Consciousness and Spatial Navigation

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One of the essential gifts that humans possess is the ability to orientate, a feature that is also included as a “survival pack” for animals. As birds can fly back to their nests after a long journey for food, we humans are also able to make our way back home after a long day of work. Our brain has the ability to capture spatial cues and store them into mini-neural circuits so as to guide us to the desired place. What would life be like if individuals had absolutely no idea about where they were, how to reach a certain place for food, or something as simple as going back home? If you were asked to describe your way back home, you would most probably point in the direction of your apartment and use various visually striking landmarks (such as corner shops, water fountain, or even traffic lights) to serve as cues to further complement the explanation. These landmarks form a conscious repertoire for reaching a desired place. However, what if that question was asked when you had high blood alcohol content? At that stage, your conscious level drops, and so is your ability to recall those familiar visual cues from your working

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memory. You will be disorientated and your route back home will not be as smooth as when you are sober. In other words, both intrinsic and extrinsic factors can affect the human body and the inner balance of the human mind, thereby disturbing our ability to navigate. Our conscious experience of navigation indeed emerges from processing within complex brain circuitries.

Neural Substrates for the Recognition of Spatial Orientation

Accurate spatial navigation requires an awareness of a location and its relationship with other cues, that is, an internal map of the environment. The map consists of three elements: what items are present in the environment, where are they in relation to each other, and where we are in relation to these items. The generation and operation of such maps require the integration of multiple neural systems in our brains.

Recent studies have unfolded mechanisms underlying cognitive spatial navigation in animals. Gene knockout and labyrinth-lesion studies provide evidence that information from the vestibular system is essential for accurate spatial orientation and navigation in laboratory animals and humans (Schautzer et al. 2003; Stackman et al. 2002; Stackman and Taube 1997; Wallace et al. 2002; Yoder and Taube 2009). The ability of animals to acquire a sense of direction and spatial memory depends on the capacity of the vestibular system to process sensory inputs arising from the semicircular canals and the otolith organs within the inner ear. An internal spatial reference is actually present in the brain for coding the spatiotemporal signals and this map emerges during the course of postnatal development. A cascade of maturation time for the recognition of three-dimensional spatial orientation has been revealed along the vestibular circuitry (Lai et al. 2008, 2010; Tse et al. 2008). Cells in the developing vestibular neural circuitry show progressive maturation in deciphering spatiotemporal cues for encoding head orientation. The maturation of functional properties of central vestibular cells also depends on connectivity with the cerebellum and with inputs from the opposite inner ear (Chan et al. 1999).
Activity- and age-dependent changes in excitatory neurotransmission underlie the maturation of neural circuitries for learning and retaining memory. To construct a central neural network that can function properly, membrane receptors for excitatory and inhibitory neurotransmitters need to be expressed at the right time and the right place in order to shape activities of the entire network. A principal mechanism by which neurons regulate neurotransmission is by altering the number and composition of receptors at the postsynaptic plasma membrane. As the neural circuitry is particularly susceptible to changes during postnatal development, sensory deprivation at the early postnatal stage can lead to profound effects in the adult. Deprivation of sensory inputs to the central vestibular circuitry by perturbing either the excitatory or inhibitory neurotransmission resulted in deterring the orderly establishment of spatial reference in mature animals. These animals also showed functional deficits in sensory-motor coordination and motor learning. The formation of the internal spatial reference for spatial coding is experience dependent, and a postnatal time window for the establishment and refinement of a central vestibular network is present for accurate spatial recognition in the adult.

O’Keefe and Dostrovsky (1971) first suggested that the hippocampus is responsible for the cognitive spatial map in animals. The function of this map was not only to permit spatial navigation of animals through an environment, but also to act as a memory system for significant items and episodes of experience. Hippocampal place cells are presumably the principal cells that can be activated with respect to the location of an animal within a particular environment. The characteristic of a place cell is that when an animal moves across a specific location within the environment, the cell becomes active. In the 1990s, the concept of “path integration” emerged. Path integration focuses on the ability of an animal to synthesize its motor activity into a navigational context, in terms of direction, velocity, and time spent in specific movement. To accomplish path integration, the animal needs to compute its return distance and direction vector so that it can return directly to its starting point. The homeward path can be computed with the help of cues from the external environment as well as several self-movement cues (that is, kinaesthetic information or efferent copy from movement commands). Although the
precise areas of the brain that are involved in path integration are still not well understood, there is evidence that relevant processes are executed in multiple brain areas and several types of cells are involved in the computation. Besides place cells, grid cells are also involved in path integration (McNaughton et al. 2006). Grid cells, found in the entorhinal cortex, discharge at multiple locations within an environment, and these locations form regular and repeating grid patterns across the entire environment. Anatomical and electrophysiological studies have shown that cells within the entorhinal cortex are interconnected with cells in hippocampus and thalamus in the forebrain (Moser and Moser 1998; Zhang and Bertram 2002), forming an integrated network for spatial navigation.

The central vestibular system together with the thalamo-hippocampal-cortical network acts as a *Global Positioning System* inside the brain such that animals can consciously interpret their current location and direction, so as to make decisions for appropriate movement. Any deprivation of sensory inputs within this neural network may cause impairment of spatial navigation. For example, lesion of vestibular-related thalamic regions in rats led to impairment in path integration and spatial navigation, indicating the importance of vestibular information for spatial navigation. Similar deficit was also reported with lesion of hippocampus and parietal cortex (Save et al. 2001; Stackman et al. 2002), suggesting that working memory and cognitive processes also play important roles in spatial navigation. It remains to be resolved how spatial information is integrated at the thalamo-hippocampal-cortical level in order to give us the consciousness of spatial orientation.

Does this mean that spatial orientation emerges only at the conscious level? Although there is a lack of a universal definition of consciousness, it is mostly agreed that consciousness must involve arousal and awareness of the perceived stimulus (Zeman 2001) and that one is able to recall its properties when asked, or during introspection. Taking navigation as an example, one is able to name various visual cues when trying to describe one’s way home, and yet much more information is indeed stored in our brain without our awareness, such as things in-between the registered visual cues. Such stored information may however be retrieved with an increase in one’s attention level for enhancing consciousness.
Our consciousness is mostly accessed by our accuracy in reporting events or facts. But which parameter(s) could possibly report the events in our brains? This view can be further elaborated in line with studies supporting the idea that consciousness is maintained by interplay within the thalamocortical system (Joliot et al. 1994). Three basic physiological facts about consciousness were described by Seth et al. (2005). First, consciousness is associated with low amplitude, high frequency (20–70 Hz) electrical activity of the brain (Berger 1929). The second is association between consciousness and the thalamocortical system. Observations from patients who underwent surgical removal of a cortical lobe or an entire brain hemisphere, surgeries commonly used in the past as a treatment for epileptic seizures, have shown that the cortex alone does not seem to be critical for maintaining a conscious state, since there was no report any loss in any of these patients after the neurosurgery. Yet, the state of coma (a profound stage of unconsciousness) is known to be associated with damage of the brainstem reticular formation (Sundsten and Nolte 2001) which has ascending connections with the thalamus and subsequently the cerebral cortex. These suggest that the brainstem is crucial for maintaining the state of consciousness while interaction of the cortex and thalamus sustains its contents for accurate interpretation of our senses (Baars et al. 2003). Lastly, consciousness seems to be associated with widespread activation of the cerebral cortex (Srinivasan et al. 1999; Dehaene et al. 2001):

1. the somatosensory cortex in the parietal lobe for accurate interpretation of stimuli from the body;
2. the prefrontal cortex for an increase of attention;
3. the medial-temporal lobe, in particular the hippocampus, for declarative memory, i.e. conscious memory for facts and events.

(Squire et al. 2004)

Notably, more regions in the cortex are activated when the task involves more consciousness, whereas cortical activation is decreased when the task becomes automatic and unconscious (Baars 2002).

To date, most of the findings in the field of consciousness are based on reports from humans and these in turn rely heavily on perception, imagery, feelings, inner-speech, and ideas. Little has been done in apply-
Ing the study of consciousness into the spatial orientation system. The consciousness system relies heavily on interplay between the thalamus and higher cortical areas, and in analogy with this, the spatial orientation system also shares similar neural structures. Therefore future research collaboration by neuroscientists, psychologists, neurologists, and psychiatrists at multiple levels should facilitate the translation of information derived from the study of spatial navigation into the understanding of the complex world of human consciousness.

**FROM ORIENTATION TO RELIGION: THE NAVIGATING “SELF”**

The mind/body dilemma has always been a core concern from as early as the ancient Greeks. Despite great advancement in science, the delicate relationship between the two is still uncertain. The existence of
the mind (also referred to as self) depends on conscious awareness of our existence. By focusing on the neuropsychological basis of the conscious self, we address this idea of self in both spatial and spiritual navigation.

The phenomena of spatial navigation and consciousness rely on functional neural substrates. One interesting approach to accommodate the two phenomena came from the “Allocentric-Egocentric Interface Theory of Consciousness” (Mandik 2005). Various cognitive abilities, including spatial navigation, are resultants from egocentric (self-centered) and allocentric (object-centered) representations. Egocentric representation relies on an efficient update of spatial relations since it focuses on the relationship between oneself and each object. It is an active process since the relationship between each object and observer changes as the observer moves (Wang et al. 2006). In contrast, allocentric representation is more stable, as it considers only the relationship between objects in the environment, like the map of a known place (Waller and Hodgson 2006). According to this theory, consciousness is a hybrid state that involves reciprocal interaction between the two representations (Mandik 2005). During motor imagery, it was proposed by Boussaoud and colleagues (1996) that a conscious state requires projections from parietal areas to premotor areas via the prefrontal cortex while unconscious ones only require direct parietal-premotor projections. These suggest that the prefrontal area plays a crucial role in consciousness, independent of the type of representation processing.

Spatial navigation operates regardless of whether the processing content is conscious to us. Both representations (egocentric/allocentric) require a working relationship between oneself and the environment or internalized representation of the environment. Therefore, both cannot function in conditions where there are no clear boundaries between self and environment.

There has been a continuous debate on the concept of human self, and none of the existing approaches have received unanimous consent (Singer 2001). Nevertheless, the Freudian theory of the self (Freud 1923) has had a wide impact on many contemporary theories of the self. Based on Freud’s tripartite architecture of the human mind (1923), consciousness was considered as the tiny tip of the iceberg shown on the sea surface and analogically as the only part of our mind (selves) that we are
Consciousness and Spatial Navigation

The strengths and limitations of the *self* has been a constant topic of debate since the time of the ancient Greek philosophers such as Aristotle. According to one classic idea, God could only be accessed or worshiped when one could transcend oneself. The idea of self-transcendence has been always associated with spiritual and supranatural phenomena and as a consequence has been studied largely within the religious context, until recently when scientists have started to look at data regarding self-transcendent experiences (such as mystical experiences) as phenomena that has their own neural circuitry.

<table>
<thead>
<tr>
<th>Type of navigation</th>
<th>Source</th>
<th>Representation</th>
<th>Underlying neural activity</th>
<th>Orientation towards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiritual Navigation</td>
<td>Based on strong focus in religious thought</td>
<td>The self is merged with the environment; the self is without limits</td>
<td>Increases activity of the prefrontal cortex/decreased activity of the orientation association area</td>
<td>Extremely self-centered (transcendent state of mind)</td>
</tr>
<tr>
<td>Spatial Navigation</td>
<td>Based on externalized representations</td>
<td>Egocentric (updating the relationship between person and environment; active)</td>
<td>Increased activity of the precuneus and dorsal premotor cortex</td>
<td>Self-centered (for unknown places)</td>
</tr>
<tr>
<td></td>
<td>Based on internalized representations</td>
<td>Allocentric (memory as resource; passive)</td>
<td>Increased activity of the hippocampus</td>
<td>Environment centered (for well known places)</td>
</tr>
</tbody>
</table>

Table 1. Characteristics of spatial navigation and spiritual navigation.
One important difference among different models of navigation is subsequent representation of the self on how to exceed its limit leading to self-transcendence. To understand this process, Newberg and d’Aquili (1998) have used a single photon emission computed tomography measuring the cortical blood flow of Christian prayer and Buddhist meditation. In both cases, there was an increase in activity in the prefrontal cortex, a region responsible for attention, together with a reduced activity in the parietal lobe, in particular the posterior superior lobe. These were taken by these authors as the “orientation association area” in humans. During mystical experience, an interplay of different brain areas is registered. Activation of the prefrontal cortex helps focus attention in prayer and meditation while activation of the limbic system regulates our emotions of joy and fear during mystical experiences. On the other hand, depression of the “orientation association area,” which is responsible for delineation of the physical boundaries between the body and its surroundings, leads to diminished perception of the sense of “selfness.”

These findings have led Newberg and d’Aquili (1998) to propose that unlike normal spatial navigation mechanisms, in which conscious awareness of the body in relation to the environment is crucial, spiritual rituals guide our brains into a state of meditation as characterized by increased attention and decreased self awareness. Therefore, it is believed that ritual and liturgy allow the self to be in a state of self-centered attention by suspension of our self-awareness.

Studies on orientation are of crucial importance, as they result in revealing mechanisms that enable us to understand navigation in the world. While the intersection between space and time is well recognized to be a cardinal parameter that governs navigation, a reductionist approach is inadequate in addressing the complex issue of inner balance and how direction in life is being sought after. Spiritual navigation indeed relies on our fellowship with God in transcending the bodily world to the spirit world. The closer we orientate towards ourselves, the closer we are with God. Regardless of which spiritual practice, men believe that “God lives inside of us,” allowing us to be introspective and achieve spiritual navigation.
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