

## **Movement coding at the mesoscale in posterior parietal cortex**

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## Abstract

Neural correlates of movement planning have been studied most using signals isolated from single-cells. However, in this issue of *Neuron*, Wilber et al. (2017) show that movement trajectories are encoded and replayed in the collective activity of thousands of cells at a time in the posterior parietal cortex.

Imagine you are walking down the street looking for lunch. Spotting a place across the road, you prepare to turn, but at the last moment see a friend and instead keep walking to meet them. Though you never actually followed through with the turn, the fact is your brain still generated a measurable plan in preparation for doing so. Fleeting though they may be, movement intentions emerge through interactions across a network of cortical regions extending well beyond the motor areas that drive your legs to walk.

We owe much of our knowledge of movement planning to decades of work in cortical neurophysiology, primarily in awake, behaving monkeys performing tasks while seated in a recording chair. Such experiments established that spatially targeted movements of the hand or eye, for example, are preceded by signals from a list of cortical regions that often begins at the posterior parietal cortex (PPC) (Andersen and Buneo, 2002). In addition to sensorimotor functions, more recent work pointed toward a navigational role for PPC in monkeys, showing that neurons there encoded route segments in virtual reality houses, and that inactivating PPC caused the monkeys to lose their way (Sato et al., 2006). Recordings in rodents in the 80's and 90's also suggested a role for PPC in navigation (McNaughton et al., 1994). Here it was found that a substantial fraction of PPC cells (30-50%) encoded basic modes of movement, such as turning, running or combinations of movements while freely-behaving subjects traversed an 8-arm radial maze. Unlike simple motor responses, neural firing in PPC was gated by the animals' position in the maze when a movement was made (firing only at the end of a maze-arm, for example). The PPC neurons thus signaled conjunctions of movement and spatial context, and subsequent work showed that this type of coding provided a scalable, route-centered metric for tracking an animal's progress along irregular paths (Nitz, 2006).

Regardless of the species involved, one feature that links many studies in behavioral electrophysiology is the use of individual cells as the basic unit of neural computation, and physiologists typically go to lengths to ensure that their signals come from well-isolated cells. But the study by Wilber et al. (2017), on the other hand, specifically examined the collective background chatter from thousands of PPC cells, either in the form of multi-unit activity (MUA) or high-frequency filtered local field potentials (HF-LFP), while rats ran across an open arena to reach cued or remembered reward locations (Figure 1). Surprisingly, the authors found that self-motion representations—the kind typically recorded from single PPC neurons—were expressed stably in the sea of cortical activity. Moreover, the movement correlates of the MUA / HF-LFP could differ sharply from one recording site to the next, yet at a given site the tuning was conserved across cortical layers. It is exactly what one would expect to see if PPC contained cortical columns. Even more interesting was the fact that the putative cortical modules replayed

MUA sequences during post-task sleep sessions (Figure 1), suggesting a previously unconsidered role for PPC in storing memories of the movements the animals made.

Wilber et al.'s analysis of broader-bandwidth neural activity thus uncovered fascinating evidence that self-motion representations in the rat PPC are organized in modular patches, at a larger anatomical scale than previously known. An arguably comparable revelation occurred in the mouse visual system ten years ago, when it was found that the secondary visual cortex, once considered homogenous, actually consisted of a cluster of anatomically distinct subareas surrounding V1 (Wang and Burkhalter, 2007). But as with any new insight in science, the new findings raise new questions.

For example, how is it that a uniform correlate for a single type of locomotor behavior emerges from thousands of individual cells with different tuning properties? Unlike orientation columns in visual cortex or grid modules in entorhinal cortex, there is little evidence of fine-scale functional clustering in the rodent PPC. Rather, neurons that prefer left-turns comingle with cells that prefer forward running, and these are all comingled with neurons that have nothing to do with movement whatsoever (Whitlock et al., 2012). Wilber et al. propose that the partial overlap of firing fields from thousands of individual cells could lead to the emergence of a single, overarching movement correlate. If this is the case, it would not be the first time that a coarse remnant of single-cell tuning was reported at the macroscale. One cannot help but to think of the hexagonally symmetric directional tuning observed in the human entorhinal cortex during virtual navigation, and its possible connection with the hexagonal firing pattern of single grid cells (Doeller et al., 2010). Though it is unlikely that such macroscopic phenomena result directly from the tuning of single-cells, they can nevertheless provide clues regarding organizational principles of neural coding at larger anatomical levels.

Another question is whether the movement correlates expressed by the putative modules are specific to the task used in the study. For context, previous work has shown that the movement correlates of individual PPC cells change completely across different navigational routes (Nitz, 2006) and different behavioral tasks (Whitlock et al., 2012). This naturally raises the question of whether coding properties at the mesoscale would change across different behavioral paradigms. Testing this idea could prove intriguing, since the results would suggest whether tuning expressed at larger scales in PPC is functional in nature (i.e. task-dependent), or biologically hardwired via genetics or anatomical connections. On a related note, it is entirely possible that the modules described by Wilber et al. overlap anatomically with some of the higher-order visual areas described by Wang and Burkhalter (2007), and it would indeed be fascinating to see whether patches with different movement preferences also exhibited distinct retinotopic maps for visual stimuli. If this were true, the findings could begin to reveal an even bigger picture of how sensorimotor transformations are organized in PPC and surrounding areas.

In any case, the existence of modular tuning in the rat PPC fits well with the notion that PPC in monkeys, and likely humans, is parcellated into specialized sub-regions. Previously, the primate PPC was conceptualized as forming an "intentional map" made of distinct subareas for planning movements of the eye, arm or hand (Andersen and Buneo, 2002). Systematic electrophysiological

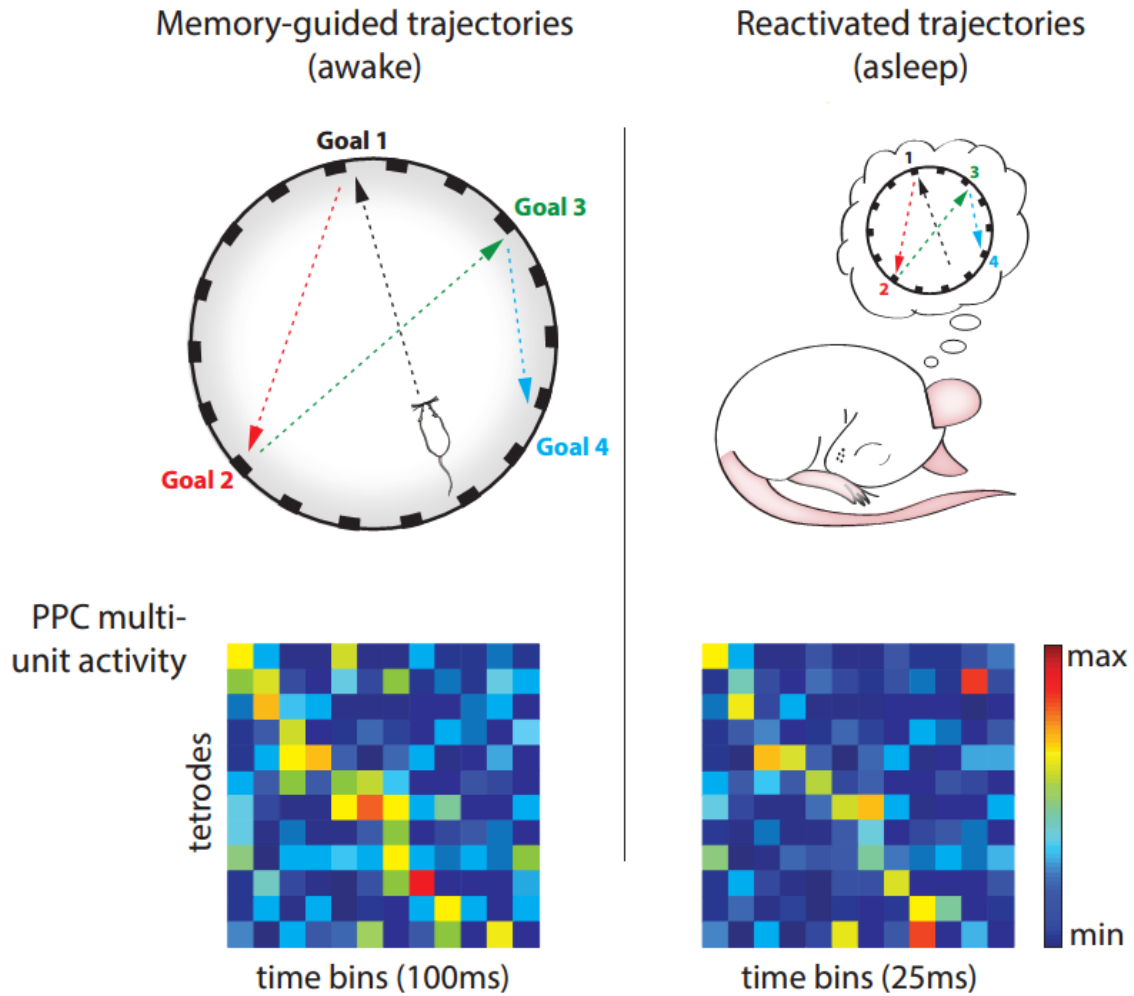
mapping has also shown the existence of graded topographies along the surface of the inferior parietal lobe in monkeys (Rozzi et al. 2008). Specifically, a somatotopic organization was found for various motor responses, with movements of the mouth being most rostral, movements of the hand next, and arm movements most caudal. In light of these observations one cannot help but wonder whether movement representations in the rodent PPC are also arranged according to an underlying somatotopic or behaviorally-relevant organization. Addressing this question in rodents, however, would first require either a substantial upgrade in the detail of behavioral monitoring, or the use of simplistic tasks during head-fixation to isolate movements of the paw, face, whiskers, and mouth.

Another provocative finding from the Wilber et al. (2017) study is that the activity patterns recorded across multiple tetrodes during task performance were replayed during subsequent sleep sessions (Figure 1), implicating PPC as a possible actor in memory consolidation. This is a surprising finding since the rodent PPC has rather weak connectivity with the hippocampal formation, where replay is most prevalent. Yet the post-task activity patterns in PPC exhibited several hallmarks of memory-related replay described originally in the hippocampus (Wilson and McNaughton, 1994), including the dependence on prior experience and the occurrence at compressed timescales. In some instances the replayed activity maintained the same sequential ordering across tetrodes as seen during the trajectory-running task, demonstrating that the internally generated activity patterns were organized across several hundred microns or more. In this sense Wilber et al. are the first to provide evidence of offline cell assembly activity in PPC, and the manner in which it was detected suggests that it happens across relatively large scales. It remains to be seen whether reactivation in PPC during sleep plays a causal role in storing route information, for example to a newfound food source, but closed-loop inactivation during hippocampal sharp waves or other approaches could be used to test this idea. For now it seems that a phenomenon whose primary domain was once thought to be the limbic system occurs outside of it as well, hinting at the possibility that replay could happen throughout the neocortex.

On the whole, the approach of sampling large-scale neuronal activity by Wilber et al. has given us a wider window through which to view the function and organization of neural representations in the rat PPC. By examining signals recorded from larger volumes of cortex, this study steps into a middle ground between single-unit electrophysiology in animal models and functional imaging in humans. The intermediate recording scale used here could help identify emergent patterns in the way signals are computed and transmitted across cortex, and can only help bridge the gap between the very different datasets yielded in animal models *versus* humans. In an age where mesoscopic sampling of neural activity is accomplished more frequently, there is good hope that we will continue to uncover emergent patterns in information processing which were in front of us all along, though on a scale too large to see.

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**Figure 1. Task-specific multi-unit activity in PPC is replayed during post-performance sleep**  
 Left: each rat was trained to run in a sequence of remembered trajectories in an arena, with MUA activity (below) recorded during the last moment before an animal reached the rewarded locations. Right: during post-task sleep sessions, similar patterns of MUA activity played out in the same order, but compressed temporally by 4x or more.