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Where was I going? Vestibular-visual integration in the retrosplenial cortex

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We need to keep track of our heading direction, and head direction cells in various brain regions represent exactly that; therefore, they have been identified as key substrates of direction coding. But how is such a variable computed? Head direction representation is thought to arise from the integration of angular velocity, suggesting the existence of angular head velocity (AHV) neurons. Theoretically, vestibular, visual, proprioceptive and motor command signals can all contribute to angular velocity computations, while the actual coding mechanisms have remained unclear.Keshavarzi et al. addressed this by separately controlling vestibular and visual cues in a head-fixed configuration (Keshavarzi et al., 2022b). They targeted the retrosplenial cortex (RSC), a multisensory associational area known to be important for the integration of egocentric and allocentric information during navigation (Solari & Hangya, 2018). The use of high channel-count multielectrode arrays (silicon probes) allowed the authors to track a large number of neurons through different conditions, including free exploration of an open field arena. They identified subsets of neurons representing head direction, AHV, locomotion speed or a combination of these variables.

A large fraction of AHV neurons showed similar tuning properties during free exploration and passive rotation in the dark, demonstrating the importance of vestibular input. In agreement, lesioning the semicircular canals largely reduced these responses. Next, mice were presented with visual motion stimuli while remaining stationary. This showed that visual signals also contributed to AHV coding and specifically suggested that they increased the gain and improved the signal-to-noise ratio of AHV representations. Mice trained on discriminating rotational stimuli showed improved performance when both visual and vestibular information was available compared to either vestibular-only or visual-only stimuli, further demonstrating the integration of the two types of sensory cues. Finally, the availability of both vestibular and visual information improved

decoding accuracy of angular speed from ensembles of retrosplenial cortex neurons compared to single modality stimuli, at least at the beginning of motion.

Keshavarzi et al. provide compelling evidence for the critical role of vestibular input in encoding AHV within the RSC. While the widespread presence of vestibular signals in rodent cortical circuits is well-documented (Rancz et al., 2015), this study significantly advances our understanding by demonstrating that RSC neurons can also encode AHV. These findings align with research that identified AHV representations in the RSC and adjacent cortical regions, including primary visual, secondary visual, posterior parietal, primary motor, secondary motor and primary somatosensory cortices (Hennestad et al., 2021), and with later work that showed AHV in parahippocampal circuits (Spalla et al., 2022).

Notably, the relative contributions of vestibular and visual signals to AHV encoding likely depend on the specific cortical area and the AHV amplitude. Visual flow may be more prominent at lower AHV ranges (0-90 deg/s), while vestibular input likely dominates AHV representation at higher speeds (Stahl, 2004; Hennestad et al., 2021). This suggests a complementary contribution of vestibular and visual information, enabling encoding a broader range of angular velocity and driving a widespread AHV signal across cortical areas.

This is an elegant study in which a creative and clear experimental design helps teasing apart different contributors of a specific computation that normally appear linked during natural behaviors. This way it also demonstrates the power of precise experimental control, while immediately extrapolating to natural behavior by examining the same neurons during free exploration. It additionally demonstrates a non-trivial multisensory integration in the retrosplenial cortex that can directly contribute to egocentric spatial representations during navigation (Alexander & Nitz, 2015, 2017).

Editorial note: A preprint version of this article was peer-reviewed by PCI Neuroscience. The refereed preprint can be found through the cited link here (Keshavarzi et al., 2022a), and the peer-review process here.

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