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Spatial Memory

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Synonyms

Spatial cognition; Spatial abilities; Spatial navigation; Cognitive map; Way finding

Definition

From an evolutionary perspective, spatial memory is crucial to foraging and reproduction but, at the same time, multiplies the risks of getting lost, being killed or consumed by other animals (predation). Thus, survival of mobile species depends on their ability to reach a feeding location, return home quickly and safely, find shortcuts and avoid dangerous places. These basic behaviors are crucial for successful interactions with the environment and call upon effective spatial navigation skills.

The capacity to move through space may appear to be a very simple behavior consisting in maintaining a body trajectory from a place to another. However, getting from place to place is more than a body displacement. Indeed, ►navigation is an action oriented by a goal that at least involves knowing where I am and where I go. Such knowledge requires the encoding and the gathering of multimodal information concerning our body position relative to the position of other objects. This ability – called spatial memory – is now considered as analogous to human ►episodic memory (memory of personal, experiential events) since both rely on the coding, storing and retrieving of events in a spatio-temporal context (e.g. [1]).

Characterizing spatial orientation and spatial memory skills requires an understanding of how cognitive and neural mechanisms underlie adaptive behavior to environmental requirements. The following section summarizes the basic concepts and findings issued from this research effort.

Characteristics

Reference Frames

Fixing and maintaining a trajectory from place to place is done through the establishment of a relationship between subject and object. This relationship is commonly categorized in egocentric and ►allocentric reference frames.

Frameworks centered on the subject (e.g. body parts such as head, trunk, arm, or receptor surfaces such as retina) are called ►egocentric reference frames. Such ►reference frames allow the subject to directly estimate the position of an object relative to their own body. However, the egocentric bearing is not invariant with respect to the subject's orientation and position. Frameworks centered outside of the body, on a fixed point in the environment (e.g. mountain, corner of a room or individual object), are allocentric reference frames. Such reference frames provide two main advantages: (i) to be invariant with respect to the subject's position and orientation in the environment, and (ii) to represent the relative location of objects independently from the subject's viewpoint.

Although these two systems of knowledge allow navigation, their respective weight depends on learning. Indeed, if a local or egocentric frame is immediately available even for naive subjects, a relational or allocentric frame depends on the development of spatial skills.

Spatial Navigation Strategies

Spatial cognition is assumed to be a hierarchical set of reference frameworks -or maps- containing landmarks, routes, locations, and configurations that integrate relative information about landmarks, routes and locations in a coherent structure. It is based on what information is perceived, represented and processed by the subject to solve navigation tasks. Adaptive spatial behavior relies on the flexibility in the use of reference frames depending on the problem to be solved. This involves the capability to choose among different cognitive possibilities that are referred to as spatial strategies.

A four-level hierarchy of ►spatial navigation strategies based on a large range of researches [e.g. 2–4] can be resumed as following (fig. 1):

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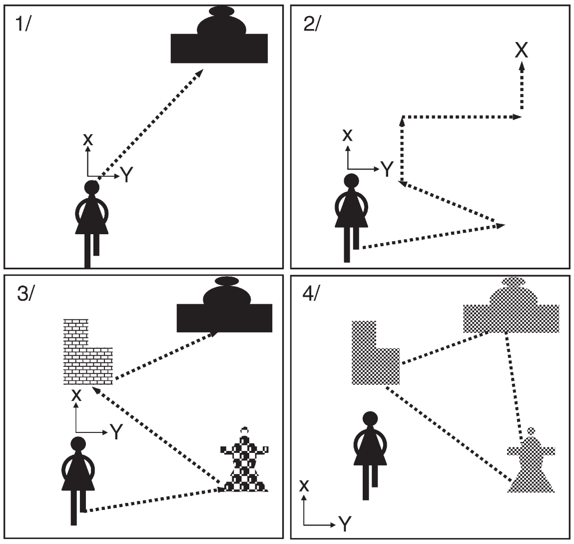

Spatial Memory. Figure 1 Egocentric and allocentric reference frames. The egocentric reference frame (1 taxon, 2 praxis and 3 route navigation strategies) is centered on the subject (x and y arrows) whereas the allocentric reference frame is centered outside the body (4 relational or configural strategy).

- ►Taxon navigation strategy (level 1) is used when a location coincides with a conspicuous cue. In such case, approaching a goal location is easy if the latter is either directly visible or identified by a visible cue. Such behavior does not require spatial memory per se, but rather an association between the cue and the goal to initiate a guided movement.
- ►Praxis navigation strategy (level 2) is used when a subject can navigate towards a hidden goal by executing a specific motor sequence acquired by extensive training. For example, if the goal is never moved and the individual always starts at the same location and with the same orientation, it can easily learn the appropriate of taxon and sequence of movements leading to that goal.
- ►Route navigation strategy (level 3) is a more complex strategy where the subject has learnt to associate a direction of movement to each sensory view. This strategy is appropriate, when a goal is identified by a sequence of specific sensory cues. Then, instead of single cue guidance, the subject can use more elaborate chaining sequences of taxon and praxis strategies
- Relational or configural strategy (►Relational or configural navigation strategy) (level 4) is based on the coding of relations between attributes of the environment into an internal ►spatial representation. An important property of this representation is that it offers a flexible spatial behavior adapted to each situation. In a familiar environment for example, subjects can get to a place from different starting points, as well as choose a novel path when the usual one is unavailable.

To summarize, taxon, praxis and route navigation strategies are based on an egocentric frame of reference depending on sensory-action associations where the position of the goal is directly estimated with respect of body-based references. They are inflexible in the sense that they prevent the taking into account that different paths may join the same place. Relational or configural strategy is based on an allocentric reference frame (a spatial representation of the environment) where the relationships between stimuli are maintained invariant with respect to the subject's position.

Multimodal Sensory Information

The establishment of an efficient spatial representation relies on the integration of multimodal sensory information that has been divided into allothetic (►allothetic information) and idiothetic (►idiothetic information) categories.

Stimuli provided by environment-like visual, olfactory, sound, tactile stimuli- are allothetic signals providing spatial information to the subject. Orientation based on allothetic stimuli allows, for example, identifying a place through visual features of a particular object.

Stimuli provided by the body-like vestibular, proprioceptive and motor command efferent copies are idiothetic signals providing information about continuous changes of the subject position and orientation. Orientation based on idiothetic stimuli allows deriving the subject's current position in relation to a starting position by the integration of its angular and linear displacements. This ability to keep track of spatial location relying on self-motion information is referred to as ►path integration (e.g. [5]). Although path integration is available in all types of environments (unknown, absence of landmarks, darkness), its use is limited by its vulnerability to cumulative non-systematic errors over distance. However, when allothetic landmarks are available, path integration can be reset in order to maintain orientation.

Therefore, prevention of ambiguous information relies on the combination of different sensory information that is encoded within different reference frames. Thus, multisensory integration requires the integration of different reference frames into a unified spatial framework, and the hippocampus appears to be the brain region in charge of such process.

Spatial Coding and Hippocampal Brain Area

Studies of the hippocampal formation occupy a central position in the advance of theories concerning episodic and spatial memory. Early experimental evidences for

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location-sensitive neurons in the rat hippocampus called "place cells," and the "►cognitive map theory" promoted by O'Keefe and Nadel [6] make out the hippocampus as the brain area that mediates allocentric spatial coding. Hippocampal function appears to be required in spatial representation, path integration and exploration (e.g. [7]) concerning the encoding of trajectories, single cell recording data suggests that the hippocampus represents the animal's position in the context of a trajectory through space while the enthorinal cortex represents regularities across different trajectories that could allow for generalization across experiences. Apart from the hippocampal area, the posterior parietal cortex seems to be in charge of egocentric spatial coding that represents body location related to subject's environment. It has been hypothesized that the multiple egocentric representations from sensory receptors and motor effectors converge from the parietal cortex onto the hippocampal formation where they are translated into an allocentric spatial reference frame. This postulate is based on findings showing strong neuronal connections between the posterior parietal cortex and the hippocampal formation, and between the hippocampal formation and the parahippocampal region. Thus, it could be postulated that spatial memory and flexible navigation requires the combination of both egocentric and allocentric components of the task, which is based on the cooperation of parietal cortex and the hippocampus respectively. This hypothesis is supported by a large convergence of data from experimental psychology, comparative anatomy and field research (for reviews see for example [8–10]).

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