Neuronal dynamics underlying behavioral response variability during sensorimotor transformation

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Behavioral variability is a fundamental feature of animal behavior, yet its neuronal basis remains poorly understood. In *C. elegans*, prior work has shown that brain-wide dynamics encode motor actions, but how these intrinsic dynamics shape sensory processing and behavioral variability remains unclear. We examined *C. elegans* responses to aversive oxygen stimuli (21% O_2), which reliably evoke a bimodal escape behavior: ~60% of trials result in transient backward crawling, while the remainder lead to sustained fast forward movement. To uncover the underlying neuronal mechanisms, we performed whole-brain calcium imaging at single-cell resolution in immobilized animals, where fictive motor outputs can be decoded. This approach revealed an equivalent response variability, enabling us to trace sensorimotor transformations at whole-brain scale with single-neuron resolution. Variability did not originate in sensory neurons but emerged within interneurons and motor circuits: activity in multiple interneurons prior to stimulus onset predicted the behavioral outcome. Machine learning revealed that a distributed pre-stimulus brain state best predicts the response. Targeted neuronal manipulations via chemogenetics and optogenetics confirmed the causal role of these neurons. Our findings demonstrate that while sensory input is reliably encoded, behavioral variability arises not from random noise in neuronal circuits but from an intrinsic dynamic brain state that biases decision-making.