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Advances in Space Navigation Reference System Research

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Abstract: Spatial navigation is a process in which the human body builds a complex cognitive map based on its own position and external environment, so as to realize correct navigation. Space navigation capability is closely related to flight safety. In recent decades, the air force at home and abroad has been researching and practicing on flight space disorientation, but the serious flight accidents caused by flight space disorientation are still very serious. Eocentric and allotypic central reference frames are commonly used reference frames in spatial navigation. Most current studies believe that humans can use these two reference frames to extract spatial information, perform route planning, and thus navigate to the correct destination. With the advent of advanced neuroimaging techniques, more and more studies have found that humans activate specific brain regions when using different spatial navigation reference frames, and that there are specific neural conduction pathways for spatial navigation information. However, there is no systematic review of the activation and nerve conduction of spatial navigation. Therefore, this paper integrates the spatial navigation reference frame with the neuroimaging technology, and summarizes the activation and information transmission of the brain regions corresponding to the spatial navigation reference frame, so as to explore the relationship between the human navigation and the spatial reference frame. Based on the existing research, the use of appropriate means, such as resting-state fMRI, can provide a basis for selecting suitable people to engage in spatial navigation related work such as flight, and also has practical significance for developing personalized spatial navigation ability training programs for pilots.

Keywords: Spatial Navigation, Spatial Reference System, Allocentric, Egocentric

1. Introduction

Spatial navigation is the ability to construct complex cognitive maps based on one's own location and the external environment, including multiple complex cognitive processes such as visual perception, spatial orientation, memory, planning and decision making, which are essential for maintaining daily life [1-2]. A spatial reference system is a framework for organisms to obtain spatial information with reference to their own position in relation to external objects or between objects. Most studies now agree that humans can use two frames of reference to extract spatial information for proper navigation, one relying on the position of self or a part of the body relative to the environment, called egocentric, which is often expressed as front-to-back, and the other

relying on the relative position of objects to each other in the environment, called homocentric, which is often expressed as east-west, north-south [3-4]. A person can use either of the two reference systems to gather information, plan a route, make a correct turn and travel the correct distance toward a goal in a different space. The brain regions that are activated when using different reference systems differ, and the study of the brain activation regions associated with different reference systems may help to understand the role of these brain regions in spatial navigation, and may be important for further understanding of human spatial navigation abilities and treatment of spatial navigation-related diseases. Different reference systems have their own specific roles in navigation and are implemented through different information conduction pathways, and understanding the conduction of

acquired spatial information in the brain is important for understanding spatial navigation abilities.

2. Background

The idea of using "cognitive maps" to represent spatial information and navigate through the environment was first proposed by Tolman in 1948, but the corresponding neural mechanisms have never been discovered. [5] The corresponding neural mechanisms were never discovered. It was not until 1957 that Brenda Milner suggested that the hippocampus and its adjacent brain regions play an important role in spatial memory and may be a major component of cognitive maps. [6] In 1971, John O'Keefe discovered through electrode recording experiments in the hippocampus that a class of cells existed in the hippocampus that always fired when rats arrived at a specific location, which he named positional cells and suggested that the hippocampus was an important vehicle for spatial cognitive maps. In 1990, Jeffery Taube et al. found that when the head orientation of rats changed, certain specific nerve cells were activated. When the environment was rotated, the preferred direction of these cells was also deflected by the same angle. He called such cells head-oriented cells. [7] In 2008, May-Britt MoserEdvard Mose and his wife discovered the presence of grid cells discharging in a hexagonal grid in an area near the hippocampus called the entorhinal cortex. It was proposed that the grid cells, the positional cells and the head-directed cells could work together to create a coordinate system for spatial navigation, adding a reference system to the hippocampal "cognitive map". [8] This is a reference system for the hippocampal "cognitive map". Today, more and more cognitive studies are focusing on the role of reference systems in spatial navigation, trying to explain how people can flexibly use different spatial reference systems to achieve correct navigation.

3. General Space Navigation Related Brain Areas

There are regions in the brain associated with spatial navigation, and it has been found that functional magnetic resonance imaging (fMRI) activation areas are consistent with the firing of spatial cells in the brain and can be used to identify activation in different brain regions during spatial navigation [9]. These regions are mainly found in the medial temporal lobe (MTL) and include the hippocampus (HIP), parahippocampal gyrus (PHG) and entorhinal cortex (EC) [10, 11]. The thalamus (THAL), posterior squamous cortex (RSC), occipital region (OPA), prefrontal cortex (PFC) and parietal cortex have also been found to be associated with spatial navigation [12-16]. There are many other studies on spatial navigation-related activating brain regions. The cerebellum, in combination with the contralateral hippocampus and the medial prefrontal or medial parietal cortex, is coactivated with the hippocampus in spatial navigation [17].

These activated brain regions have their own distinct functions and they work together to ensure proper spatial navigation. The hippocampus is located in the medial temporal lobe and is surrounded by the entorhinal, parahippocampal and periorbital cortices, which are part of the Papez circuit and are central to the reception of multiple sensory information afferents [10-11, 14]. The entorhinal olfactory cortex is the cerebral cortex that connects the hippocampus to the parahippocampal system and is the main source of information input to the hippocampal cortex [14]. The hippocampus and medial entorhinal cortex are key brain regions for spatial learning and memory, and they work synergistically primarily to construct, store, and remember statements about locations in the environment and to retrieve them from fragments when needed to aid in flexible navigation [14, 18]. Similar activation patterns exist in the parahippocampal area (PPA), the posterior squamous cortex (RSC) and the occipital area (OPA). the PPA is involved in processing visually relevant information and analyzing geometric features of landmarks, especially boundaries, as well as local elements. the RSC is associated with spatial memory and helps one determine location and orientation in the external world by anchoring in a reference system of local environmental features, and the OPA processes visual scenes that are important for landmark recognition. These parts may join forces to build a coherent and detailed representation of the scene, help identify features of the local environment, and integrate these features to determine a person's position and orientation in the environment [16, 19, 20]. The thalamus (THAL) may integrate visual and body-based orientation cues as a way to encode self-centered spatial information that provides information about the direction of navigational movements [15]. The parietal cortex, in turn, is associated with egocentric spatial navigation [12]. The prefrontal cortex (PFC) is associated with executive function and goal-directed behavior. [13].

4. Brain Areas Associated with Different Spatial Reference Systems

Various experimental designs have been used in neuroimaging and electrophysiological studies to investigate the neural correlates of spatial reference systems. Egocentric correlates exist in the brain, and these cells are abundant in the hippocampus and parahippocampal gyrus (PHG) and support egocentric navigation by encoding the distance between reference points and themselves [21]. Another fMRI-related task design study showed that although the parietal frontal cortex is activated in both reference systems, it is more activated in the egocentric task and may be involved in memory-related encoding and conversion to signals such as motor planning in spatial navigation, and this study also showed more significant egocentric activation in the superior and inferior occipital gyrus [22] In addition, the striatal system and the hippocampus have been shown to be more active. In addition, there are complex interactions between the striatal and

hippocampal systems in spatial navigation, and the caudate nucleus is also activated in egocentric navigation [23]. Other areas mentioned in relation to egocentric navigation include the cerebellum, posterior cingulate cortex, amygdala, right superior and middle occipital gyrus, middle and superior frontal gyrus, precuneus (PCC) and superior parietal lobe. [24].

Homozygous centers depend on the right hippocampus and, more specifically, on neural networks involving positional cells (hippocampus) and grid cells (internal olfactory cortex) to participate in the formation of homozygous center reference systems and perform related navigation tasks by elaborating spatial relationships [25]. In addition to the increased activity of posterior pressure cortex, posterior superior parietal cortex, and anterior cuneus in homozygous central navigation, the anterior cuneus and posterior pressure cortex appear to form a network of brain regions that are associated with the retrieval of object locations in stable reference systems [25]. Another study found significant activation in visual cortex in a homunculus-centered task, with more significant activation signals observed in the inferior temporal gyrus and inferior occipital gyrus [22]. There were also correlations between the homunculus center and the lingual gyrus, right middle temporo-occipital gyrus, left superior temporal gyrus, and frontal cortex [24].

The RSC and PCC connect the parietal and medial temporal structures and play an important role in the interconversion of the homologous allocentric reference system to the egocentric reference system, and four regions of the parietal and frontal cortices (right anterior cuneus, bilateral dorsal premotor cortex and the right anterior region) are also involved in this homozygous to egocentric transition. [22, 26]. Of course, the brain regions activated by the two reference systems are not completely separated, especially in the bilateral PPA and the right RSC, which show a common brain area activation [27].

The relationship between the two reference systems and their associated brain regions was also confirmed in aging and in some disease-related decreases in spatial navigation ability. Lesions of the right precuneus and angular gyrus and atrophy of the parietal cortex lead to impairments in egocentric orientation. Lesions in the posterior pressure cortex, which is associated with both egocentric navigation and transitions between the two reference systems, may lead to a disorder called heading disorientation [24]. Patients with mild cognitive impairment (MCI) and Alzheimer's disease (AD) have more severe decreases in spatial navigation than normal older adults, particularly greater difficulty with homozygous centric representation, which may be associated with decreased neuronal density in hippocampal areas CA1 and CA3 involved in homozygous centric reference system representation [3]. The impaired spatial processing of homozygous centers often exhibited by patients with Williams syndrome (WS) shows consistency with damage to their parietal and extraoccipital cortices and impairment of the hippocampus and brain regions interconnected with the hippocampus [28].

5. Functions of Different Reference Systems

5.1. Role in Navigation

Achieving proper navigation involves multiple processes such as visual perception, route planning, memory and decision making, and homozygous and egocentric centers may play a role in different processes of navigation. In the case of visual perception, the information transmitted by the egocentric and allogeneic centers is consistent with the "perception-action" model of vision, where the allogeneic center reference system is primarily used for visual perception, identifying itself and its environment and understanding its position in the environment and making plans based on perception, while the egocentric center plays a role in The ego center plays a role in visuomotion, providing control of motor behavior based on visual information. [29].

In the context of learning planning, relevant task design studies have used scene- and orientation-related pointing (SOP) tasks to analyze egocentric performance. The relative orientation judgment (JRD) task was used to analyze the performance of heterocentricity. It was found that path learning tends to represent the environment through scene- and orientation-related trajectories and is largely associated with egocentricity. Map learning primarily uses interrelationships among landmarks to represent and uses more homo- and heterocentric knowledge [30, 31].

There are also different functions in goal-directed arrivals; the information obtained in egocentric terms is faster and can provide more accurate information and account for a greater proportion of real-time motion, but egocentric information decays quickly, so memory guidance will rely more on the information provided by the homologous heterocentric reference system, for example when we need to make a relative position of an object based on our memory of the position of previously encountered objects judgments [32].

In addition, spatial navigation takes place at different scales, including small-scale space (e.g., "visionary space") and large-scale space (e.g., "ambient space"), where one can see the entire space from a single perspective, and ambient space, where one must space where people have to integrate spatial information from different perspectives during movement. [33] The environmental space is the space from which one must integrate spatial information from different perspectives during movement. In visionary space, more egocentric reference systems are used, while in environmental space, more homogeneous heterogeneous reference systems are used because viewpoints alone do not solve the problem well. [34]. However, current research shows that in most cases involves the interplay and transformation of these two reference systems, and the use of one reference system alone can bring great errors.

5.2. Information Transmission Channel

The correct conduction of information in the brain is crucial to achieve proper navigation. Past studies have suggested that

information conduction in different reference systems is independent of each other, following a 2-stream model of vision, implemented in different cortical pathways [35]. Action and real-time movements are processed in a dorsal stream from primary visual cortex to posterior parietal cortex using an egocentric reference system. Perceptually and memory-guided movements are processed using a homozygous allograft-centered reference system in a ventral stream projecting from primary visual cortex to occipitotemporal cortex [35]. Recent studies have shown that the ventral stream processes spatially relevant information not only in the homologous allogeneic center but also in the egocentric frame of reference, and that the egocentric frame is also related to memory guidance [36]. Dorsal streams can also use homozygous allo-centric frames of reference, and humans can use allo-centric information in both real-time arrival and memory guidance [37, 38]. These studies confirm that these two conduction systems are not completely independent and that the human brain can flexibly combine information from both egocentric and homozygous allo-centric reference systems in localizing spatial targets depending on the context [30, 39, 40].

It is now thought that information from homozygous reference systems may be converted to egocentric in the brain, enter the egocentric conduction system, and conduct the same information as egocentric information to eventually make the command to perform the action [41]. Self-centered visual target information enters from early visual cortex via dorsal occipital cortex into higher cortical areas of posterior parietal cortex (PPC) and frontal cortex, including precuneus, posterior intraparietal sulcus (pIPS), middle posterior parietal sulcus (mIPS), angular gyrus (AG), and dorsal premotor cortex (PMd). The conversion from visual to motor information is performed in these areas, and the resulting motor information is then sent to the cortical primary motor area (M1) of the precentral gyrus to make planning. In contrast, information from congruent centers may be converted to egocentric information in parietal and frontal cortical areas, including precuneus, PMd, and the premotor assistance area (SMA), and then conduct the same as egocentric information and make the executed action [29]. These two conduction pathways seem to be consistent with the previous view that self-centered conduction is faster, whereas allo-centered conduction has better performance in delayed memory-related navigation, and that the combination of the two ensures the best navigation experience. It has also been argued that all spatial representations are ultimately egocentric [31]. This view is subject to further validation, but even so, achieving proper environment perception and navigation requires reference to the external environment.

6. Summary and Outlook

Spatial navigation is an important cognitive ability that is one of the early indicators for assessing aging and can predict the onset of dementia syndromes in aging, but heterocentric and egocentric information is often underappreciated in the development of assessment protocols [42]. Based on the development of neuroimaging techniques, further study of how the brain represents spatial reference systems and the construction of different reference system information transmission pathways based on this would be beneficial for early assessment of spatial navigation decline. There are many clinical diseases that lead to the decline of spatial navigation ability, such as Alzheimer's disease and mild cognitive impairment, and the decline of navigation ability is different in different diseases. The study of brain regions associated with different reference systems can help to understand these diseases more clearly, and is also relevant for the development of more appropriate rehabilitation programs at a time when there is an increasing use of virtual reality technologies to help patients recover their spatial navigation abilities. At present, there is still no unified view on how information from different reference systems is transmitted in the brain, how they are converted to each other, and how the brain makes decisions when two types of information conflict, and further research is needed.

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