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Reframing spatial frames of reference: What can aging tell us about egocentric and allocentric navigation?

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Abstract

Representations of space in mind are crucial for navigation, facilitating processes such as remembering landmark locations, understanding spatial relationships between objects, and integrating routes. A significant problem, however, is the lack of consensus on how these representations are encoded and stored in memory. Specifically, the nature of egocentric and allocentric frames of reference in human memory is widely debated. Yet, in recent investigations of the spatial domain across the lifespan, these distinctions in mnemonic spatial frames of reference have identified age-related impairments. In this review, we survey the ways in which different terms related to spatial representations in memory have been operationalized in past aging research and suggest a taxonomy to provide a common language for future investigations and theoretical discussion.

This article is categorized under:

Psychology > Memory
Neuroscience > Cognition
Psychology > Development and Aging

KEYWORDS

aging, allocentric, egocentric, frames of reference, spatial memory

1 | REPRESENTING SPACE IN MIND

Successful navigation of our environment is dependent on the ability to understand and interpret spatial information, such as street signs, maps, and landmarks. This information is often dynamic, changing in relation to our own position and orientation in space. Tolman's (1948) concept of the *cognitive map* (see Glossary) first introduced the idea that such spatial information can be represented in memory, inspiring a rich theoretical discussion on the neural correlates of mnemonic visuospatial representations (Ekstrom, Arnold, & Iaria, 2014; Epstein, Patai, Julian, & Spiers, 2017) and how they change during the course of aging (Colombo et al., 2017; Lester, Moffat, Wiener, Barnes, & Wolbers, 2017; Moffat, 2009). Though it has been well established in the human and animal literature that spatial representations are necessary for flexible navigational behavior (Holdstock et al., 2000; Rosenbaum et al., 2000; Wang, Chen, & Knierim, 2020), there is far less consensus as to how these representations are encoded and stored. In other words, how are spatial representations organized in human memory?

Typically, spatial information is described through two relationships: an egocentric frame of reference and an allocentric frame of reference (Figure 1). Broadly, the egocentric frame of reference describes a subject-to-object relationship, in which one's own position in space is encoded relative to external landmarks, whereas the allocentric frame

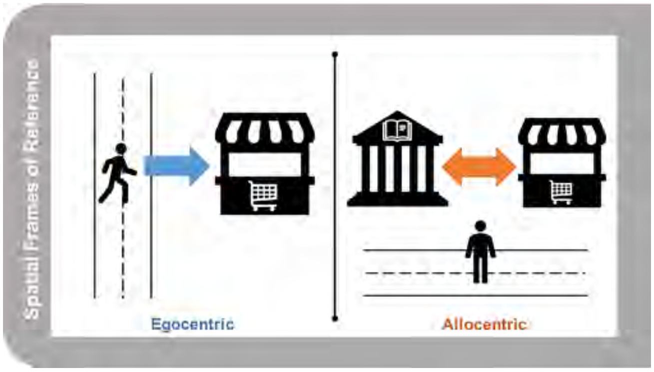

FIGURE 1 Egocentric and allocentric spatial frames of reference. (a) Knowing that one is to the right of the grocery store is an example of an egocentric representation of space. (b) Knowing that the library is across from the grocery store is an example of an allocentric representation of space

of reference describes an object-to-object relationship independent of one's own location. For example, when navigating a city street, knowing that the grocery store is to your right-hand side requires an egocentric representation of space, whereas knowing that the library is across from the grocery store requires an allocentric representation.

But, are these two terms behaviorally and cognitively dissociable? Whether spatial information is encoded and stored as egocentric- and allocentric-based representations in memory remains a controversial question (Ekstrom et al., 2014; Filimon, 2015; Shelton & McNamara, 2001). In order to pave the way for answering this question, we first need to define the terms "egocentric" and "allocentric" as they are currently used in navigation research. In this review, we examine the ways in which these spatial frames of reference have been differentiated and operationalized in past research, with the aim of supplying a taxonomy that will advance our understanding and promote further research. The value of this taxonomy lies in its function as a launching point to establish a common language in the spatial memory field and is therefore meant to provide an organizational framework rather than a rigid set of terms that encompasses all boundary conditions. This review begins with a larger overview of the debate in human navigation research on spatial frames of reference, and then provides a focused synthesis of the way relevant terms have been used in past visuospatial research. Given recent findings suggesting an age-related impairment in representing space (Colombo et al., 2017; Coughlan, Laczó, Hort, Minihane, & Hornberger, 2018; Gazova et al., 2013; Lester et al., 2017; Lithfous, Dufour, & Després, 2013; Moffat, 2009), we used spatial memory research specifically among older adults as a case study to support this aim.

2 | WHAT WE SEE IN SPACE VERSUS WHAT WE REMEMBER

It is hardly controversial to say that our visual input of the three-dimensional (3D) world around us is inherently based in an egocentric experience. That is, we see elements within our environment, such as landmarks, relative to our own position in space. How this experience is encoded and stored in memory is far more disputed. On one end, some researchers suggest that humans represent space in memory purely by maintaining these egocentric experiences in mind (Wang & Spelke, 2002). Perhaps a more widely adopted view is that humans store spatial information through a combination of egocentric and allocentric representations (Burgess, 2006; Zaehle et al., 2007; Zhong & Kozhevnikov, 2016). Broadly, approaches to defining spatial frames of reference in spatial memory research fall under two frameworks: one in which egocentric and allocentric exist separately, and the other in which they are integrated in the mind. For simplicity, in this review we will refer to this first conceptualization as a parallel framework and to the second conceptualization as an integrated framework.

2.1 | A parallel framework of spatial frames of reference

Under a parallel framework of spatial representations in memory, egocentric and allocentric frames of reference exist independently and work in parallel to support navigational behavior according to the demands of any given task (Burgess, 2006; Ring, Gaigg, Altgassen, Barr, & Bowler, 2018). This framework has also been previously described as a dual representation theory of spatial cognition (Bisby, King, Brewin, Burgess, & Curran, 2010; Waller & Hodgson, 2006). Here, successful memory-based navigation can be achieved by using only one frame of reference at a time. Specifically, relying on an egocentric-based representation allows for navigation between landmarks without knowing the allocentric relationship between them. In this case, the representation of the navigational trajectory is stored in a series of high-resolution first-person scenes in memory (Ekstrom & Isham, 2017). Likewise, an egocentric representation is not necessary for allocentric-based navigation, such as in the case when strong knowledge of a spatial route already exists (Iachini, Ruotolo, & Ruggiero, 2009; Ruggiero & Iachini, 2006). The parallel framework also maintains that an allocentric representation of space in mind emerges as the number of locations and the distances between locations increases in a navigational task in a large-scale *environmental space*, beyond a small-scale *vista space* (Yeap, 2014). More specifically, an allocentric map in memory, which is independent of our own position and as such does not require continuous updating of this information, is seen as a more efficient way of storing large-scale spatial information. Many experimental approaches to testing spatial representations in human memory adopt this view, including in aging research discussed below, dichotomizing egocentric and allocentric with the aim of independently assessing navigational performance in the two frames of reference (Fabroyir & Teng, 2018; Gazova et al., 2013; Harris & Wolbers, 2014; Laczó et al., 2017; van Gerven, Ferguson, & Skelton, 2016).

2.2 | An integrated framework of spatial frames of reference

In contrast, under an integrated framework, spatial representations are effectively stored as egocentric in memory (Wang & Spelke, 2000). The argument here is that representations traditionally described as allocentric, such as landmark locations in relation to each other, are always encoded in our visual field from our own egocentric perspective and thus stored this way, too. More specifically, the integrated framework holds that egocentric-based spatial navigation can occur independently of an allocentric representation of space, whereas allocentric-based spatial memory is dependent on successfully integrating visuospatial information into an egocentric representation first (Ekstrom et al., 2014; Ekstrom & Ranganath, 2018; Filimon, 2015). Indeed, in a review of the neural underpinnings of allocentric representations, Ekstrom et al. (2014) were unable to identify a spatial memory task which targeted an allocentric-based representation of space independently of an egocentric frame of reference. This idea is supported by findings among patients with *spatial neglect*, where an allocentric deficit is found only in conjunction with an egocentric one (Rorden et al., 2012). More specifically, patients with hemispatial neglect may show either isolated egocentric deficits or egocentric deficits paired with allocentric ones, but not pure allocentric deficits alone (Yue, Song, Huo, & Wang, 2012).

3 | SPATIAL REPRESENTATIONS IN THE AGING BRAIN

One limitation in the debate between the parallel framework and integrated framework of spatial representations in memory is the lack of consensus on the terms "allocentric" and "egocentric" frames of reference. However, a growing body of work exploring age-related differences in the way that older and younger adults use spatial information for navigation offers an avenue for disentangling these terms (Colombo et al., 2017; Fricke & Bock, 2018; Serino et al., 2018).

3.1 | Egocentric frames of reference

Consistently across studies involving an egocentric frame of reference, this term is defined as a 3D representation of space from one's own visual perspective (Bryant & Tversky, 1999; Kozhevnikov & Hegarty, 2001). In memory, this representation is stored as a series of scenes progressing through a route trajectory from the perspective of the individual traveling through it. The most prevalent way of testing spatial memory in an egocentric frame of reference is in 3D multiviewpoint spaces (Byagowi & Moussavi, 2012; Schöberl, Zwergal, & Brandt, 2020). With the advent of *virtual reality* technology, these spaces are designed more and more as arenas in which individuals see the environment from their own first-person perspective on a computer screen (Figure 2). Specifically, many studies that aim to capture this memory representation often rely on testing *path integration*, or dead reckoning, wherein participants need to keep track of a starting location in relation to their own position in space (Bierbrauer et al., 2020; Byrne, Becker, & Burgess, 2007). This tracking, in turn, relies on the integration of multimodal sensory cues generated both from self-motion and the surrounding environment, referred to as respectively as *idiothetic* and *allothetic* spatial cues. These cues essentially describe the way in which a given sensory modality conveys information for navigation, as opposed to *egocentric* and *allocentric* which refer to the way the navigator represents this spatial information (Arleo & Rondi-Reig, 2007).

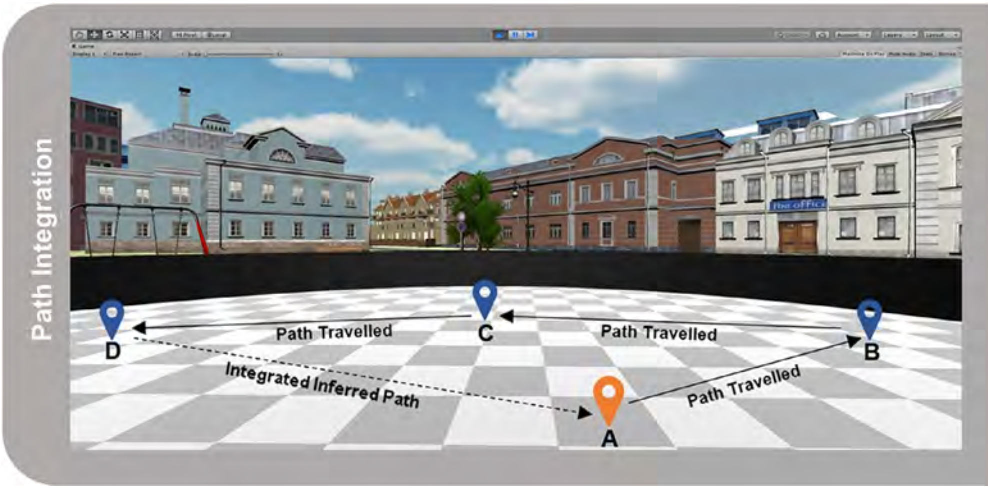

FIGURE 2 Path integration. An example of a virtual reality arena presented from a first-person perspective on a computer screen created using OpenMaze (https://openmaze.duncanlab.org/) in Unity (Unity Technologies, San Francisco, CA). Participants move through the space using the keyboard arrow keys or a joystick, and what is visible on the screen at any given moment represents their field of view. Solid-lined arrows represent the path taken between the start point (Location marker A, in orange) and intermediate stops (Location markers B, C, and D, in blue). The dotted-lined arrow represents the integrated inferred path back to the start point not explicitly learned during the path integration task

Egocentric-based navigation among healthy older adults seems to be largely preserved relative to younger adults. For example, Gazova et al. (2013) compared younger and older adults on an egocentric maze task, wherein participants were asked to locate a target goal by using their own starting position in a cylindrical *Morris Water Maze* arena adapted from rodent research (Morris, Garrud, Rawlins, & O'Keefe, 1982). The researchers did not find age-related differences in performance in the egocentric navigation task. Similarly, Fricke and Bock (2018) found no evidence of an age-related decline in egocentric navigation within a desktop virtual reality setting. Interestingly, an egocentric navigation deficit among older adults may be a sign of cognitive impairment above-and-beyond normal aging, perhaps due to difficulties in integrating allothetic cues from the surrounding environment (Kalová, Vlček, Jarolímová, & Bureš, 2005).

3.2 | Accounting for spatial scale

Despite evidence that older adults perform similarly to younger adults when using an egocentric representation of space for navigation, there is a growing body of work suggesting an age-related impairment may arise when the scale of space increases (Colombo et al., 2017; Merriman et al., 2018; Wolbers & Wiener, 2014). In other words, older adults seem to perform like younger adults on small-scale spatial tests but show increasing difficulty in large-scale environments, perhaps due to an increasing complexity of spatial cues. It is important to note that in small-scale vista space, relevant spatial information can be acquired from a single viewpoint (Montello, 1993; Wolbers & Wiener, 2014), thus reducing the burden placed on working memory to update information out of view. We therefore propose a categorization of the egocentric frame of reference into two components by scale: egocentric single-viewpoint and egocentric multi-viewpoint (Figure 3). In memory, egocentric single-viewpoint information in vista space can be represented entirely relative to one's location in a single position in space. Meanwhile, egocentric multi-viewpoint information can be represented in memory as a series of viewpoints or scenes that need to be continuously updated based on one's own moving position in space.

3.3 | Allocentric frames of reference

Perhaps much less clear-cut than the term "egocentric," the term "allocentric" frame of reference has been variably adopted by researchers to include any spatial representations where locations are encoded relative to external reference points, independent of a navigator's point-of-view. It is sometimes tested within a 3D, single-viewpoint representation

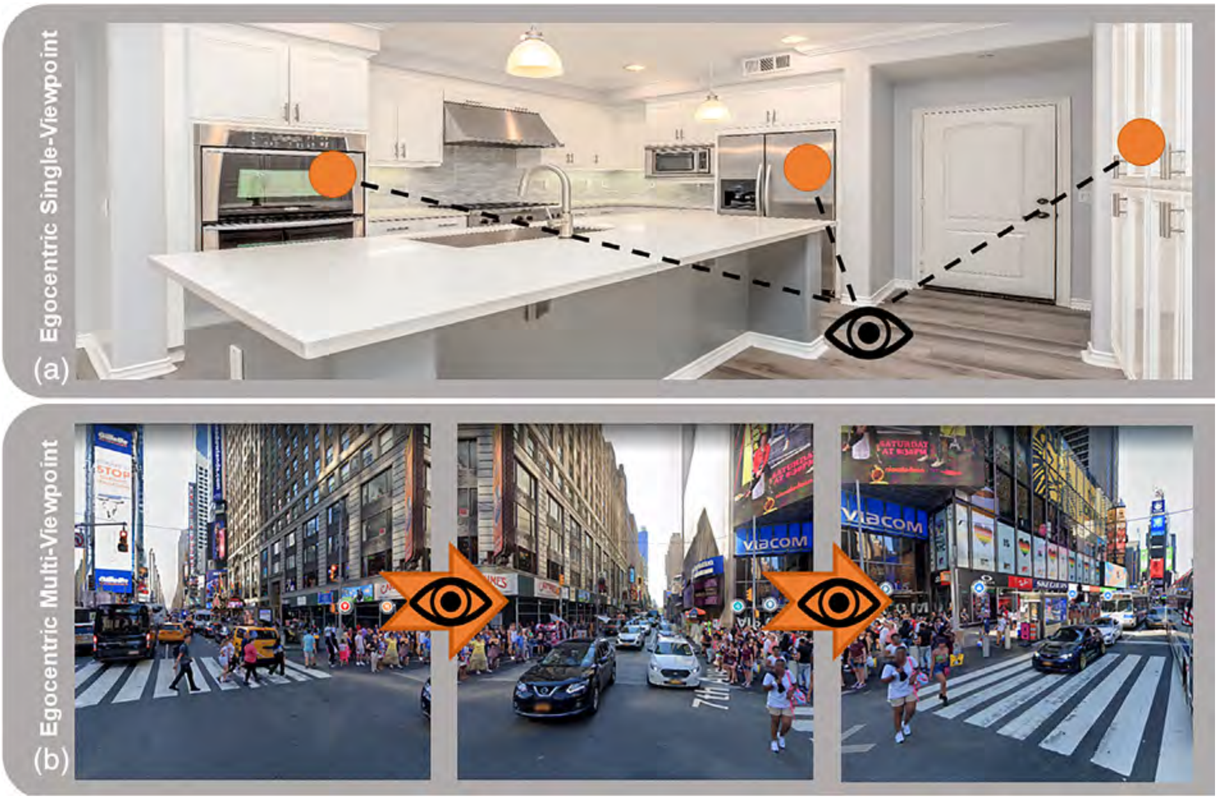

FIGURE 3 Single-viewpoint versus multi-viewpoint egocentric space. (a) Egocentric-single-viewpoint representations account for spatial information in small-scale, vista space that can be fully apprehended from a single position in space. In this example, the full kitchen can be seen from a single perspective relative to one's own position (indicated by the eye icon), including key features as indicated by the orange circles. (b) Egocentric-multi-viewpoint representations need to account for spatial information in large-scale environmental space, which is not always visible from a single point of view and needs to be continuously updated through time. For example, a city square is a large-scale environment that requires head rotations to see all the important features from multiple perspectives (indicated by the eye icons on the orange arrows)

(such as a *wayfinding* task), while other times it is tested using a two-dimensional, bird's eye view map (Figure 4). Furthermore, the synonymous term "exocentric" is used instead of "allocentric" in some research (Sanders, Holtzer, Lipton, Hall, & Verghese, 2008; Sterken, Postma, Haan, & Dingemans, 1999).

The idea that an undistorted replication of any real-world environment existing as a map in the mind has been largely discounted (Rescorla, 2009; Shelton & McNamara, 2001); instead, most authors use the term allocentric map to mean a general representation of the distal geometric aspects of the environment independent of one's own position. This idea echoes the concept of the cognitive map, which has been largely supported by research on the medial temporal lobes (MTL) in navigation, including the hippocampus (Epstein et al., 2017; O'Keefe & Nadel, 1978). This line of research maintains that regions of the MTL support map-like spatial codes in the context of navigation and that these representations are impacted by aging (Lester et al., 2017). Interestingly, there is compelling evidence for interindividual variability in the use of allocentric-based cognitive maps as strategies for encoding routes during navigation (Brunec et al., 2019; see Box 1).

BOX 1 Preference for spatial strategy correlates with navigational abilities

The Navigational Strategies Questionnaire is a self-report measure of individual preferences for strategies in navigating through space (Brunec et al., 2018). Individuals are categorized as either "scene-based" or "map-based" navigators, reflecting their preference for either strategy. These two categories of navigators correspond to the concepts of egocentric and allocentric, respectively. It is important to note that map-based strategy preference is related to a greater flexibility in navigation (Brunec et al., 2019; Foo, Warren, Duchon, & Tarr, 2005) and different neural dynamics in the hippocampus (Brunec et al., 2018).

FIGURE 4 Multi-versus single-viewpoint allocentric space. (a) A three-dimensional (3D), multi-viewpoint representation of allocentric space. Here, the relative relationships between feature locations (striped yellow and blue circles) are encoded with regard to a target location (solid green circle) independent of the navigator's position in space. (b) A two-dimensional (2D), single-viewpoint representation of allocentric map-like space, with landmarks encoded relative to each other indicated by the colored circles. In spatial memory tasks, older adults tend to perform better on 2D single-viewpoint allocentric tasks than 3D multi-viewpoint allocentric ones, suggesting a fundamental difference between these two spatial representations that needs to be clarified

Healthy older adults show marked difficulties related to an allocentric frame of reference (Antonova et al., 2009; Lithfous, Dufour, Blanc, & Després, 2014), though these findings are dependent on the way that "allocentric" is operationalized (Galati, Pelle, Berthoz, & Committeri, 2010). Specifically, there is an important distinction between spatial memory tasks that rely on a two-dimensional allocentric representation—which can be apprehended from a single point of view—and a 3D allocentric representation—which requires a rotating, or shifting, point of view to apprehend the spatial dimensions. We discuss the key differences between these representations as they relate to aging subsequently.

Some researchers have attempted to isolate allocentric abilities in tasks requiring the learning and subsequent recall of two-dimensional maps, which can be studied from a single viewpoint (Meneghetti, Fiore, Borella, & Beni, 2011; Meneghetti, Pazzaglia, & De Beni, 2015; Thomas, Bonura, & Taylor, 2012; Yamamoto & DeGirolamo, 2012). In our example in Figure 4b, participants encode the relative positions of three landmarks (indicated by circle icons) on the map from a single viewpoint for subsequent recall. Critically, they can learn these relative landmark positions without requiring knowledge of their own location on the map. In one study that used this conceptualization of allocentric space, younger and older adult participants studied the locations of landmarks on a series of spatial maps (Thomas et al., 2012). They found that while older adults recalled fewer landmarks than younger adults, this performance difference could be reduced when older adults were encouraged to use a feature-based strategy at encoding. Likewise, Yamamoto and DeGirolamo (2012) found that older adults were not necessarily less accurate than younger adults in remembering landmarks from an aerial perspective. We propose that—like with the egocentric single-viewpoint frame of reference—two-dimensional maps allow participants to see all relevant spatial information from a single viewpoint (though, it should be noted that encoding one's own viewpoint relative to locations on the map is irrelevant to performance on these tasks). Thus, we suggest that allocentric map-based tasks be categorized as dependent on an "allocentric single-viewpoint" frame of reference. The relative preservation of allocentric single-viewpoint mapping in healthy older adults suggests that spatial impairments seen with aging when tasks require a switch from map-based learning to a 3D space at testing are not primarily due to encoding deficits in this frame of reference.

In contrast, studies that have adopted a conceptualization of allocentric space as a 3D object-to-object relationship find pronounced age-related deficits in task performance relative to egocentric-only navigation (Antonova et al., 2009; Lithfous et al., 2014). In Figure 4a, participants immersed in a virtual reality room would need to learn the positions of several locations (indicated by the striped yellow and blue circles in the figure) to encode the relative position of a target landmark (indicated by the solid green circle) for subsequent recall. In one study, researchers used a desktop virtual maze requiring participants to learn positions of target locations in an arena independent of their own position in space (Antonova et al., 2009). Since the starting position within the arena differed from encoding to retrieval, the task required participants to adopt an allocentric strategy to encode target locations relative to each other. In other words, participants could not rely on their own position in the arena to remember target locations. The researchers found that older adult participants were less precise in recalling the locations of previously learned targets than younger adult participants.

Perhaps the most compelling evidence for an age-related deficit related to the 3D allocentric frame of reference is from the population-based cohort ($n = 27{,}108$) collected by Coughlan et al. (2019) through the mobile app-based cognitive task "Sea Hero Quest" (Glitchers, https://glitchers.com/; Box 2). Levels in Sea Hero Quest feature progressively more challenging environments and are divided into either egocentric-based path integration or allocentric-based wayfinding. The predictive value of age among participants between the ages of 50 and 75 years old in the allocentric wayfinding levels of Sea Hero Quest was greater than that for the egocentric-based path integration levels in this cohort. These results are consistent with earlier findings that normal age-related deficits appear first in allocentric processing and perhaps only much later in egocentric processing (Moffat, Zonderman, & Resnick, 2001; Mokrisova et al., 2016; Ruggiero, D'Errico, & Iachini, 2016). Interestingly, Coughlan et al. (2019) also found that participants in a lab-based cohort ($n = 60$) who were carriers of the *APOE ε4* genotype and thus genetically at-risk for Alzheimer's disease traveled significantly less efficiently in the allocentric wayfinding levels of Sea Hero Quest than individuals who were not carriers of this allele. As will be discussed further, this may be due to the complexity of these Sea Hero Quest levels recruiting a spatial representation far beyond what can be captured from a fixed viewpoint of the virtual environment.

BOX 2 Mobile app "Sea Hero Quest" as an immersive tool for testing spatial ability

The rapidly increasing worldwide rate of Alzheimer's disease, an age-related neurodegenerative disease, is among the greatest medical challenges faced today. Traditionally, Alzheimer's disease was assessed through episodic memory impairments, but recent evidence suggests that cognitive decline related to the spatial domain may be even more predictive of disease progression. Moreover, there is a growing understanding of spatial impairments associated with normal, healthy aging, as well. The mobile app game "Sea Hero Quest" (Glitchers, https://glitchers.com/), created in partnership with a global team of dementia and spatial navigation researchers along with application developers, offers a unique way of testing spatial navigation abilities across the lifespan on a cellular phone or tablet. The global Sea Hero Quest database (Coutrot et al., 2018) includes data from over 2.5 million individuals from every country in the world and is a critical step in advancing our understanding of the factors determining navigational ability, including the use of allocentric and egocentric frames of reference as mnemonic spatial representations.

Given the differences in age-related performance on pure map-based allocentric tasks (which we categorized above as allocentric single-viewpoint) from these types of 3D allocentric tasks, we propose a second category of the allocentric frame of reference: "allocentric multi-viewpoint." In memory, the allocentric multi-viewpoint frame of reference requires continuous updating of information in the visual field about landmark locations relative to one another. This final frame of reference also seems to be key in detecting early signs of cognitive impairment beyond normal aging (Coughlan et al., 2019; Guderian et al., 2015). However, when performing tasks that require an allocentric multi-viewpoint representation, older adults may instead prefer a *beacon strategy* (Wiener, de Condappa, Harris, & Wolbers, 2013). This type of navigation does not rely on a representation of a coordinate space and only requires recognition memory

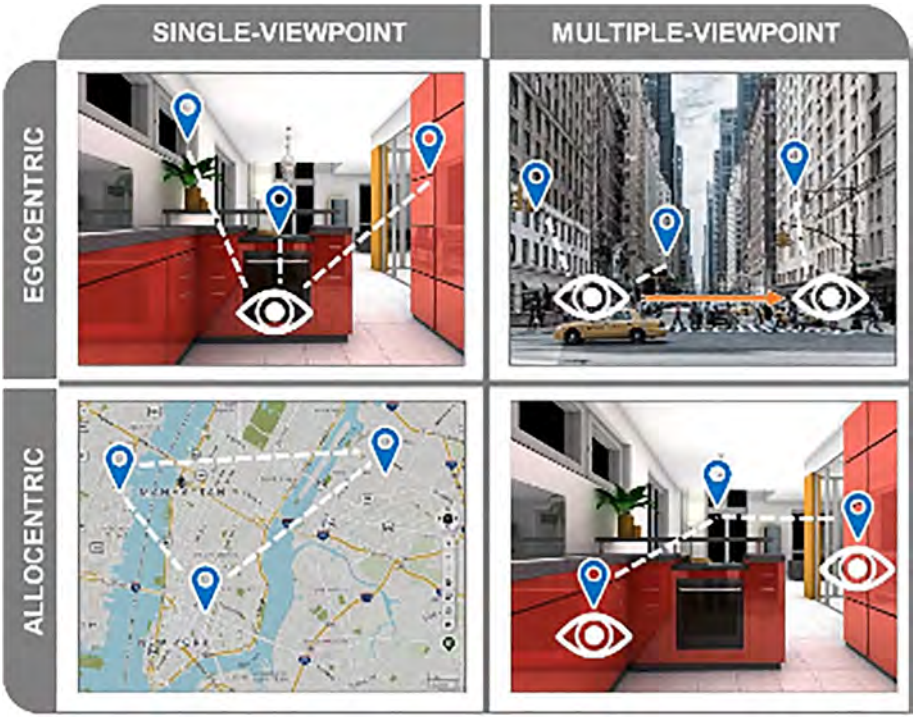

FIGURE 5 Summary of egocentric and allocentric frames of reference. A visual summary of the taxonomy outlined in this review regarding spatial frames of reference as representations of space. The top images are separated from the bottom images on the basis of the spatial relationship highlighted in the representation (i.e., subject-to-object in egocentric space and object-to-object in allocentric space). The left images are separated from the right images on the basis of the observer's point-of-view(s) to apprehend all relevant landmarks in a space

for the target landmark itself, as well as the ability to discriminate it from other landmarks (Ekstrom & Isham, 2017). In other words, movement responses toward a landmark bring one closer to a goal but do not require explicit encoding of directional information or motor responses. As such, relying on a beacon strategy during learning may result in an impoverished memory representation of a route or of an environment such that the removal of target landmarks leads to poorer navigational performance at testing (Ishikawa, Fujiwara, Imai, & Okabe, 2008). This compensatory strategy in older adults may be especially detrimental when the frame of reference presented during the learning phase differs from the testing phase of a navigation task, since the recognition of target landmarks would require a flexible switch between allocentric and egocentric representations in mind. It is crucial that future tasks aiming to test navigation performance among older adults in the allocentric multi-viewpoint frame of reference account for the possibility that older adults may be deferring to a beacon strategy and so should explicitly test memory for directional information in space.

4 | CONCLUSIONS

The question of whether visuospatial information is encoded and stored as egocentric- and allocentric-based in memory remains in dispute. From the perspective of a parallel framework of spatial frames of reference, these two terms are dissociable in human spatial memory, while from the perspective of an integrated framework they are much less so. Yet, emerging evidence highlights the importance of spatial representation deficits in memory, beyond episodic memory deficits, in identifying both normal and pathological age-related cognitive decline. To help resolve this inconsistency, we saw a need to define the terms “egocentric” and “allocentric” as they are used in current human navigation research, separated on the axis of the amount of spatial information that can be apprehended from the viewer's point-of-view (Figure 5). Specifically, we suggest “egocentric multi-viewpoint,” “egocentric single-viewpoint,” “allocentric single-viewpoint,” and “allocentric multi-viewpoint” as useful terms for future spatial memory research and theoretical debate. While our taxonomy focuses primarily on the visual domain, which contains arguably the largest body of work on aging and spatial navigation, we see it as compatible with the sensorimotor domain in that multisensory integration of allothetic and idiothetic cues are crucial to formation of these spatial representations.

As described earlier and outlined in Figure 5, one important way in which these terms are differentiated from each other is in the amount of spatial information that can be captured from the viewer's point-of-view. In spatial memory tasks that rely on multi-viewpoint frames of reference, integration of these many perspectives is a key requirement for successful performance. This may make these types of tasks, conceptualized in our framework as “egocentric multi-viewpoint" and "allocentric multi-viewpoint," vulnerable to age-related decline as higher burdens are placed on working memory and visual perception. Indeed, viewpoint changes in spatial tasks have been shown to be relevant for performance not only among older adults but also among clinical groups with deficient hippocampal-dependent cognition, including patients with amnesia or schizophrenia spectrum disorders (Lee et al., 2005; Wilkins et al., 2013). Furthermore, unlike single-viewpoint frames of reference, point of view updating in these multi-viewpoint representations occurs not just in a spatial context but in a temporal context, too. Compared to younger adults, older adults show marked decline in the ability to recall landmarks along a learned route in chronological order despite intact recognition memory (Wilkniss, Jones, Korol, Gold, & Manning, 1997). Future research may seek to disentangle the additional cognitive demands placed on older adults in updating points of view from multi-viewpoint frames of reference, though task difficulty and memory load might simply be an inherent feature of the single-viewpoint versus multi-viewpoint distinction.

In this review, we provided a new taxonomy of spatial frames of reference through the lens of aging research with the goal of furthering our understanding of these terms and encouraging future research. With these defined terms that can be shared among researchers, we hope that constructive debates about the organization of spatial representations in human memory—including across the lifespan—can be supported with more clear experimental data going forward.

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AUTHOR CONTRIBUTIONS

Natalia Ladyka-Wojcik: Conceptualization; visualization; writing-original draft; writing-review and editing. **Morgan Barense:** Conceptualization; visualization; writing-original draft; writing-review and editing.

GLOSSARY

Beacon strategy—A response strategy when navigating to a single landmark that does not require a representation of space in memory, and involves only moving toward or away from a recognized target.

Cognitive map—A mental representation or model of one's surrounding physical environment.

Environmental space—A spatial layout in which properties of one's surroundings and relationships of objects and landmarks must be integrated across multiple perspectives.

Morris Water Maze—A behavioral procedure developed for testing rodent ability to navigate by swimming from a start location to a target platform, which has been adapted through virtual reality technology for human research.

Path integration—The ability to use idiothetic, or self-relevant, cues to determine one's position in space by continuously monitoring one's trajectory in relation to a starting location.

Spatial neglect—A behavioral syndrome following brain injury, including trauma or neurodegenerative disease defined by an inability to perceive, report and orient to sensory events in the side of space contralateral to the damaged brain hemisphere.

Virtual reality—A simulated experience on a screen presented in laboratory-based experiments that provides a naturalistic but controlled manner for testing spatial navigation and memory.

Vista space—A spatial layout in which properties of one's surroundings and relationships of objects or landmarks can be perceived from one vantage point, such as a single room.

Wayfinding—A behavioral spatial test that requires one's understanding of their own position in space, memory of a route trajectory, and relationships between landmarks to determine a target location.

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