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Integration of Plasticity Mechanisms within a Single Sensory Neuron of C. elegans Actuates a Memory

Graphical Abstract

Highlights
- Sensory adaptation and presynaptic plasticity act within a single neuron in vivo
- Integration of these plasticity mechanisms underpins a temperature preference memory
- Sensory adaptation enables migrating animal to detect temperature changes
- Presynaptic plasticity transforms this thermosensory information into a preference

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In Brief
Neural plasticity, the ability of neurons to change their cellular properties in response to past experiences, underpins memory. Hawk et al. show that in C. elegans a single-cell logic system can both represent sensory stimuli and guide memory-based behavioral preference.

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Article

Integration of Plasticity Mechanisms within a Single Sensory Neuron of C. elegans Actuates a Memory

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SUMMARY

Neural plasticity, the ability of neurons to change their properties in response to experiences, underpins the nervous system’s capacity to form memories and actuate behaviors. How different plasticity mechanisms act together in vivo and at a cellular level to transform sensory information into behavior is not well understood. We show that in Caenorhabditis elegans two plasticity mechanisms—sensory adaptation and presynaptic plasticity—act within a single cell to encode thermosensory information and actuate a temperature preference memory. Sensory adaptation adjusts the temperature range of the sensory neuron (called AFD) to optimize detection of temperature fluctuations associated with migration. Presynaptic plasticity in AFD is regulated by the conserved kinase nPKCc and transforms thermosensory information into a behavioral preference. Bypassing AFD presynaptic plasticity predictably changes learned behavioral preferences without affecting sensory responses. Our findings indicate that two distinct neuroplasticity mechanisms function together through a single-cell logic system to enact thermotactic behavior.

INTRODUCTION

When an animal experiences a favorable condition, it can form a memory that guides its future behavior. The subsequent performance of these learned behavioral preferences requires the animal to navigate sensory-rich environments, extract behaviorally relevant information, and differentially act based on its previous experience. While it is widely accepted that plasticity mechanisms underpin experience-driven behaviors, how different plasticity mechanisms act in vivo and within single cells to facilitate recall and actuation of learned behavioral preferences is not well understood (Basu and Siegelbaum, 2015; Davis, 2011; Gjorgjieva et al., 2016; Mayford et al., 2012).

The nematode C. elegans does not have an innate preferred temperature. Instead, C. elegans cultivated at a given temperature will remember this temperature (TC) and migrate toward it when on a thermal gradient (Hedgecock and Russell, 1975). This memory can be trained to a new temperature within 4 hr (Biron et al., 2006; Chi et al., 2007; Hedgecock and Russell, 1975; Mohri et al., 2005; Ramot et al., 2008b) (Figures 1B–1D). Neurons specifically required for thermotaxis behavior have been identified by neuronal ablation studies (Beverly et al., 2011; Biron et al., 2006; Kuhara et al., 2008; Mori and Ohshima, 1995), and their connectivity is known (White et al., 1986). From this work, we understand that temperature preference depends on a thermosensory neuron called AFD, which has specialized molecular pathways that allow it to respond to temperature changes smaller than 0.1°C (Clark et al., 2006; Kimura et al., 2004; Mori and Ohshima, 1995; Ramot et al., 2008a). AFD responses are observed only near an adaptable sensory threshold that correlates, on long timescales, with the cultivation temperature memory. These observations led to the hypothesis that the AFD thermosensory threshold represents the memory for the preferred temperature (Aoki and Mori, 2015; Biron et al., 2006; Garrity et al., 2010; Kimura et al., 2004; Luo et al., 2014; Yu et al., 2014). AFD has also been observed to adapt its thermosensory threshold on short timescales (Ramot et al., 2008a; Yu et al., 2014), but the behavioral repercussions of this more rapid adaptation have not been examined. Thus, the role of the adaptable AFD sensory threshold in the actuation of the cultivation temperature memory is not well understood.

RESULTS

To better understand AFD sensory responses in relationship to thermotaxis behavior, we developed a custom thermoelectric
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