Rat thalamic neurons encode complex combinations of facing and movement directions and trajectory route during translocation with sensory conflict

感覚不一致を生じさせる移動課題において、ラット視床ニューロンは、頭部の向き、移動方向および移動ルートの複合的組合せを符号化する。

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〔目的〕

Previous studies have reported that some thalamic neurons encode the animal's directional heading, and these are referred to as head direction cells. Head direction (HD) cells, which are neurons that fire when the animal is facing a particular direction relative to a fixed location or landmark in the environment, are believed to represent the animal's perceived directional heading in its environment.

The HD signal is dependent upon multiple sensory modalities, including ideothetic (vestibular, visual, and proprioceptive) inputs. The present study investigated effects of sensory mismatch among ideothetic cues on anterodorsal (AD) and laterodorsal (LD) thalamic neurons.

〔方法〕

The rats were operated to implant cranioplastic caps for the semichronic recordings. After recovery from the surgery, the rats were trained in a translocation task in which the rats ran on a treadmill stage that moved in a figure-8-shaped pathway. In the sensory-mismatch condition, although the rat ran forward on the treadmill, the mobile stage was translocated backward in terms of the rats' direction; the proprioceptive inputs and/or motor efferent copy during locomotion (locomotion-related inputs) did not match the visual (optic flow)/vestibular inputs. After training, a tritrode (a 4-cores-Quarts-Platinum/Multifiber electrode) was stereotaxically inserted into the AD and LD while the rats performed the translocation task. The single neuronal activities were isolated by a cluster cutting analysis.

The direction at which a given neuron fired maximally was defined as the neuron's preferred firing direction. The direction-related neurons were defined in each route in each translocation task as follows: 1) the maximal firing rate at its preferred firing direction (maxPFR) should be significantly greater than both the maximal firing rate at the opposite direction (maxOPFR) and the average firing rate during the linear movement to the north and south in each route; 2) the maxPFR should be greater than 2 times the average firing rate in the whole pathway in each route; and 3) the selectivity index (SI) for the preferred firing direction should be greater than 1.0. The SI was defined by the following formula:

SI = (maxPFR – maxOPFR)/Mean firing rate during whole translocation

across the translocation conditions

〔結果〕

Of the 222 neurons, 60 neurons showed direction-related responses. Of these 60, 19 (19/60, 31.6%) neurons showed facing direction-dependent responses regardless of movement direction. Twenty neurons (20/60, 33.3%) displayed facing and movement direction-dependent responses; activity of 10 and the remaining 10 neurons increased during forward and backward movement, respectively. Twenty one neurons (21/60, 35%) showed movement direction-related responses regardless of facing direction. Furthermore, the activity of some direction-related neurons increased only in a specific trajectory.

All of these neurons were located in the AD and LD thalamic nuclei. The various types of direction-related neurons were intermingled and found in both the AD and LD thalamic nuclei. In the LD, there was a significant difference in recording positions along the anterior-posterior axis among the different types of direction-related neurons [One-way ANOVA; $F(4, 32) = 3.765$, $p = 0.0128$]. The post-hoc tests revealed that the miscellaneous direction-related neurons were located in the more anterior positions than the other types of the direction-related neurons except the forward movement-related neurons (Ryan's method, $p<0.05$). In the AD, there was no significant difference in the recording positions among the different types of the direction-related neurons [One-way ANOVA; $F(4, 13) = 0.832$, $p = 0.5283$]. These results indicated that 4 types of the direction-related neurons (the facing direction-related, forward and backward movement-related, and movement direction-related neurons) were intermingled in both the AD and LD.

〔総括〕

The present results indicated existence of 4 types of the direction-related neurons in the thalamus. Especially, two subpopulations of the HD cells in the AD and LD coded separately heading and movement directions (heading direction-related, and movement direction-related neurons) regardless of direction of translocation (forward or backward). These neurons might code directional information in an allocentric reference frame. Furthermore, the forward and backward movement-related neurons might code movement direction in an egocentric reference frame. These results suggest that the HD system can code

different kinds of directional information separately when multiple sensory information contradicts. Previous studies suggest that the AD and LD receive multisensory inputs and these inputs are integrated to reduce the error of the head direction signal of the HD cells. The present study provides additional evidence with respect to a role of the HD system in directional processing; the rodent HD system extracts different types of directional information in different reference frames in a conflicting situation. The previous studies suggest the rats could adapt to backward translocation, and hippocampal neurons showed plastic changes in place fields after repeated experience of backward translocation in the same setup as in the present study. The HD neurons reported in the present study might play important roles for spatial updating during the backward translocation. Taken together, the present study suggests that the AD and LD generate complex direction-related signals for robust spatial updating under different conditions. Because the AD and LD nuclei serve as an important interactive for the limbic spatial learning system (Jankowski et al., 2013), the functions of the AD and LD nuclei might reflect those in other limbic areas. Future works and modeling will help to elucidate the complex function of the AD and LD thalamic nuclei.