# Free Exploration and Sketch-Map Recall: A Cognitive Neuroscience Perspective

## Introduction

Spatial cognition, the ability to acquire, process, store, and utilize spatial information, is fundamental to human interaction with the built environment. Understanding how individuals learn, represent, and recall spatial layouts is crucial for designing effective architectural spaces that support wayfinding, orientation, and a positive overall user experience. This review explores the intricate relationship between free exploration of an environment and subsequent sketch-map recall, a common method for assessing spatial knowledge acquisition. Free exploration, unlike directed or cued navigation, allows individuals to actively engage with the environment, choosing their own paths, focusing on features they find salient, and creating their own individualized experience of the space. This active learning process is hypothesized to promote a richer and more flexible spatial representation, which can then be externalized and analyzed through the creation of sketch maps. Sketch maps, while inherently subjective and schematic, provide valuable insights into an individual's cognitive map, revealing their understanding of spatial relationships, landmarks, and the overall environmental structure. They offer a tangible window into the subjective experience of space, allowing researchers to glean insights into how individuals perceive, organize, and remember spatial information.  
  
The investigation of free exploration and sketch-map recall has a rich history, drawing upon seminal work in cognitive psychology, behavioral geography, and neuroscience. Early theories of cognitive mapping, such as those proposed by Tolman (1948) and O'Keefe & Nadel (1978), laid the groundwork for understanding how spatial knowledge is acquired and represented in the brain. These theories emphasized the role of the hippocampus in forming allocentric representations, allowing individuals to understand their position in space relative to other locations, independent of their own body orientation. Subsequent research has explored the neural underpinnings of spatial navigation, identifying key brain regions involved in processing spatial information during both free exploration and recall. Furthermore, methodological advancements in spatial data collection and analysis, including the development of sophisticated software for quantifying and comparing sketch maps, have enabled researchers to gain a more nuanced understanding of individual differences in spatial cognition and the factors that contribute to these variations.  
  
This literature review synthesizes key findings from a range of studies examining the relationship between free exploration and sketch-map recall. We will explore the theoretical foundations of spatial knowledge acquisition, including cognitive mapping theory, the role of landmarks, and the influence of environmental factors. We will then examine key methodologies employed in this research area, including different types of sketch maps and their associated metrics, as well as neuroimaging techniques used to investigate the neural correlates of spatial navigation. The review will also delve into individual differences in spatial abilities, exploring how factors such as age, gender, experience, and cognitive style can influence spatial learning and recall. Finally, we will discuss the implications of these findings for architectural design and wayfinding, emphasizing the importance of creating environments that support effective spatial learning and navigation for diverse user populations.

## Theoretical Foundations

### Cognitive Mapping Theory

The concept of the cognitive map, as introduced by Tolman (1948), provides a foundational framework for understanding how individuals acquire and represent spatial knowledge. Tolman's work with rats navigating mazes suggested that they develop internal representations of the environment, allowing them to take shortcuts and detours even when previously learned routes are blocked. This concept was later extended to humans, with O'Keefe and Nadel's (1978) work demonstrating the role of the hippocampus in forming cognitive maps. They proposed that the hippocampus functions as a cognitive map, encoding spatial relationships between locations and allowing for flexible navigation. This theory has been supported by numerous studies, including neuroimaging research showing hippocampal activation during spatial tasks. The cognitive map is not a literal map, but rather a complex, multi-layered representation that integrates various types of spatial information, including metric distances, directional relationships, and landmark information. This allows individuals to navigate efficiently and flexibly, even in novel environments. Furthermore, the cognitive map is not static but constantly updated as new information is acquired through exploration and experience. More recent research has expanded on this theory, exploring the role of other brain regions, such as the parietal cortex and the entorhinal cortex, in supporting spatial navigation and memory (Ekstrom et al., 2003). These regions are thought to contribute to different aspects of spatial processing, such as path integration, landmark recognition, and the formation of spatial schemas. The cognitive map, therefore, represents a dynamic and distributed neural system that allows individuals to learn, represent, and utilize spatial information in a flexible and adaptive manner.

### The Role of Landmarks

Landmarks play a crucial role in spatial navigation and sketch-map recall. Lynch's (1960) seminal work on the image of the city highlighted the importance of landmarks in shaping individuals' mental representations of urban environments. He identified five key elements that contribute to the legibility of a city: paths, edges, districts, nodes, and landmarks. Landmarks serve as prominent reference points, aiding in orientation and wayfinding. They can be both physical features, such as buildings or monuments, and perceptual events, such as changes in vista or lighting. Research has shown that individuals tend to recall landmarks more accurately than other spatial features, and that the presence of salient landmarks can improve sketch-map accuracy (Sorrows & Hirtle, 1999). Furthermore, the type and salience of landmarks can influence how individuals organize and represent spatial information. For example, landmarks with strong visual or semantic properties are more likely to be remembered and used for navigation. The strategic placement of landmarks in architectural design can therefore enhance wayfinding and improve the overall user experience. Recent research has also explored the neural basis of landmark processing, demonstrating that specific brain regions, such as the parahippocampal place area (PPA), are involved in encoding and recognizing landmarks (Epstein et al., 2017). The interaction between landmarks and the cognitive map is complex and dynamic, with landmarks serving as anchors for spatial memories and providing contextual information that helps individuals orient themselves and navigate effectively.

### Environmental Complexity and Spatial Cognition

The complexity of the built environment plays a significant role in how individuals acquire, represent, and recall spatial information. Environments that are highly complex, with numerous interconnected pathways, ambiguous landmarks, and a lack of clear visual cues, can pose significant challenges for spatial learning and wayfinding. Research has shown that individuals tend to perform worse on spatial tasks in complex environments, exhibiting lower accuracy on sketch maps, longer navigation times, and increased disorientation (Passini, 1984). This is likely due to the increased cognitive load imposed by complex environments, which require individuals to process and integrate a greater amount of spatial information. Conversely, simpler environments, with clear pathways, distinct landmarks, and a well-defined spatial structure, tend to facilitate spatial learning and navigation. These environments provide a clearer and more readily interpretable spatial framework, reducing cognitive load and promoting the formation of accurate and robust cognitive maps. Architectural design can play a crucial role in mitigating the negative effects of environmental complexity by incorporating clear wayfinding cues, strategically placed landmarks, and a logical spatial organization. This can improve the legibility of the environment, making it easier for individuals to navigate and orient themselves effectively (Zimring & Reizenstein, 1980). Furthermore, research suggests that providing users with access to maps or other navigational aids can help them overcome the challenges posed by complex environments, particularly in unfamiliar settings.

### Individual Differences in Spatial Cognition

Individual differences in spatial abilities play a significant role in how people acquire, represent, and recall spatial information. Research has identified a range of factors that contribute to these differences, including gender, age, experience, and cognitive style. Lawton's (1994) work on gender differences in wayfinding strategies found that women tend to rely more on landmarks and route knowledge, while men tend to use more metric and Euclidean information. However, these findings are not universally consistent, and other studies have reported minimal or no gender differences in spatial abilities. Age also plays a role in spatial cognition, with younger adults generally outperforming older adults on spatial tasks, particularly those involving memory and processing speed. However, older adults can often compensate for age-related declines in spatial abilities by relying on experience and learned strategies. Experience with a particular environment can significantly improve spatial knowledge and wayfinding performance. Individuals who are familiar with a space tend to develop more detailed and accurate cognitive maps, allowing them to navigate more efficiently and recall spatial information more effectively. Cognitive style, which refers to individual differences in how people process and organize information, can also influence spatial abilities. For example, individuals with a field-independent cognitive style, who are better at isolating and analyzing individual elements within a complex scene, tend to perform better on spatial tasks than those with a field-dependent style. These individual differences have implications for architectural design, as designers need to consider the diverse needs and abilities of users when creating navigable spaces. Providing multiple wayfinding cues, such as maps, signage, and landmarks, can accommodate different cognitive styles and improve wayfinding for all users. Furthermore, designing environments that are easy to learn and navigate, regardless of age, gender, or experience, can promote inclusivity and enhance the overall user experience (Ishikawa & Montello, 2006).

## Key Findings and Methodologies

Research on free exploration and sketch-map recall utilizes various methodologies to assess spatial knowledge acquisition. Sketch maps, a common data collection tool, provide a visual representation of an individual's cognitive map. Different types of sketch maps exist, including sequential maps, which are drawn while navigating the environment, and recall maps, which are drawn from memory after exploration. Sequential maps offer insights into the ongoing process of spatial learning, capturing the order in which individuals encounter and represent spatial features. Recall maps, on the other hand, provide a snapshot of the consolidated spatial knowledge acquired during exploration. Researchers have developed various metrics to quantify and compare sketch maps, such as the number of landmarks included, the accuracy of spatial relationships, and the overall topological structure. Blades (1990) examined the reliability of data collected from sketch maps, finding that while sketch maps can be subject to individual variations and distortions, they provide a valuable and generally reliable measure of spatial knowledge. Rovine and Weisman (1989) investigated sketch-map variables as predictors of way-finding performance, demonstrating that the accuracy and completeness of sketch maps correlate with real-world navigation abilities. Krukar, Bell, and Montello (2023) explored task-dependent sketch maps, demonstrating that the purpose of the sketch map can influence its content and structure. For example, sketch maps drawn for navigation purposes may emphasize routes and landmarks, while those drawn for communication purposes may focus on conveying the overall layout of the environment. Pazzaglia and De Beni (2001) studied strategies of processing spatial information in survey and route learning, finding that individuals employ different strategies depending on the task demands. Some individuals prioritize route knowledge, focusing on learning specific paths and sequences of turns, while others prioritize survey knowledge, developing a more comprehensive understanding of the spatial layout.

Neuroimaging studies have provided insights into the neural correlates of spatial navigation during free exploration and recall. Ekstrom and colleagues (2003) identified cellular networks underlying human spatial navigation, demonstrating the involvement of the hippocampus, entorhinal cortex, and other brain regions in processing spatial information. Maguire et al. (2000) demonstrated navigation-related structural changes in the hippocampi of taxi drivers, suggesting that extensive spatial experience can lead to neuroplasticity in brain regions involved in spatial navigation. Snider et al. (2013) found that human cortical theta oscillations during free exploration encode spatial information and predict subsequent memory performance. These findings highlight the role of the hippocampus and other brain regions in processing spatial information during free exploration and recall. Furthermore, research comparing virtual and real-world navigation has shed light on the transferability of spatial knowledge across different environments. Meilinger, Frankenstein, and Bülthoff (2016) investigated how virtual and real-world navigation relate, finding that while there are some differences in the specific cognitive processes involved, spatial knowledge acquired in virtual environments can transfer to real-world settings. Meneghetti, Borella, and Pazzaglia (2021) examined the effects of maps and verbal descriptions on navigation performance in virtual environments, demonstrating that providing navigational aids can improve spatial learning and wayfinding in virtual settings. Tlauka, Anacta, and Wilson (2024) studied spatial learning using Google Streetview in an online wayfinding experiment, demonstrating the potential of virtual environments for studying spatial cognition and the accessibility of online platforms for conducting large-scale spatial research.

Overall, research on free exploration and sketch-map recall has revealed a complex interplay between environmental features, individual differences, and neural processes. The findings have implications for architectural design, wayfinding, and urban planning, emphasizing the importance of creating environments that support effective spatial learning and navigation. By understanding how individuals acquire, represent, and recall spatial information, designers can create spaces that are intuitive, easy to navigate, and promote a positive user experience.

## Summary Table of Empirical Findings

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| Research Domain | Key Finding | Supporting Studies | Theoretical Implications |
| Cognitive Mapping | The hippocampus plays a crucial role in forming and retrieving cognitive maps. | O'Keefe & Nadel (1978), Ekstrom et al. (2003), Maguire et al. (2000) | Supports the idea of an allocentric spatial representation system. |
| Landmarks | Landmarks serve as prominent reference points, aiding in orientation and wayfinding. | Lynch (1960), Sorrows & Hirtle (1999) | Highlights the importance of salient features in spatial memory. |
| Individual Differences | Spatial abilities vary across individuals due to factors like gender, experience, and cognitive style. | Lawton (1994), Hegarty et al. (2006), Ishikawa & Montello (2006) | Emphasizes the need for diverse wayfinding strategies in design. |
| Sketch Maps | Sketch maps provide valuable insights into an individual's cognitive map. | Blades (1990), Rovine & Weisman (1989), Krukar et al. (2023) | Offers a method for externalizing and analyzing spatial representations. |
| Neuroimaging | Specific brain regions, including the hippocampus, are activated during spatial navigation tasks. | Ekstrom et al. (2003), Maguire et al. (2000), Snider et al. (2013) | Provides neural evidence for cognitive mapping theory. |
| VR vs. Real World | Virtual environments can be used to study spatial learning and navigation, and findings often generalize to real-world settings. | Meilinger et al. (2016), Meneghetti et al. (2021), Tlauka et al. (2024) | Offers a controlled setting for manipulating environmental variables and studying spatial cognition. |
| Wayfinding | Effective wayfinding relies on clear spatial cues and environmental legibility. | Golledge (1999), Weisman (1981), Spiers & Maguire (2008) | Informs the design of navigable spaces and emphasizes the importance of clear signage and landmarks. |
| Environmental Complexity | The complexity of an environment can influence spatial learning and wayfinding performance. | Passini (1984), Zimring & Reizenstein (1980) | Suggests that simpler, well-organized environments are easier to navigate and promote better spatial learning. |
| Developmental Aspects of Spatial Cognition | Spatial cognition develops throughout childhood and adolescence, with continued refinement into adulthood. | Piaget & Inhelder (1967), Newcombe & Huttenlocher (2000) | Highlights the importance of early spatial experiences and the ongoing plasticity of spatial abilities. |
| Methodological Approaches | Various methods are used to study spatial cognition, including behavioral experiments, neuroimaging, and virtual reality simulations. | Pazzaglia & De Beni (2001) | Provides a diverse toolkit for researchers to investigate spatial processes from multiple perspectives. |
| Literature Reviews and Meta-Analyses | Reviews and meta-analyses synthesize findings from multiple studies, providing a comprehensive overview of the field. | Wolbers & Hegarty (2010), Waller & Nadel (2013) | Offers valuable summaries of existing research and identifies key areas for future investigation. |
| Theoretical Debates in Spatial Cognition | Ongoing debates exist regarding the nature of spatial representations, the role of different brain regions, and the relationship between navigation skills and spatial knowledge. | McNamara (2003), Foo et al. (2005) | Encourages further research to refine theoretical models and address open questions in the field. |
| Dynamic Nature of Cognitive Maps | Cognitive maps are dynamic and constantly updated through experience, reflecting the plasticity of spatial representations. | Epstein et al. (2017) | Emphasizes the adaptability of spatial knowledge and the ongoing interaction between individuals and their environment. |

## Conclusion and Future Directions

The relationship between free exploration and sketch-map recall is a complex and multifaceted area of research with significant implications for understanding human spatial cognition. From seminal theories of cognitive mapping to advanced neuroimaging techniques, the field has made substantial progress in unraveling the neural and behavioral mechanisms underlying spatial knowledge acquisition. Key findings highlight the crucial role of the hippocampus and other brain regions in forming and retrieving cognitive maps, the importance of landmarks in aiding navigation, and the influence of individual differences in shaping spatial abilities. Methodological advancements, such as the use of virtual environments and sophisticated sketch-map analysis techniques, have enabled researchers to explore spatial cognition in greater detail, providing richer and more nuanced insights into the complexities of spatial processing.

Future research should focus on several key areas. First, further investigation of the neural mechanisms underlying sketch-map recall is needed. While studies have identified key brain regions involved in spatial processing, the precise neural computations supporting the transformation of a cognitive map into a graphical representation remain largely unknown. Exploring the neural dynamics during the act of drawing a sketch map, using techniques such as EEG or fMRI, could shed light on the cognitive processes involved in translating spatial memories into external representations. Second, research should explore the impact of environmental factors, such as lighting, color, and acoustics, on free exploration and sketch-map recall. Understanding how these factors influence spatial learning can inform the design of more effective and user-friendly built environments. For example, manipulating lighting conditions in a virtual environment and assessing subsequent sketch-map recall could reveal how lighting affects spatial memory and orientation. Third, longitudinal studies are needed to examine how spatial skills develop over time and how they are affected by experience and training. This research can inform educational interventions aimed at improving spatial reasoning abilities. Tracking spatial development in children and adolescents, using both behavioral and neuroimaging measures, could identify critical periods for spatial learning and inform the design of targeted interventions. Finally, future work should explore the potential of virtual and augmented reality technologies for enhancing spatial learning and rehabilitation. These technologies offer immersive and interactive environments that can be tailored to individual needs and learning styles. Developing virtual reality training programs for individuals with spatial deficits, such as those with brain injuries or neurodevelopmental disorders, could offer new avenues for rehabilitation and improve real-world spatial functioning.

One specific testable future direction is to investigate the effects of different types of landmark cues on sketch-map recall following free exploration in a virtual environment. Participants could explore a virtual museum with either visually salient landmarks, semantically meaningful landmarks, or no landmarks. Subsequent sketch-map recall could be assessed using a combination of quantitative metrics, such as landmark inclusion and spatial accuracy, and qualitative analysis of the maps' overall structure and organization. This research could provide valuable insights into how different types of landmarks influence spatial learning and representation, with implications for the design of virtual museums and other educational spaces. Furthermore, incorporating neuroimaging measures, such as fMRI, could reveal the neural correlates of landmark processing and how different types of landmarks engage distinct brain regions.

## References

* **(Core Theory)** O'Keefe, J., & Nadel, L. (1978). The hippocampus as a cognitive map. Oxford: Clarendon Press.
* **(Core Theory)** Tolman, E. C. (1948). Cognitive maps in rats and men. Psychological Review, 55(4), 189–208.
* **(Neuro/Imaging)** Ekstrom, A. D., Kahana, M. J., Caplan, J. B., Fields, T. A., Isham, E. A., Newman, E. L., & Fried, I. (2003). Cellular networks underlying human spatial navigation. Nature, 425(6954), 184–188.

doi:10.1038/nature01964

* **(Neuro/Imaging)** Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. Proceedings of the National Academy of Sciences, 97(8), 4398–4403.

doi:10.1073/pnas.070039597

* **(Methods)** Blades, M. (1990). The reliability of data collected from sketch maps. Journal of Environmental Psychology, 10(4), 327–339.

https://www.sciencedirect.com/science/article/abs/pii/S0272494405800325

* **(Methods)** Rovine, M. J., & Weisman, G. D. (1989). Sketch-map variables as predictors of way-finding performance. Journal of Environmental Psychology, 9(4), 217–232.

https://www.sciencedirect.com/science/article/pii/S0272494489800362

* **(Constructs)** Montello, D. R. (1998). A new framework for understanding the acquisition of spatial knowledge in large-scale environments. In M. J. Egenhofer & R. G. Golledge (Eds.), Spatial and temporal reasoning in geographic information systems (pp. 143–154). New York: Oxford University Press.
* **(Constructs)** Siegel, A. W., & White, S. H. (1975). The development of spatial representations of large-scale environments. In H. W. Reese (Ed.), Advances in child development and behavior (Vol. 10, pp. 9–55). New York: Academic Press.
* **(Environmental Complexity)** Passini, R. (1984). Wayfinding in architecture. New York: Van Nostrand Reinhold.
* **(Environmental Complexity)** Zimring, C. M., & Reizenstein, J. E. (1980). Architectural implications of cognitive mapping: Wayfinding in hospitals and other complex buildings. In G. T. Moore (Ed.), Emerging methods in environmental design and planning (pp. 398–414). Cambridge, MA: MIT Press.
* **(Landmarks)** Sorrows, M. E., & Hirtle, S. C. (1999). The nature of landmarks for real and electronic spaces. In D. R. Montello (Ed.), Spatial information theory: Cognitive and computational foundations of geographic information science (pp. 37–50). Berlin: Springer.
* **(Landmarks)** Lynch, K. (1960). The image of the city. Cambridge, MA: MIT Press.
* **(Individual Differences)** Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, T., & Lovelace, K. (2006). Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning. Intelligence, 34(2), 151–176.

doi:10.1016/j.intell.2005.05.007

* **(Individual Differences)** Lawton, C. A. (1994). Gender differences in way-finding strategies: Relationship to spatial abilities and spatial anxiety. Sex Roles, 30(11-12), 765–779.

doi:10.1007/BF01544112

* **(VR vs Real)** Meneghetti, C., Borella, E., & Pazzaglia, F. (2021). Navigating in virtual environments: Does a map or a verbal description improve performance? Cognitive Research: Principles and Implications, 6(1), 1–18.

doi:10.1186/s41235-021-00286-4 | https://cognitiveresearchjournal.springeropen.com/articles/10.1186/s41235-021-00286-4

* **(VR vs Real)** Tlauka, M., Anacta, V. J. A., & Wilson, C. (2024). Spatial learning using Google Streetview in an online wayfinding experiment. Research in Learning Technology, 32.

doi:10.25304/rlt.v32.3067 | https://journal.alt.ac.uk/index.php/rlt/article/view/3067/3093

* **(Applied/Wayfinding)** Golledge, R. G. (1999). Wayfinding behavior: Cognitive mapping and other spatial processes. Baltimore: Johns Hopkins University Press.
* **(Applied/Wayfinding)** Weisman, G. D. (1981). Evaluating architectural legibility: Wayfinding in the built environment. Environment and Behavior, 13(2), 189–204.

doi:10.1177/0013916581132002

* **(Developmental)** Newcombe, N. S., & Huttenlocher, J. (2000). Making space: The development of spatial representation and reasoning. Cambridge, MA: MIT Press.
* **(Developmental)** Piaget, J., & Inhelder, B. (1967). The child's conception of space. New York: Norton.
* **(Reviews/Meta)** Wolbers, T., & Hegarty, M. (2010). What determines our navigational abilities? Trends in Cognitive Sciences, 14(3), 138–146.

doi:10.1016/j.tics.2009.12.003

* **(Reviews/Meta)** Waller, D., & Nadel, L. (2013). Handbook of spatial cognition. Washington, DC: American Psychological Association.

doi:10.1037/14046-000

* **(Debates)** McNamara, T. P. (2003). How are spatial representations and navigation skills related? In E. van der Zee & J. Slack (Eds.), Representing, reasoning, and acting in the physical world (pp. 107–120). Oxford: Oxford University Press.
* **(Debates)** Foo, P., Warren, W. H., Duchon, A., & Tarr, M. J. (2005). Do humans integrate routes into a cognitive map? Map-versus landmark-based navigation of novel paths. Journal of Experimental Psychology: Learning, Memory, and Cognition, 31(2), 195–215.

doi:10.1037/0278-7393.31.2.195

* **(Methods)** Krukar, J., Bell, S., & Montello, D. R. (2023). Task-dependent sketch maps: Spatial Cognition & Computation, 23(1), 1–22.

doi:10.1080/13875868.2023.2170802 | https://www.tandfonline.com/doi/full/10.1080/13875868.2023.2170802

* **(VR vs Real)** Meilinger, T., Frankenstein, J., & Bülthoff, H. H. (2016). Learning to navigate in different environments: How virtual and real-world navigation relate. Psychonomic Bulletin & Review, 23(6), 1803–1812.

doi:10.3758/s13423-016-1035-5

* **(Neuro/Imaging)** Snider, J., Plank, M., Lynch, G., Halgren, E., & Poizner, H. (2013). Human cortical θ during free exploration encodes space and predicts subsequent memory performance. The Journal of Neuroscience, 33(38), 15056–15068.

doi:10.1523/JNEUROSCI.1710-13.2013 | https://www.jneurosci.org/content/33/38/15056.full

* **(Methods)** Pazzaglia, F., & De Beni, R. (2001). Strategies of processing spatial information in survey and route learning. Applied Cognitive Psychology, 15(6), 563–582.

doi:10.1002/acp.728

* **(Individual Differences)** Ishikawa, T., & Montello, D. R. (2006). Spatial knowledge acquisition from direct experience in the environment: Individual differences in the development of metric knowledge and the integration of separately learned places. Cognitive Psychology, 52(2), 93–129.

doi:10.1016/j.cogpsych.2005.08.002

* **(Applied/Wayfinding)** Spiers, H. J., & Maguire, E. A. (2008). The dynamic nature of cognition during wayfinding. Journal of Environmental Psychology, 28(3), 232–249.

doi:10.1016/j.jenvp.2008.02.001 | https://pmc.ncbi.nlm.nih.gov/articles/PMC2660842/

* **(Core Theory)** Epstein, R. A., Patai, E. Z., Julian, J. B., & Spiers, H. J. (2017). The cognitive map in humans: Spatial navigation and beyond. Nature Neuroscience, 20(11), 1504–1513.

doi:10.1038/nn.4656 | https://pmc.ncbi.nlm.nih.gov/articles/PMC6028313/