Neural Representations of Natural Self-Motion: Implications for Perception & Action

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Abstract:

A fundamental question in neuroscience is how does the brain compute accurate estimates of our self-motion relative to the world and orientation relative to gravity in order to ensure accurate perception and motor control. In this talk I will describe recent findings from my laboratory's research that have revealed that the vestibular system encodes information during everyday activities.

First, our research has examined the statistics of natural self-motion signals experienced by mice, monkeys, and humans. We then explored the neural coding strategies used by early vestibular pathways to encode these natural self-motion signals, focusing on the relationships between neural variability, detection thresholds, and information transmission. Out findings have revealed that two distinct sensory channels represent vestibular information at the level of the vestibular periphery: more regularly discharging afferents have better detection thresholds and use rate coding, while more irregular afferents take advantage of precise spike timing (i.e, temporal coding) and are better optimized for processing natural vestibular stimuli.

Second, our research has established the brain combines vestibular and extra-vestibular signals at the first stages of central sensory processing in a behaviourally-dependent manner. Importantly, we have shown that while vestibular afferents respond identically to passive and active self-motion, this is not the case at first stage of central vestibular processing. Vestibular nuclei neurons mediating the vestibulo-spinal reflexes, as well as ascending thalamocortical pathways respond robustly to passive self-motion. In contrast, their responses are dramatically suppressed (>70%) for active self-motion. We have further shown this suppression occurs only in conditions when there is a match between the expected sensory consequences of active movement and the actual sensory feedback (as would be the case during normal voluntary behaviours). Notably, our studies have also revealed that when unexpected vestibular inputs become persistent during active motion, a cerebellar-based cancellation mechanism is rapidly updated to re-enable the vital distinction between active and passive motion to ensure the maintenance of posture and stable perception.

Taken together, our results have important implications for ascending thalamocortical vestibular pathways - including the head-direction (HD) cell network, which is generally assumed to generate a fixed representation of perceived directional heading based on vestibular input. We speculate that the cerebellum plays a critical role in maintaining the

stability of the HD network when the relationship between active movement and its sensory consequences is altered. Such situations include navigation in virtual reality and head-restricted conditions, where the natural relationship between vestibular and extravestibular cues is altered. Moreover, since the properties of the motor system are constantly changing (fatigue, growth, etc.), we propose that continual recalibration of the HD network is also required to ensure perceptual stability and accurate motor control in everyday life.