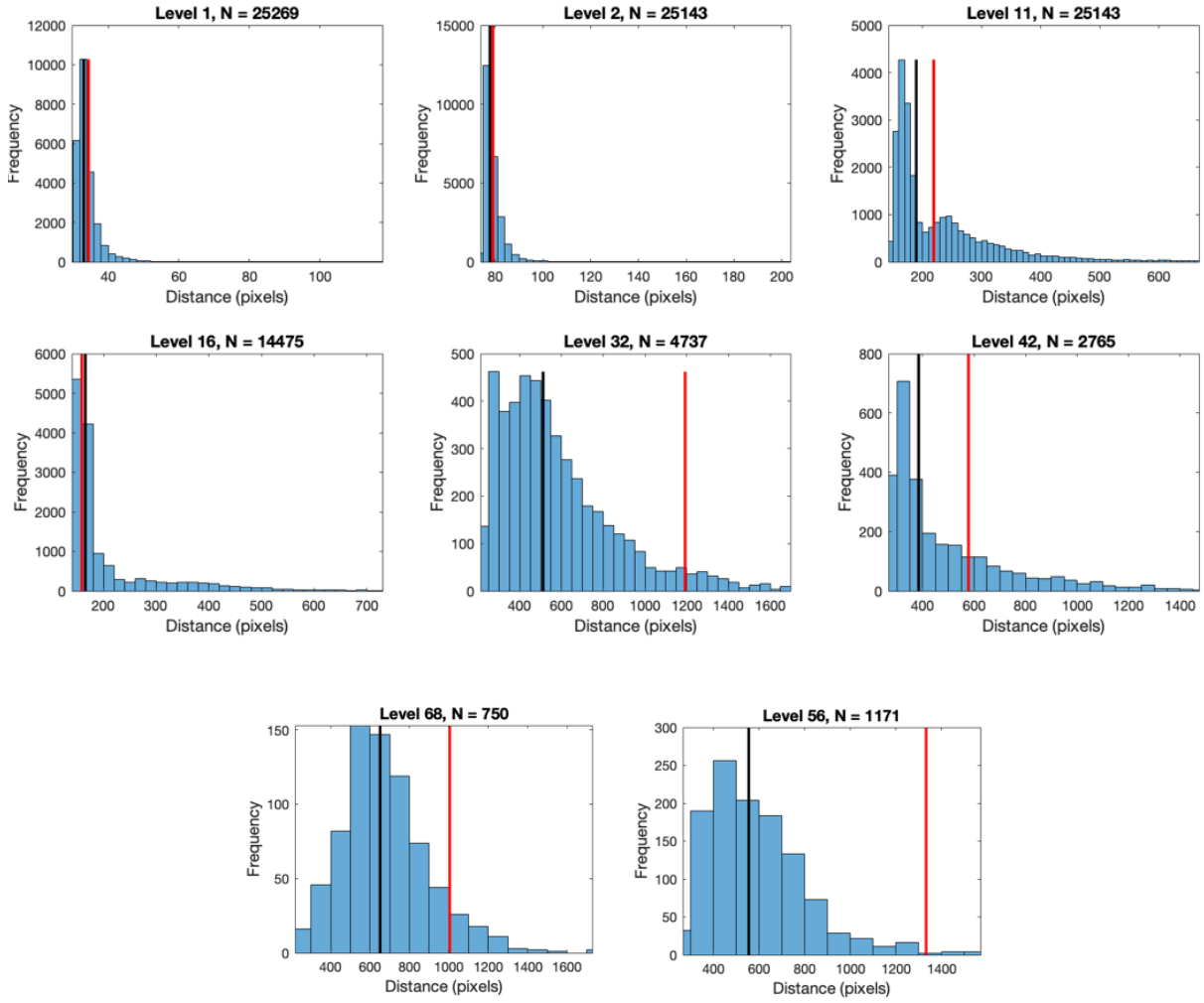
SHQ Findings

Each level is characterized in Table 4, including difficulty, weather, and decision points, along with SD's performance (in percentile), the distance of her trajectories, and the number of controls. To compare SD's performance to matched controls, we determined the percentile rank of SD's trajectory length (distance) within the control distribution at each level. A higher percentile indicates that SD's trajectory was comparable to or shorter than that of most controls, indicating good performance, whereas a lower percentile indicates that SD's trajectory was longer than that of most controls, indicating worse performance.

Her ability to navigate in the "super easy" to "easy" levels are generally in the average range, as she achieved scores better than 30 to 65% of controls. However, as the maps increase in difficulty, SD's performance declines significantly, with scores surpassing only 5% to 26% of age- and sex-matched controls. Notably, on the most difficult map (Level 56), she performed at the 2nd percentile, performing worse than 98% of age- and sex-matched controls – see Figure 3.

Figure 3.

SD's Trajectory Relative to Age- and Sex-Matched Controls



Note. Graphs represent SD's trajectory (red line) in comparison to age- and sex-matched controls. The black line represents the median of the control distribution.

Table 4

SHQ Performance in SD vs. age- and sex-matched controls

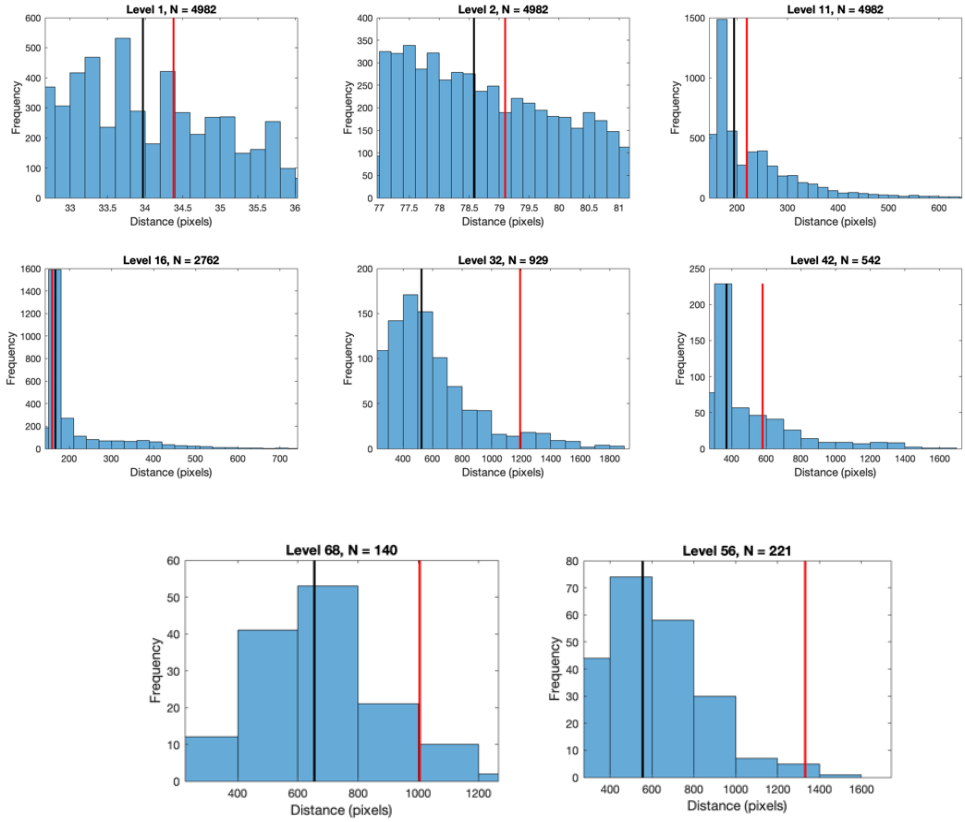
Map Level	Weather	Decision Points	Performance (percentile)	Distance/Trajectory	# of Controls
Super Easy Maps					
1	Clear	0	30	34.37	25,269
2	Clear	0	36	79.10	25,143

Easy Maps					
11	Clear	1	41	219.13	25,143
16	Clear	3	65	159.11	14,475
Medium Maps					
32	Clear	8	5	1192.45	4737
42	Fog	6	26	578.22	2765
68	Fog	5	9	1004.69	750
Hard Maps					
56	Clear	5	2	1331.83	1171

Gaming ability was also considered in the SHQ data analysis to determine whether it influenced SD's performance. For these analyses, only controls whose performance fell within a tenth of the standard deviation of the level 1 and 2 distance distributions around SD's values were included. During the easier levels, her performance was within the average range, with scores surpassing 36% to 68% of controls with similar gaming experience. However, as the difficulty of the levels increased, a consistent decline in her performance was observed. On the harder levels, she achieved scores better than only 9% to 25% of controls with similar gaming ability, reflecting a significant drop in performance. Most strikingly, on the hardest level, her performance was in the 2nd percentile, indicating that she performed worse than 98% of controls, even when accounting for comparable gaming experience. These results suggest that her gaming ability did not hinder her performance; instead, they solidify that the findings are an accurate representation of her difficulties with the task demands on spatial navigation as the difficulty increased – see Figure 4 and Table 5.

Figure 4

SD's Trajectory Relative to Controls with Similar Gaming Ability



Note. Graphs represent SD's trajectory (red line) in comparison to controls with similar gaming ability. The black line represents the median of the control distribution.

Table 5

SHQ Performance in SD vs. age- and sex-matched controls

Map Level	Weather	Decision Points	Performance (percentile)	Distance/Trajectory	# of Controls
Super Easy Maps					
1	Clear	0	36	34.37	4982
2	Clear	0	38	79.10	4982
Easy Maps					
11	Clear	1	43	219.13	4982

16	Clear	3	68	159.11	2762
Medium Maps					
32	Clear	8	8	1192.45	929
42	Fog	6	25	578.22	542
68	Fog	5	9	1004.69	140
Hard Maps					
56	Clear	5	2	1331.83	221

Recent and Remote Spatial Memory Tasks

Proximity Judgments

SD's performance was comparable to that of BD, JD, and HD on proximity judgment tasks based on remotely learned (Tampa and Washington D.C.) and recently learned (West Virginia) environments. All participants performed equally on the Tampa trial. In the Washington D.C. trial, HD demonstrated slightly higher accuracy than SD. For the West Virginia trial, both participants showed the same level of accuracy. All scores can be found in Table 6.

Distance Judgments

Mean distance error was calculated as the absolute difference between the estimated and actual distance, with smaller values indicating greater accuracy. For the remote environments, SD exhibited a larger distance error (2.33) compared to JD (1.73) but smaller than BD (2.42) for Tampa, and smaller distance error (0.47) than HD (0.94) for Washington D.C. For the recent

environment (West Virginia), SD's distance error (2.45) was smaller in comparison to HD (3.65; see Table 6).

Landmark Sequencing

Sequence accuracy was calculated as the percentage of landmarks placed in the correct order. SD's performance was relatively lower than controls for the remote environments (except for BD). However, for the recent environment, SD exhibited similar but still lower accuracy than HD (see Table 6).

Table 6

Results of Coarse Spatial Memory Measures

Participant	Proximity Judgment Accuracy (Allocentric)	Mean Distance Error (Allocentric)	Landmark Sequence Accuracy (Egocentric)
Tampa			
SD	50%	2.23	50%
JD	50%	1.73	100%
BD	50%	2.42	25%
Washington D.C.			
SD	90%	0.47	60%
HD	100%	0.94	100%
West Virginia			
SD	66.7%	2.45	37.5%
HD	66.7%	3.65	50%

Landmark Recognition and Identification

Performance on the task was classified using signal detection theory, where "hits" refer to correctly identifying the familiar landmark, "misses" refer to not identifying the familiar landmark, "correct rejections" refer to correctly identifying unfamiliar landmarks, and "false alarms" refer to misidentifying unfamiliar landmarks.

The performance of SD and controls is summarized in Table 7. For remote conditions, SD performs slightly lower than JD for Tampa, achieving a hit rate of 78.6%, compared to JD's 100% hit rate. However, for Washington D.C., SD outperforms HD with a hit rate of 86.6%, while HD achieves only 53.3%. For the recent condition (West Virginia), SD and HD perform similarly, each achieving a hit rate of 71.43%. SD's performance varies across the conditions, with more comparable accuracy for the recent environment compared to the remote ones.

Table 7

Landmark Recognition Results

	Participant	Hits	False alarms	Misses	Correct Rejections
Tampa	SD	78.6%	7.14%	21.43%	92.6%
	JD	100%	14.3%	0%	85.7%
	BD	50%	0%	50%	100%
D.C.	SD	86.6%	13.3%	13.3%	86.6%
	HD	53.3%	0%	46.6%	100%
W.V.	SD	71.43%	7.14%	21.43%	100%
	HD	71.43%	0%	28.57%	100%

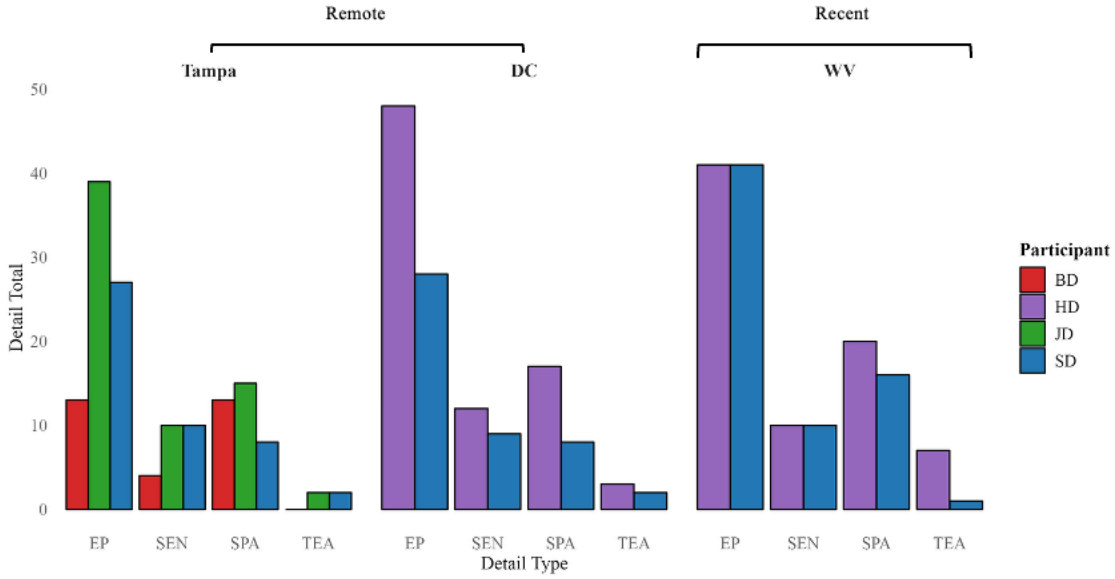
Note. D.C. refers to Washington D.C., and W.V. refers to West Virginia.

Route Description

SD demonstrated a high degree of navigational accuracy, providing correct route directions across all three environments. However, SD reported fewer total details for the remote environments, Tampa (M = 11.8, SD = 10.7) and Washington D.C. (M = 11.8, SD = 11.3), compared to JD (Tampa: M = 16.5, SD = 15.9; D.C.: M = 20, SD = 19.5). BD reported the fewest details for Tampa (M = 7.5, SD = 6.6). However, in the recent environment, West Virginia, SD's detail total (M = 17, SD = 17.1) was comparable to that of HD (M = 19.5, SD = 15.4). JD and HD reported more details than SD across locations, while BD's recollection of details was consistently low across categories. Interestingly, SD recalled fewer EP details (M = 27.5) and SPA details (M = 8) for the remote environments in comparison to controls (EP: M = 43.5, SPA: 16) but recalled the same or a comparable number of details (except for TEA, where she recalled only one detail) for the recent environment, suggesting an effect of familiarity (see Figure 5).

Figure 5

Route Description Details for Remote and Recent Environments



Note. Bars represent the total number of details recalled by participants. Tampa and D.C. are remote environments; W.V. represents the recent environment. Detail categories include EP (Entity Presence), SEN (Sensory Details), SPA (Spatial References), and TEA (Thought/Emotion/Action Details).

Discussion

The current study aimed to uncover the ways in which visual imagery supports different aspects of spatial memory and navigation. We examined how lack of visual imagery shaped spatial representations over time in SD, a person with aphantasia who also presents with depth perception difficulties, prosopagnosia, and SDAM, the latter verified in the current study with formal testing. Visual imagery has long been implicated in spatial memory, particularly egocentric processing, yet its precise role remains debated. Drawing on the topographical orientation taxonomy proposed by Aguirre and D'Esposito (1999), we examined how SD's performance across different tasks, which are known to tap dissociable aspects of spatial memory, aligns with or challenges the framework, and how her pattern of performance may guide updates to this taxonomy.

Areas of Preserved Spatial Memory

We used the VVIQ and the AI to assess aphantasia and SDAM, respectively, in SD. Results from both measures provide support for SD's report of aphantasia and SDAM. That SD's performance was significantly worse than that of a group of older adults further strengthens evidence of impoverished autobiographical episodic memory, as this ability is known to decline in older age (Levine et al., 2002). Nevertheless, SD's ability to learn new environments with minimal spatial complexity, recognize landmarks, provide navigationally accurate route descriptions (albeit at a coarse level), and recall semantic details from autobiographical memories appears preserved. On the "super easy" and "easy" levels of SHQ (i.e., 1 and 2), her wayfinding was intact. The "super easy" levels have been described as opportunities for players

to familiarize themselves with the virtual gaming environment and the gaming controls (Coughlan et al., 2019). The “easy” levels are characterized by minimal complexity, with fewer decision points and checkpoints, clearer maps, and better visibility as participants steer their boat. SD’s consistent performance across these levels suggests no difficulty with allocentric processing under these low-complexity conditions.

SD’s preserved recognition of familiar landmarks distinguishes her from cases of landmark agnosia described by Aguirre and D’Esposito (1999), where individuals were unable to recognize familiar cues despite intact spatial knowledge and object recognition. This case also provides evidence of intact landmark recognition, with impaired landmark imagery. However, while SD’s ability to correctly identify landmarks was largely comparable to that of controls, her relatively high false alarm rate across environments suggests a limitation in her ability to reliably discriminate between similar-looking landmarks. This pattern may reflect a compensatory reliance on schematic or semantic encoding in the absence of visual imagery. Although her performance aligns with literature emphasizing the role of spatial context over detailed visual features in landmark-based navigation (Rosenbaum et al. ,2024; Shelton & Yamamoto, 2021), it also adds nuance; the absence of visual imagery may hinder the parsing of perceptually similar landmarks, supporting theories that visual imagery and the retention of specific visual features assist in rejecting foils during recognition (O’Craven & Kanwisher, 2000). SD’s case illustrates that, while landmark recognition can be maintained and is dissociable from other ventral stream disruptions like prosopagnosia, it may not be wholly supported through compensatory strategies when fine perceptual distinctions are required.

The route description task revealed a further nuance as all of SD’s directions were accurate, indicating preserved structural knowledge of spatial layouts despite her visual imagery

deficits. This pattern echoes findings from Van der Ham et al. (2021) where K.S., an individual with landmark agnosia, retained accurate spatial configurations without vivid scene re-experiencing. Notably, SD accurately recalled and used all the street names along the route, pointing to the use of semantic scaffolding in supporting route knowledge when visual imagery is unavailable. Her capacity to recall external, semantic details in autobiographical narratives was also intact, with no measurable differences from control participants across life periods, further highlighting her preserved semantic memory and its potential role in supporting spatial memory.

Areas of Compromised Spatial Memory

In contrast to areas of preserved function, SD exhibited difficulties on tasks that tap both allocentric and egocentric processing as well as generation of fine-grained details within remotely experienced environments, suggesting that visual imagery plays a more general role that extends beyond egocentric representations of the external world. As SHQ levels increased in complexity, difficulties in allocentric processing emerged relative to controls, despite intact performance on real-world tasks relying on allocentric representations. Further, she struggled to recall fine-grained details of remote environments on the route description and Autobiographical Interview tasks.

SD's pattern of performance suggests a dissociation between the role of visual imagery within egocentric and allocentric spatial processing. While Aguirre and D'Esposito (1999) emphasized egocentric impairments in conditions involving deficits in visual imagery, SD's allocentric performance also appears to be affected by the absence of the "mind's eye." Although she succeeded in navigating simpler SHQ levels, her performance declined as task complexity increased. Yesiltepe et al. (2023) identified several features contributing to SHQ difficulty, including the number of decision points, reduced map visibility, and environmental factors like

weather. Since our data are limited to levels assessing allocentric wayfinding, SD's declining performance may reflect a vulnerability in allocentric processing under conditions of increased spatial detail load. One potential explanation comes from Trace Transformation Theory, which posits that detailed, context-rich memories gradually consolidate into more schematic, gist-like representations supported by neocortical systems. SD's preserved performance in simpler environments may reflect reliance on such schematic representations, while the absence of visual imagery affects her ability to generate and/or update detailed allocentric maps under high load conditions. This pattern mirrors findings from Goodroe and colleagues (2025) who reported that older adults (ages 54-74 years) performed well on basic SHQ levels but experienced difficulty with more complex ones. Further, studies have shown that performance in the medium-difficulty levels are predictive of real-world navigation abilities (Goodroe et al., 2025; Coutrot et al., 2019). SD struggled with the medium levels, aligning with her self-reported spatial disorientation. Visual imagery may therefore play an active role in the transformation of detail to gist-like representations necessary for the construction of allocentric representations. This expands the current taxonomy, which does not explicitly account for visual imagery as a necessary mechanism in allocentric processing. Our findings provide evidence in favour of the extension of the taxonomy to include imagery as an active factor in the construction of allocentric spatial representations under complex conditions.

It is well-established that visual imagery is intimately connected to episodic memory (Hassabis et al., 2007), possibly supporting the vivid re-experiencing of spatial layouts and enabling egocentric remembering of previously encountered environments (Duan et al., 2025; Fan et al., 2023; Gardini et al., 2006). Episodic memory was found to be compromised in SD, who recalled fewer internal details than controls across three life periods in the Autobiographical

Interview (AI) and fewer details in the route description task, particularly for more remote memories. This temporal gradient mirrors patterns observed in individuals with SDAM, which lends further support to the hypothesis that SD also presents with SDAM (Palombo et al., 2015). Notably, SD reported an inability to vividly recall the events themselves but retained awareness of them through descriptions in her personal journal. This dissociation between experiential recollection and factual knowledge reflects Tulving's (1989) distinction between "remembering" and "knowing", suggesting a reliance on semanticized personal knowledge in the absence of true episodic retrieval. This distinction becomes especially relevant when navigating complex environments learned long ago. SD's impaired recall of details contained within remote environments but better performance in more recently learned spaces contrasts findings from Li et al. (2025), who reported that aphantasics recalled fewer sensory details for recent than remote environments. It may be that, unlike SD, the aphantasic individuals tested by Li et al. (2025) had a less severe form of aphantasia and/or aphantasia without SDAM, which affects the ability to benefit from familiarity over time, specifically for fine-grained details. Even remote environments may not be "functionally familiar" if episodic memory is impaired. Further, her difficulty recalling entity details (EP) from remote environments, but relatively preserved recall in the recent condition, does not fully align with our hypothesis: we expected SD to produce fewer vivid details across all environments, regardless of temporal distance, due to her aphantasia, while still maintaining coarse spatial representations, particularly for familiar environments. These patterns suggest a broader episodic memory impairment that becomes more pronounced with increasing temporal distance or when fine-grained perceptually rich representations are needed for flexible wayfinding. The overlap between reduced detail in route descriptions and diminished internal details on the AI indicate that SD's general difficulty

constructing vivid, coherent mental representations of past experiences extends to the retention and retrieval of detailed contextual information, especially when the environments were experienced in the remote past. Thus, egocentric representations, which often depend on vivid, first-person re-experiencing, may be especially compromised when visual imagery and episodic memory are both impaired. This is further supported by SD's performance on the landmark sequencing task, a measure that has been found to rely to a greater extent on egocentric processing (Ciaramelli et al., 2010), where she frequently made "swap" errors involving landmarks located in close proximity to each other. These findings offer compelling support for the role of visual imagery in sustaining egocentric spatial representations over time and further reinforces the idea that recent and remote spatial memory may rely on distinct mechanisms.

Interestingly, despite having a more complex profile - including SDAM, prosopagnosia, and stereoblindness - SD outperformed her brother (BD), who only has aphantasia, across most spatial memory tasks. SD's superior performance may reflect the use of more effective compensatory strategies, such as verbal mediation, semantic encoding, or preserved spatial updating mechanisms. Notably, her background in journalism may have either contributed to the development of these strategies or benefitted from them, as journalistic training often emphasizes structured narrative recall, attention to factual detail, and semantic organization, all of which could facilitate navigation and memory in the absence of visual imagery (Palombo et al., 2015). Alternatively, her results may indicate individual differences in cognitive flexibility or task engagement. Despite the combined presence of SDAM and stereoblindness, SD demonstrated preserved abilities in forming and using coarse spatial representations, as well as recognizing landmarks. The close comparison between two individuals with aphantasia with overlapping navigational experience for a remotely learned environment underscores the variability in how

aphantasia and related conditions manifest and interact, and highlights the heterogeneity of topographical disorientation mentioned by Aguirre and D'Esposito (1999).

Limitations

While this study provides valuable insights into the relationship between spatial memory and visual imagery, a few limitations should be considered when interpreting the findings. First, as a single-case study, the extent to which these results generalize to other individuals with similar differences remains uncertain. Although case studies offer rich, qualitative data, they limit broader applicability.

Additionally, assessment of aphantasia is largely based on, such as the VVIQ, which may be influenced by subjective interpretation. This limitation makes it difficult to determine the extent to which SD's reported lack of visual imagery directly contributes to her spatial memory performance. Future studies should incorporate multiple, objective measures of object and spatial imagery to help determine if task performance is specifically due to lack of imagery (Pearson et al., 2013).

Another limitation concerns the structure of SHQ, which requires players to complete each level sequentially (i.e., one needs to complete level N to move on to level N+1). This design introduces a selection bias, as only the most skilled or motivated participants progress to the later levels, potentially limiting the generalizability of performance comparisons across levels (Spiers et al., 2023). However, in SD's case, this bias may be less of a concern because she successfully completed all the levels. The sequential nature of the levels is also necessary, as failure on an earlier level is likely to predict failure in subsequent levels. Another mitigating factor is the large sample size of the controls, which helps to preserve variability in performance despite this selection effect.

Lastly, we cannot rule out the effects of SDAM and stereoblindness. Both conditions may contribute to SD's reduced ability to construct richly detailed, spatially organized representations of past events and environments. SD's reported lack of visual imagery may further compound these effects. Dawes et al. (2022) found that individuals with aphantasia produce significantly fewer episodic details – especially visual ones – when recalling past or simulating future events. This diminished visual detail was accompanied by lower ratings of phenomenological richness and reduced use of perceptual language, highlighting the role of visual imagery in reconstructing episodic experiences. Complementing these findings, Bone et al. (2025) showed that individuals with SDAM exhibit reduced low-level visual reactivation in the early visual cortex and posterior hippocampus during memory retrieval, instead relying more on semantic-based reactivation. Despite this shift, their memory performance remains intact, suggesting a compensatory mechanism. Consistent with these patterns, SD exhibited reduced internal (episodic) details compared to controls, while her external (semantic) details were comparable. Together, these findings suggest that SD's performance on the tasks may reflect a reliance on semantic scaffolding in the absence of visual imagery and visual scene construction, consistent with the known effects of both SDAM and aphantasia.

The relationship between spatial memory and stereopsis or the lack thereof (stereoblindness) is under-investigated, even relative to episodic memory and spatial memory. Initial hints of a relationship were described in an interesting case study of Private W.F., a 30-year-old man who suffered a traumatic brain injury (Holmes & Horrax, 1919). W.F. presented with depth detection difficulties after his injury, accompanied by disturbances of spatial orientation and navigation. Holmes and Horrax described him as totally devoid of topographical memory, unable to provide route descriptions or engage in path integration. They concluded that

these difficulties with spatial information were largely attributable to his visual disturbances (i.e., stereoblindness). This case highlights the possible effects of stereoblindness on the encoding and retrieval of spatial information, particularly when dependent on depth cues or egocentric updating. While causality cannot be determined from this case, it underscores the need for further empirical investigation into how impairments in binocular depth perception may compromise both egocentric and allocentric navigation processes.

Future Directions

This case study highlights areas of preserved and compromised certain spatial memory and navigation abilities in the context of aphantasia. Areas of preserved performance offer valuable insight into the underlying mechanisms of spatial memory and navigation, suggesting that other cognitive processes may compensate for the lack of visual imagery. Future research could further examine this preservation and its implications in a few ways. Future studies could incorporate neuroimaging techniques to examine the neural correlates of spatial memory and navigation in individuals with aphantasia. To our knowledge, there are currently only five published neuroimaging studies focused on aphantasia (Zeman et al., 2010; Milton et al., 2021; Furman et al., 2022; Zhao et al., 2022; Megla et al., 2024). These studies highlight the difference in memory processing for aphantasics in comparison to controls. In a recent study, Megla and colleagues (2024) had a pair of identical twins – one with reduced visual imagery and one with normal imagery – view and mentally imagine the same items. They found preserved visual information in the aphantasic twin despite reduced quality of the mental image of the items. Differences in mental imagery nevertheless were associated with reduced connectivity between occipitotemporal and fronto-parietal areas, identifying the first unique neural correlates of aphantasia in the brain. Understanding the brain regions involved in these processes, together

with more objective perceptual-cognitive paradigms, could lead to a better understanding of whether visual imagery is needed for certain abilities and, when visual imagery is identified as necessary, the extent to which recruitment of alternative brain regions and networks underlies potential compensation.

The preservation of spatial memory and navigation abilities in SD suggests that, together with neural reorganization/compensation, SD relies on alternative cognitive strategies in the absence of visual imagery, such as semantic encoding and verbal scaffolding. It would be valuable to investigate other ways in which individuals with aphantasia compensate for the lack of visual imagery, particularly in how they process and store spatial information. For example, findings from Bainbridge et al. (2021) show that aphantasics might rely more heavily on verbal scaffolding, such as describing spatial relationships in terms of landmarks or directions, rather than visualizing them. Their spatial memory may be more reliant on semantic memory than episodic memory. However, our findings suggest that visual imagery may also support the semanticization of spatial information, disrupting the recall of allocentric spatial details from remote memories. Exploring these compensatory strategies would shed light on how spatial memory operates without the support of visual imagery and could reveal broader insights into the flexibility of cognitive systems.

A growing body of research suggests that aphantasia arises from disruptions in the neural networks supporting visual imagery. Specifically, Sokolowski and Levine (2023) proposed that aphantasia is a neurodevelopmental condition stemming from deficits in the feedback connections from prefrontal regions to visual areas – connections that are crucial for generating mental images. Although perceptual processing remains intact, these individuals do not appear to benefit from perceptual priming and do not exhibit physiological responses to imagined (but not

perceived) fear-inducing stimuli, indicating a dissociation between perceptual and imagery-driven processing (Wicken et al., 2021). In support of this proposal, functional connectivity research (Zeman et al., 2024) has shown that although individuals with aphantasia show activation in appropriate visual cortices during imagery tasks, they show reduced long-range connectivity between the fusiform imagery node (FIN) and the left frontotemporal regions engaged by imagery tasks. Broader theories also implicate altered frontal-posterior connectivity, limited access to episodic representations, and a reduced capacity for conscious visual awareness (Blomkvist, 2023; Li et al., 2025; Lorenzatti, 2025; Siena et al., 2024). Many individuals with aphantasia report low subjective vividness and confidence in imagery tasks, even when object performance is comparable to controls. This discrepancy, mirrored in cases of parietal damage (Simons et al., 2010), suggests a failure of metacognitive access to internally generated scenes. Together, these findings suggest that aphantasia reflects a breakdown in the integration between higher-order control systems and sensory-perceptual networks. Future studies may examine the feasibility of these theories to further inform our understanding of the role of visual imagery in domains like spatial memory and navigation.

Finally, given our proposal to extend the Aguirre and D'Esposito (1999) taxonomy to include visual imagery as a critical mechanism for allocentric spatial processing for complex environments, future research should empirically test this hypothesis. Paradigms involving individuals with varying imagery capacities could help determine whether visual imagery is necessary for constructing or retrieving allocentric representations when information load is increased. Clarifying whether imagery plays a core, modulatory, or compensatory role would refine the taxonomy's applicability across diverse cognitive profiles.

Conclusion

To conclude, this study provides novel insights into how visual imagery supports different forms of spatial memory and navigation. Using SD as a case example, we evaluated how the absence of visual imagery – alongside co-occurring deficits in face recognition, depth perception, and episodic memory – impacts performance across egocentric and allocentric tasks. SD's preserved performance on basic spatial tasks suggests that her egocentric processing may be intact without imagery, but her difficulties with complex navigation and recalling remote environments point to impairments in constructing or accessing allocentric spatial representations. These findings support our proposal to extend the Aguirre and D'Esposito (1999) taxonomy by incorporating visual imagery as a key mechanism in allocentric spatial processing as well as consideration of dissociations between details vs. gist in spatial memory.

While this single case study contributes to understanding how individual differences in spatial representations influence spatial memory, certain limitations such as reliance on self-report measures and selection biases (i.e., the sequential nature of SHQ gameplay) should be acknowledged. Studies with larger samples and more diverse tasks will help determine whether imagery is a necessary, modulatory, or compensatory component of allocentric navigation, and whether subtypes of aphantasia exist that differentially affect object vs. spatial imagery. Ultimately, this work may inform strategies for supporting spatial memory and navigation.

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