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Divisions of Identified Parvalbumin-Expressing Basket Cells during Working Memory-Guided Decision Making

Highlights

- PV+ basket cells do not fire homogenously during a delayed cue-matching-to-place task
- Their firing differentiates between distinct task episodes or choice behavior
- Firing of individual basket cells is correlated with their amount of VIP+ input
- Firing patterns are impaired during task performance without memory content

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In Brief

Lagler et al. (2016) recorded from identified parvalbumin-expressing basket cells in prefrontal cortex while rats performed a delayed cue-matching-to-place task. They show that these interneurons segregate into neuronal ensembles with different firing patterns and synaptic connectivity differentiating task sequences and choice behavior.

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Divisions of Identified Parvalbumin-Expressing Basket Cells during Working Memory-Guided Decision Making

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SUMMARY

Parvalbumin-expressing basket cells tightly control cortical networks and fire remarkably stereotyped during network oscillations and simple behaviors. How can these cells support multifaceted situations with different behavioral options and complex temporal sequences? We recorded from identified parvalbumin-expressing basket cells in prefrontal cortex of freely moving rats performing a multidimensional delayed cue-matching-to-place task, juxtacellularly filled recorded neurons for unequivocal histological identification, and determined their activity during temporally structured task episodes, associative working-memory, and stimulus-guided choice behavior. We show that parvalbumin-expressing basket cells do not fire homogenously, but individual cells were recruited or inhibited during different task episodes. Firing of individual basket cells was correlated with amount of presynaptic VIP (vasoactive intestinal polypeptide)-expressing GABAergic input. Together with subsets of pyramidal neurons, activity of basket cells differentiated for sequential actions and stimulus-guided choice behavior. Thus, interneurons of the same cell type can be recruited into different neuronal ensembles with distinct firing patterns to support multi-layered cognitive computations.

INTRODUCTION

Environmental factors of rat habitats are constantly changing (Feng and Himsworth, 2014). Consequently, evolutionary pressure has favored cognitive flexibility, allowing rats to dynamically update strategies (Hamilton and Brigman, 2015). However, only few environmental changes are relevant and should induce cognitive flexibility, while the majority of changes are irrelevant, potentially represent noise, and should be ignored (Dayan et al., 2000; Granon et al., 1998; Otazu et al., 2009; Wimmer et al., 2015). Therefore, successfully directing behavior to a current goal relies on an adequate trade-off between cognitive stability and flexibility (Cools, 2012). A brain region that has been frequently associated with cognitive control, balancing between stability and flexibility, is the prefrontal cortex (Cohen et al., 1996; Miller, 2000). Particularly, active stabilization of goal-relevant representation, a fundamental process of working memory, is one of the best-described functions of the prefrontal cortex (Goldman-Rakic, 1995; Jung et al., 2008).

In the prefrontal cortex of rats, memory-guided representations of goal-directed choice behavior are present in the form of temporally organized sequences of transiently active neurons (Fujisawa et al., 2008). Task-associated synchrony between prefrontal cortex, hippocampus (Jones and Wilson, 2005; O'Neill et al., 2013), and ventral tegmental area (Fujisawa and Buzsáki, 2011), as well as modulation of synaptic interaction-strength between pairs of prefrontal neurons (Baeg et al., 2007; Fujisawa et al., 2008), has been proposed to foster the formation of goal-representing cell assemblies. Remarkably, most of the working memory task-related short-term plasticity in the prefrontal cortex is composed of increased synaptic excitation converging onto putative interneurons (Fujisawa et al., 2008). Together with their well-documented role in synchronizing and gating information flow between distant brain regions including prefrontal cortex and hippocampus (Adhikari et al., 2010; Brockmann et al., 2011; Buzsáki et al., 2004; Hartwich et al., 2009; Tierney et al., 2004), this might point to the importance of GABAergic interneurons in supporting the stable formation of choice representation in the prefrontal cortex (Rao et al., 1999; Constantinidis et al., 2002).

The existence of a large diversity of distinct types of GABAergic interneuron is a hallmark of the cerebral cortex. Parvalbumin-expressing (PV+) basket cells provide precisely timed inhibition for controlling the output of pyramidal cells (Hu et al., 2014). Their firing patterns are highly stereotyped during different network oscillations (Klausberger et al., 2003; Lapray et al., 2012; Varga et al., 2014). Using transgenic mouse lines, it has been shown that neurons expressing PV (likely to contain multiple interneuron cell types) fire also with stereotyped firing patterns during initiation of actions (Kvitsiani et al., 2013) or during freezing in mice subjected to fear conditioning (Courtin et al., 2014). We asked how unequivocally identified PV+ basket cells in the prefrontal cortex might contribute to a multidimensional behavioral paradigm involving different behavioral

