Representation of Episodic Memory in the Hippocampus

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The hippocampus is known to play an essential role in certain forms of memory. The initial evidence for the hippocampal role in learning and memory has come from a human case study. The patient H.M., who had his temporal lobes including the hippocampus removed bilaterally due to intractable epileptic seizures, could not form new memory while other intellectual capacities were relatively intact (Scoville and Milner, 1957). Later studies have shown that H.M and other similar patients were not without learning capacity. These patients could acquire certain skills and had intact priming. These and subsequent animal studies have shown convincingly that there exist hippocampus-dependent and -independent types of memory. It is now well established that there are multiple forms of memory that are subserved by different brain structures. The type of memory for which the intact hippocampus is required is called declarative (episodic and semantic) memory.

Physiological studies in rodents on the other hand led to the view that the hippocampus plays an essential role in spatial memory (O'Keefe and Nadel, 1978). Principal neurons in the rodent hippocampus show robust place-specific firing. They elevate their discharge rates within restricted regions of a given environment and mostly silent elsewhere. Since the initial discovery of such 'place cells' (O'Keefe and Dostrovsky, 1971), a number of subsequent studies invariably found place-specific firing of hippocampal neurons, suggesting that spatial location is the strongest, if not the only, determinant of hippocampal neuronal activity. These findings were followed by some debates on the scope of hippocampal memory functions, whether the hippocampus subserves mainly spatial memory or broader memory functions (declarative, relational or episodic memory).

Compared to place-specific firing, much less is known on the dependence of hippocampal neuron firing on non-spatial factors. Although some of earlier studies reported effects of non-spatial factors on hippocampal neuron firing, effects of non-spatial factors have obtained relatively little attention. In fact, non-spatial factors were deliberately minimized in the majority of subsequent studies. Recently, however, numerous studies have provided unequivocal evidence that hippocampal neuronal activity depends on both spatial and non-spatial factors. Discharges of rat hippocampal neurons change according to non-spatial sensory stimuli, task-related behavior, and movement trajectory (Eichenbaum et al., 1999; Redish, 1999, 2001).

In spite of the growing body of evidence indicating the role of non-spatial factors in determining hippocampal neuronal activity, the nature and extent of non-spatial factors influencing hippocampal neuronal activity are not clear. To understand the extent of non-spatial factors contributing to hippocampal place cell discharges, we investigated the effects of voluntary movement and behavioral task rule on hippocampal place cell discharges. We first investigated the role of active movement in location-specific firing by comparing spatial firing patterns of hippocampal neurons while rats either freely ran or rode a motorized cart on the same circular track. If the primary function of the hippocampus is spatial memory, then similar patterns of neuronal activity would be expected across the two navigation conditions. Otherwise, i.e., if the hippocampus concerns more than spatial information, then different spatial firing patterns will be observed. Consistent with the second prediction, the majority of neurons changed their spatial firing patterns across the two navigation conditions ('remapping'), and they were stably maintained across repeated active or passive navigation sessions (Song et al., 2005). These results provide strong evidence that the mode of navigation is an important non-spatial factor determining hippocampal neuronal activity, adding to the growing body of evidence that the hippocampus represents not only spatial information but also non-spatial information in storing episodic memory.

In the second study, we compared activities of hippocampal neurons across two different navigation tasks with similar behavioral responses along similar movement trajectory. In one task, rats alternatively visited two goal locations to obtain water reward in a figure 8-shaped maze (spatial delayed alternation). In the second task, rats were rewarded by repeatedly visiting only one goal location on the same maze. When we compared neuronal activity on the portions of the maze that the animals navigated in both tasks, no significant difference was observed. These results show that hippocampal neural activity remains constant over a small difference in behavioral task, when other aspects remain the same.

The two studies indicate that hippocampal neural activity is influenced by non-spatial factors under certain circumstances, but not in all circumstances. These results are consistent with the role of hippocampal neural network in pattern completion and pattern separation. Two input patterns with a small difference would be interpreted as the same pattern (pattern completion) whereas those that are sufficiently different would be interpreted as totally different patterns (patterns separation). Perhaps one role of the hippocampus is to associate spatial information with non-spatial information that are separately provided by different divisions of the entorhinal cortex (Hargreaves et al., 2005). The combined information may form the basis of episodic memory.

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