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Local Integration Accounts for Weak Selectivity of Mouse Neocortical Parvalbumin Interneurons

Highlights

- Mouse V1 lacks a functional organization for ocular dominance and binocular disparity
- PV+ interneurons are binocular but only weakly sensitive to binocular disparity
- PV+ interneuron selectivity is related to biases in local population selectivity
- PV+ interneurons pool local population responses within 100 μm

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In Brief

Excitatory and inhibitory neurons integrate local neocortical inputs differently. Parvalbumin (PV+) inhibitory neurons exhibit functional responses similar to the neighboring neurons consistent with nonspecific pooling within 100 μm, whereas excitatory neuron selectivity is unrelated to the local population.

Scholl et al., 2015, Neuron *87*, 424–436
July 15, 2015
http://dx.doi.org/10.1016/j.neuron.2015.06.030

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http://dx.doi.org/10.1016/j.neuron.2015.06.030

SUMMARY

Dissecting the functional roles of excitatory and inhibitory neurons in cortical circuits is a fundamental goal in neuroscience. Of particular interest are their roles in emergent cortical computations such as binocular integration in primary visual cortex (V1). We measured the binocular response selectivity of genetically defined subpopulations of excitatory and inhibitory neurons. Parvalbumin (PV+) interneurons received strong inputs from both eyes but lacked selectivity for binocular disparity. Because broad selectivity could result from heterogeneous synaptic input from neighboring neurons, we examined how individual PV+ interneuron selectivity compared to that of the local neuronal network, which is primarily composed of excitatory neurons. PV+ neurons showed functional similarity to neighboring neuronal populations over spatial distances resembling measurements of synaptic connectivity. On the other hand, excitatory neurons expressing CaMKIIα displayed no such functional similarity with the neighboring population. Our findings suggest that broad selectivity of PV+ interneurons results from nonspecific integration within local networks.

INTRODUCTION

Inhibitory interneurons constitute a minority of cortical cells (~20%) (DeFelipe et al., 2002) and are highly diverse in morphology and molecular composition (DeFelipe et al., 2013; Markram et al., 2004). One particular interneuron subtype, parvalbumin-expressing neurons (PV+), account for 35%–40% of interneurons in mouse neocortex (Gonchar et al., 2007). Their prevalence has made them an ideal target by which to examine the functional connectivity among neocortical excitatory and inhibitory cells. Connectivity measurements from paired intracellular recordings in vitro reveal that PV+ interneurons are densely connected to neighboring excitatory pyramidal neurons, whereas excitatory pyramidal cells are weakly connected to one another (Holmgren et al., 2003; Levy and Reyes, 2012; Oswald et al., 2009; Packer and Yuste, 2011; Shepherd and Svoboda, 2005). While these studies in vitro have demonstrated distinct connectivity patterns, the functional consequences of these patterns are less clear.

If PV+ interneurons indiscriminately pool inputs from neighboring neurons with diverse selectivity, they should exhibit broader response selectivity than nearby excitatory neurons. Evidence from two-photon imaging and targeted-extracellular recordings in vivo in mouse V1 has revealed that inhibitory neurons, and in particular PV+ interneurons, exhibit weaker orientation selectivity (Kerlin et al., 2010; Hofer et al., 2011; Atallah et al., 2012; Wilson et al., 2012; Runyan and Sur, 2013). Such broad selectivity is proposed to result from nearby presynaptic neurons displaying heterogeneous orientation preferences (Dräger, 1975; Sohya et al., 2007; Kerlin et al., 2010; Bock et al., 2011; Runyan and Sur, 2013). It is unclear whether inhibitory neurons are broadly selective for other functional properties, or whether broad selectivity is restricted to orientation selectivity which first emerges in subcortical structures.

An emergent functional property in mammalian V1 is binocularity, which provides information about the depth of objects in the environment. The different vantage points of the two eyes create spatial offsets—or disparities—between retinal images, helping to generate a three-dimensional representation of the visual world (Barlow et al., 1967; Blakemore, 1969; Hubel and Wiesel, 1973; Joshua and Bishop, 1970; Nikara et al., 1968; Pettigrew et al., 1968). Individual V1 neurons in primates, carnivores, and rodents are selective for such binocular disparity (Hubel and Wiesel, 1962; Ohzawa and Freeman, 1986; Pettigrew et al., 1968; Poggio and Fischer, 1977; Poggio et al., 1988; Scholl et al., 2013a), whereby visually evoked responses are strongly modulated by binocular stimulation, relative to monocular stimulation alone. Because this response property emerges in mouse V1, we have an opportunity to use genetic and imaging tools to explore differences in excitatory and inhibitory neurons within the cortical circuit.

The binocular response properties of interneurons in mouse V1 might arise from similar circuits as those proposed for