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Research Progress of Space Navigation Capability Based on Image Technology

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Abstract: Spatial navigation ability refers to the complex process of the human body building cognitive maps in the brain according to the external environment. It is crucial to study spatial navigation ability to understand human cognitive functions. With the advent of advanced neuroimaging technologies, such as positron emission tomography and magnetic resonance imaging, more and more evidence indicates that differences in the navigation ability of empty individuals are related to differences in brain structure and function. Functional magnetic resonance imaging (fMRI) and weighted magnetic resonance imaging (DTI) are two common methods of functional imaging and structural imaging. fMRI mimics animal experiments by measuring changes in signals related to blood oxygen levels in different regions of the brain, solving a major problem in human studies. On the other hand, structural connections are stable for short periods and are more suitable for studying differences in a single spatial navigation network without uniform training. Structural networks can be evaluated by DTI. DTI is highly sensitive to the Brownian motion of water molecules in voxels, especially in white matter. DTI results suggested that etiology is associated with disrupted fiber connections and decreased FA values, both of which occur in the prefrontal and prefrontal lobe-motor pathways. As far as we know, there is no systematic review of neuroimaging technologies related to spatial navigation functions. In order to fill this gap, in this review, we combine the structure and function of brain imaging and multimodal imaging technology and summarize the central brain regions and brain imaging features related to spatial navigation function. It provides a new method for selecting and dialing the spatial navigation ability of specific populations and a new idea for diagnosing clinical spatial navigation dysfunction.

Keywords: Spatial Navigation, sMRI, DTI, fMRI, Multimodal Brain Graph Network

1. Introduction

Spatial navigation is a complex cognitive ability that [1] targets new or familiar environments. From a survival perspective, it is one of the most basic behaviors of animals and humans. Individuals move around the environment by actively locating objects, interacting with objects, and remembering their location [2]. Like taxi drivers in London, we must remember the 25,000 streets of the city. For example, some people have no acquired brain damage or neurological problems in the general population, but they are challenging to locate in very familiar environments [3, 4]. What are the individual differences in spatial orientation ability?

Structural magnetic resonance imaging (sMRI) and Functional Magnetic Resonance Imaging (fMRI) are two commonly used medical imaging methods to study brain network connectivity, studying the human brain from a structural and functional perspective. Multimodal brain MR

imaging combines structural and functional network connectivity to study the interrelationships between brain structure and function and explore and identify connectivity across the brain network, providing complementary information. Therefore, multimode brain MR imaging may be necessary to study spatial navigation [5]. If we can explore the individual differences in spatial navigation function from multiple perspectives, this will be a significant breakthrough in imaging technology and cognition.

In this review, we present a detailed review of the imaging detection techniques that cause individual differences in spatial navigation capabilities and provide prospects for the future development of multimodal brain MR imaging.

2. Research on Spatial Navigation Capability Based on sMRI

The sMRI can reliably assess the relationship between gray matter volume and spatial navigation in various brain regions. A voxel-based morphological analysis is one of the most commonly used methods. A series of studies verified the correlation between total brain volume and spatial navigation task performance. Through voxel-based morphological analysis, they identified factors associated with total gray matter volume in spatial navigation, including the hippocampus (HIP), entorhinal cortex (EC), retrosplenial complex (RSC) [4]. The hippocampus (HIP) is involved in pathway integration and short-term memory, retrosplenial complex (RSC) is involved in spatial localization, and entorhinal cortex (EC) is involved in pathway integration [6]. Medial prefrontal cortex activity was also observed during pathway integration, interacting with the hippocampus for systemic [6] memory and execution functions. Clark [7] found a clear relationship between the volume of gray matter in the hippocampus and the ability to navigate in outer space, but not with general spatial navigation. The progressive study of the spatial navigation ability of taxi driver drivers in London by Maguire [8]. They found that the proper hippocampal gray matter posterior volume was more minor than healthy controls and London bus drivers compared to parahippocampal gray matter posterior volume. This could be due to a positive correlation between hippocampal gray matter volume and memory ability and memory, the ability to learn new environments, and the ability to gain new perspectives [9]. According to the results of different behavioral tests, what kind of people [4] classified subjects into high, medium, and low spatial orientation ability? The analysis found a negative correlation between gray matter volume in the right posterior hippocampus, low spatial orientation ability ($r= -0.35$, $p=0.048$), and high spatial orientation ($r = 0.39$, $p = 0.034$). Two different ideas about how these brain structures affect spatial navigation functions exist. One is that the hippocampus may only be part of a neural network connection that can provide specific processing aspects for brain networks to coordinate spatial navigation. Therefore, differences in spatial navigation behavior are related not only to the structure of the hippocampus but also to connections between the posterior pressurized cortex, endodermis, and hippocampus. A second possibility is that roughly dividing the gray matter volume of the hippocampus does not explain its relationship to navigation ability. After subdivision, navigational behavior is only related to gray matter volume in one part of the hippocampus [6, 10].

In addition to being associated with gray matter volume in each brain region, the cortical thickness measured in each brain region is positively associated with moderate cognitive ability; cortical thickness is measured in one dimension, while gray matter volume is measured in three dimensions. The volume of gray matter consists of two components: the thickness of the cortex and the cortical surface area of the cortical thickness [11]. A longitudinal analysis of 1,660 healthy subjects between the ages of 2 and 94 found a hemispheric and hemispheric difference in the thickness of the cerebellum cortex with age (the thickness of the right hemisphere is greater than the thickness of the left hemisphere), which is likely related to some temporal lobe structures, particularly the hippocampus and entorhinal cortex. This trend is consistent with spatial navigation ability in the entorhinal cortex and hippocampus as we age, further demonstrating the importance of the cerebral cortex and entorhinal cortex in spatial navigation in older adults [11].

3. Research on Spatial Navigation Capability Based on fMRI

The fMRI is one of the most commonly used methods to study the human brain. It measures brain activity by detecting local Blood Oxygen Level Dependence (BOLD) signals over time. Based on the BOLD signal analysis of the activated brain regions when performing specific tasks, connecting these regions can form brain activation maps, which is extremely useful for understanding the function of the human brain [12].

The fMRI has been widely used for inter-individual differences in spatial navigation and brain activity relationships, often isolating regions associated with spatial navigation, and correlating local changes in brain activity with behavioral tests of spatial navigation to identify brain regions [13] associated with individual spatial differences. Based on these studies, Kravitz [14] proposed the theory of the medial parietal-temporal cortex. They found that solid neural connections between the hippocampus, post pressure cortex, and parahippocampal gyrus suggest that these structures functionally interact with [15] in spatial cognitive tasks.

Auge [16, 17] found that subjects with high spatial navigation were more reliable in the spatial selection, possibly because subjects with high spatial navigation were more active in the posterior cortex and had more connections between the posterior cortex and the hippocampus. Sulpizio [18] has demonstrated that activation of the parahippocampal

gyrus is correlated with learning from unfamiliar surroundings. In contrast, the parahippocampal gyrus involves the body's rapid learning of specific connections between unfamiliar scenes. Sarah [19] assessed the global efficiency of the spatial navigation ability of the brain network, using graph theory analysis to assess fMRI data obtained at rest and using voxel methods to assess the global efficiency of the brain network, and found a significant relationship between the efficiency of the brain functional network and spatial navigation ability, particularly in medial parietal and temporal regions. Neubauer [20] found that brain regions activated at rest, as effective networks, matched parietal and medial temporal regions that were easily activated in people with high spatial orientation, suggesting that brain activity can be used to distinguish more and more people with high spatial orientation, even without the challenges of spatial orientation testing [21]. Because of the operability of the "efficient brain," scientists hope to conceptualize the biology of spatial navigation in the same way that machines or computers do, leading to more and more functional magnetic resonance imaging (fMRI) studies, such as electroencephalography (EEG), positron emission tomography (positron emission tomography (PET), regional brain flow analysis (fMRI), unified navigation and brain function networks: spatial navigation is a network characteristic of the brain. It is associated with neural efficiency [11, 22].

Recently, a new neurocognitive model of brain navigation has been proposed by a group of scholars that, in addition to the frontal, frontal, temporal, anterior, parietal, and occipital regions, enables clear structural and functional differentiation in areas associated with brain navigation [23, 24].

4. Research on Spatial Navigation Capability Based on DTI

DTI is an advanced MR imaging modality that explores and describes structural information in living brain tissue by quantifying the random diffusion of water molecules. DTI can detect the integrity of white matter fiber tracts and determine neural connection connectivity pathways through microscopic measures such as fractional anisotropy (fractional anisotropy, FA), Axial Diffusivity (AD), and radial diffusion coefficient (Radial Diffusivity (Radial Diffusivity, RD), which conventional MRI cannot do [25, 26].

FA is the most widely used metric in DTI and is extremely sensitive to specific microstructure changes in tissue in brain regions, especially axons [27]; In tissues such as cerebrospinal fluid, which is unrestricted or very limited, water molecules are random and uniform in all directions, and the fiber wall, such as the long axis of the fiber, limits the diffusion of water molecules along the white fiber bundle. DTI, combined with biophysical modeling, can measure the tissue and structural characteristics of fiber bundles that transmit signals between different brain regions [28]. Compared to conventional sMRI detection changes, DTI detection of brain microstructural changes in the brain can predict future neuronal degeneration; for example, detecting microstructural changes in the hippocampus of mild cognitive impairment can help predict the future of Alzheimer's disease [29].

FA is widely used in the study of individual spatial navigation ability. Initially, Iaria et al. combined DTI imaging techniques and spatial navigation behavior testing to demonstrate a positive correlation between FA values in the right hippocampus and spatial orientation ability. Chou [30] investigated the relationship between spatial orientation ability and sex based on DTI. They found that females showed more excellent FA in the frontooccipital tract, corpus callosum, and paraneurysm. In contrast, males showed great FA in the bilateral inner sac, medial frontal gyrus, spindle, hippocampus, brain island, posterior central gyrus, frontal lobe, and temporal lobe. Furthermore, male hippocampal white matter showed more great FA, and females showed more fantastic FA in the parahippocampal gyrus, explaining males' superior spatial orientation and inferior spatial memory ability [31]. Recently, Ramanoel, through the longitudinal comparison of the whole brain structure network connection study, found that the elderly and the spatial navigation network white matter integrity generally decline, hook tract (connecting the hippocampus and medial prefrontal cortex) FA reduction, speculated that the hook tract FA reduction causes the cause of the elderly spatial orientation test [32].

5. Current Status of Multimodal-Based Spatial Navigation Capability

Brain regions are not independent in terms of structural and functional connections. These two connectivity modes interact to form a neural network that extracts, integrates, and stores spatial information to guide behavior [33]. Multimodal brain imaging research combines different imaging modalities to study brain connectivity clusters, integrate different types of data or image modalities, analyze the nonlinear relationship between different patterns, and derive implicit correlations of the same functions in these image modalities [27] with structure-function relationships being the most typical of these studies. Structural connections include anatomical morphological connections and white matter fiber bundles; denotes their morphological parameter connectivity, such as gray matter mass connections and cortical thickness connections, to quantitatively measure relevant changes in brain structure in different regions [34]; and white matter fiber connectivity characterizes fiber network to estimate matter pathway [35]. Structural connections are stable over a shorter period but may vary over longer intervals, such as after long training sessions. Functional connectivity is based on the correlation of BOLD signal time courses between network nodes, and resting-state fMRI is currently the most commonly used method to assess functional brain networks. Functional connections are time-dependent, and connectivity patterns can change in [36] milliseconds. If we can explore the individual differences in spatial navigation function from multiple

perspectives, this will be a breakthrough in imaging technology and cognition.

With the development of imaging technology, more and more attention has been paid to studying the relationship between brain structure and function using multimodal imaging methods. Koon [37] combined structural properties of the brain with functional magnetic resonance imaging and behavioral testing of dormant states, suggesting that improved navigation is related to the small-universe and modular nature of navigation networks, where multiple distributed brain regions work essentially as a network, which underpins individual differences in navigation abilities. Zhu [38] described three methods for combining DTI and fMRI: 1. FMRI assisted with DTI such as fMRI guided fiber tracking or fMRI based DTI result verification; 2. DTI assists with fMRI, such as functional connectivity analysis based on DTI data; 3. Joint DTI / fMRI fusion, such as obtaining results from each model and combining them using statistical analysis. However, this combination has not yet been demonstrated in applying spatial orientation ability. The study of individual differences in navigation mainly focuses on the local variation of anatomical and functional characteristics of navigation regions. For example, the volume of gray matter in the hippocampus, parahippocampal cortex, and prefrontal lobes are correlated with navigational performance, and functional activity in the hippocampus and parahippocampal cortex is correlated with navigational behavior. A newly proposed model also suggests that non-aggregated network processes involving multiple interacting brain regions can better describe the neural underpinnings of spatial navigation. More specifically, more vital whole-brain network interaction in spatial memory retrieval was associated with successful retrieval and better performance [39]. Most human cognitive functions do not depend on a single brain region but on the coordination of several anatomically and functionally related regions. As a result, in addition to assessing local changes in specific brain regions, more attention is being paid to studying entire networks.

In summary, various connectivity methods provide essential information about human brain tissue at the network level. Studying connections and interactions between brain regions provides additional knowledge that cannot be obtained by regional analysis alone.

References

[1] Maria Luisa Rusconi, Giulia Fusi, Crepaldi M. Spatial Navigation [J]. Encyclopedia of Behavioral Neuroscience, 2022, Volume 2 (2nd edition): 553-560.

[2] Wolbers T, Hegarty M. What determines our navigational abilities? [J]. Trends in Cognitive Sciences, 2010, 14 (3): 138-146.

[3] Rusconi M L, Fusi G, Stampatori C, et al. Developmental Topographical Disorientation With Concurrent Face Recognition Deficit: A Case Report [J]. Frontiers in Psychiatry, 2021, 12.

[4] He Q, Brown T I. Heterogeneous correlations between hippocampus volume and cognitive map accuracy among healthy young adults [J]. Cortex, 2020, 124: 167-175.

[5] Liu L, Wang Y, Wang Y, et al. An enhanced multi-modal brain graph network for classifying neuropsychiatric disorders [J]. Medical Image Analysis, 2022, 81: 102550.

[6] Chrastil E R, Sherrill K R, Aselcioglu I, et al. Individual Differences in Human Path Integration Abilities Correlate with Gray Matter Volume in Retrosplenial Cortex, Hippocampus, and Medial Prefrontal Cortex [J]. eNeuro, 2017, 4 (2): 316-346.

[7] Clark I A, Monk A M, Hotchin V, et al. Does hippocampal volume explain performance differences on hippocampal-dependant tasks? [J]. NeuroImage (Orlando, Fla.), 2020, 221: 117211.

[8] Maguire E A, Gadian D G, Johnsrude I S, et al. Navigation-related structural change in the hippocampi of taxi drivers [J]. Proc Natl Acad Sci U S A, 2000, 97 (8): 4398-4403.

[9] Sherrill K R, Chrastil E R, Aselcioglu I, et al. Structural Differences in Hippocampal and Entorhinal Gray Matter Volume Support Individual Differences in First Person Navigational Ability [J]. Neuroscience, 2018, 380: 123-131.

[10] Weisberg S M, Newcombe N S, Chatterjee A. Everyday taxi drivers: Do better navigators have larger hippocampi? [J]. Cortex, 2019, 115: 280-293.

[11] Hasan K M, Mwangi B, Cao B, et al. Entorhinal Cortex Thickness across the Human Lifespan [J]. Journal of Neuroimaging, 2016, 26 (3): 278-282.

[12] Karakasis P A, Liavas A P, Sidiropoulos N D, et al. Multisubject Task-Related fMRI Data Processing via a Two-Stage Generalized Canonical Correlation Analysis [J]. IEEE Transactions on Image Processing, 2022, 31: 4011-4022.

[13] Sulpizio V, Boccia M, Guariglia C, et al. Functional connectivity between posterior hippocampus and retrosplenial complex predicts individual differences in navigational ability [J]. Hippocampus, 2016, 26 (7): 841-847.

[14] Kravitz D J, Saleem K S, Baker C I, et al. A new neural framework for visuospatial processing [J]. Nature Reviews Neuroscience, 2011, 12 (4): 217-230.

[15] Focus on spatial cognition [J]. Nature Neuroscience, 2017, 20 (11): 1431.

[16] Auger S D, Mullally S L, Maguire E A. Retrosplenial cortex codes for permanent landmarks [J]. PLoS One, 2012, 7 (8): e43620.

[17] Auger S D, Maguire E A. Assessing the mechanism of response in the retrosplenial cortex of good and poor navigators [J]. Cortex, 2013, 49 (10): 2904-2913.

[18] Sulpizio V, Boccia M, Guariglia C, et al. Neural Codes for One's Own Position and Direction in a Real-World "Vista" Environment [J]. Frontiers in human neuroscience, 2018, 12: 167.

[19] Banker S M, Ramphal B, Pagliaccio D, et al. Spatial Network Connectivity and Spatial Reasoning Ability in Children with Nonverbal Learning Disability [J]. Scientific Reports, 2020, 10 (1).

[20] Murias K, Slone E, Tariq S, et al. Development of spatial orientation skills: an fMRI study [J]. Brain Imaging and Behavior, 2019, 13 (6): 1590-1601.

[21] Arnold A E G F, Protzner A B, Bray S, et al. Neural Network Configuration and Efficiency Underlies Individual Differences in Spatial Orientation Ability [J]. Journal of Cognitive Neuroscience, 2014, 26 (2): 380-394.

[22] Javadi A, Patai E Z, Marin-Garcia E, et al. Prefrontal Dynamics Associated with Efficient Detours and Shortcuts: A Combined Functional Magnetic Resonance Imaging and Magnetoencenphalography Study [J]. Journal of cognitive neuroscience, 2019, 31 (8): 1227-1247.

[23] Ohnishi T, Matsuda H, Hirakata M, et al. Navigation ability dependent neural activation in the human brain: An fMRI study [J]. Neuroscience Research, 2006, 55 (4): 361-369.

[24] Watson T C, Obiang P, Torres-Herraez A, et al. Anatomical and physiological foundations of cerebello-hippocampal interaction [J]. Elife, 2019, 8.

[25] Benner T, Wang R, Wedeen J V. Diffusion Tensor Imaging of the Brain [J]. Springer Berlin Heidelberg, 2007, 4: 316-329.

[26] Little G, Beaulieu C. Automated cerebral cortex segmentation based solely on diffusion tensor imaging for investigating cortical anisotropy [J]. NeuroImage, 2021, 237: 118105.

[27] den Heijer T, der Lijn F V, Vernooij M W, et al. Structural and diffusion MRI measures of the hippocampus and memory performance [J]. NeuroImage, 2012, 63 (4): 1782-1789.

[28] Wandell B A. Clarifying Human White Matter [J]. Annual review of neuroscience, 2016, 39 (1): 103-128.

[29] Iaria G, Lanyon L J, Fox C J, et al. Navigational skills correlate with hippocampal fractional anisotropy in humans [J]. Hippocampus, 2008, 18 (4): 335-339.

[30] Chou K, Cheng Y, Chen I, et al. Sex-linked white matter microstructure of the social and analytic brain [J]. NeuroImage, 2011, 54 (1): 725-733.

[31] Sex Differences in the Brain: from Genes to Behavior [J]. Oxford university press, 2007.

[32] Ramanoël S, York E, Le Petit M, et al. Age-Related Differences in Functional and Structural Connectivity in the Spatial Navigation Brain Network [J]. Frontiers in Neural Circuits, 2019, 13.

[33] Hao X, Huang Y, Li X, et al. Structural and functional neural correlates of spatial navigation: a combined voxel-based morphometry and functional connectivity study [J]. Brain and Behavior, 2016, 6 (12).

[34] Fujita K, Eidelberg D. Imbalance of the direct and indirect pathways in focal dystonia: a balanced view [J]. Brain, 2017, 140 (12): 3075-3077.

[35] BENNETT I J, RYPMA B. Advances in functional neuroanatomy: A review of combined DTI and fMRI studies in healthy younger and older adults [J]. Neuroscience and biobehavioral reviews, 2013, 37 (7): 1201-1210.

[36] Hahn A, Lanzenberger R, Kasper S. Making Sense of Connectivity [J]. The international journal of neuropsychopharmacology, 2019, 22 (3): 194-207.

[37] Kong X, Wang X, Pu Y, et al. Human navigation network: the intrinsic functional organization and behavioral relevance [J]. Brain Structure and Function, 2017, 222 (2): 749-764.

[38] Zhu D, Zhang T, Jiang X, et al. Fusing DTI and fMRI data: A survey of methods and applications [J]. NeuroImage, 2014, 102: 184-191.