Laminar Organization of Encoding and Memory Reactivation in the Parietal Cortex

Highlights

- Parietal cortex MUA encodes specific movements coherently across laminae
- This organizational scheme is maintained during subsequent memory reactivation
- MUA and HF-LFP showed similar self-motion tuning and memory reactivation dynamics
- This establishes the utility of MUA and HF-LFP for human memory reactivation studies

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In Brief

Wilber, Skelin, et al. use multi-site recordings to demonstrate tuning across large populations of cells organized into modules encoding specific movements in parietal cortex. Activity patterns were shown to reactivate during post-experience sleep and were temporally coupled to hippocampal reactivation.

Wilber et al., 2017, Neuron 95, 1406–1419
September 13, 2017 © 2017 Elsevier Inc.
http://dx.doi.org/10.1016/j.neuron.2017.08.033
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SUMMARY

Egocentric neural coding has been observed in parietal cortex (PC), but its topographical and laminar organization is not well characterized. We used multi-site recording to look for evidence of local clustering and laminar consistency of linear and angular velocity encoding in multi-neuronal spiking activity (MUA) and in the high-frequency (300–900 Hz) component of the local field potential (HF-LFP), believed to reflect local spiking activity. Rats were trained to run many trials on a large circular platform, either to LED-cued goal locations or as a spatial sequence from memory. Tuning to specific self-motion states was observed and exhibited distinct cortical depth-invariant coding properties. These patterns of collective local and laminar activation during behavior were reactivated in compressed form during post-experience sleep and temporally coupled to cortical delta waves and hippocampal sharp-wave ripples. Thus, PC neuron motion encoding is consistent across cortical laminae, and this consistency is maintained during memory reactivation.

INTRODUCTION

A fundamental framework for neural coding in the parietal cortex is egocentric (Andersen et al., 1985; McNaughton et al., 1994; Nitz, 2006; Save et al., 2005; Save and Poucet, 2000; Schindler and Bartels, 2013; Whitlock et al., 2012; Wilber et al., 2014; Wolbers et al., 2008). Some studies have also found evidence for allocentric (world-centered) encoding in parietal cortex, including head direction cells (Chen et al., 1994; Chen and Nakanura, 1998; Wilber et al., 2014). Subjective assessment of head direction tuning in parietal cortex suggested common tuning across depth on a given tetrode potentially because of modular organization (Chen et al., 1994; Wilber et al., 2014). The existence of larger organizational structure of these single cells has been postulated by theoretical or computational approaches (Byrne et al., 2007; McNaughton et al., 1995; Xing and Andersen, 2000), but larger organizational structure has not been empirically confirmed.

Behaviorally relevant neural activity patterns from single cells are reactivated during memory consolidation (Dupret et al., 2010; Lansink and Pennartz, 2014). Thus, we hypothesized that modular structure may also be reflected in reactivation during post-experience-sleep—a postulated mechanism of memory consolidation originally demonstrated at the single-cell level in hippocampus (Wilson and McNaughton, 1994) and subsequently shown for hippocampal-parietal interactions (Qin et al., 1997). However, to our knowledge, no study has looked for evidence of modular-level reactivation.

Linking spiking activity with local field potential (LFP) features has been a growing area of research, most often finding correlation between spiking levels and LFP envelope in the high-gamma range (Crone et al., 2011; Liu and Newsome, 2006; Ray and Maunsell, 2011); however, the high-gamma range includes synaptic current oscillations (Colgin et al., 2009; Fries, 2005) and not just spike-related currents. Therefore, we aimed to test whether the modular organization reflected in multi-unit activity (MUA) is also detectable in high-frequency (HF) LFP (300–900 Hz), which to our knowledge has not been attributed to any functional or physiological correlates other than spiking. The HF-LFP signal provides better temporal stability, relative to single-cell recordings that are prone to minor electrode drift, and therefore produces a more reliable readout for long-term studies and for brain machine interfaces (Gliga et al., 2012). Similarly, a recent apparent connection between single-unit recording studies in rodents (grid cells in rats; Hafting et al., 2005) and fMRI data in humans (Constantinescu et al., 2016; Doeller et al., 2010) suggest that collective recordings may reveal a larger organizational structure of encoding that had largely been described at the single cell level in rodents. Thus, study of modularity of neural coding in animals using collective measures of local neural activity can help to bridge the gap between human and animal studies of neural coding and dynamics.
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