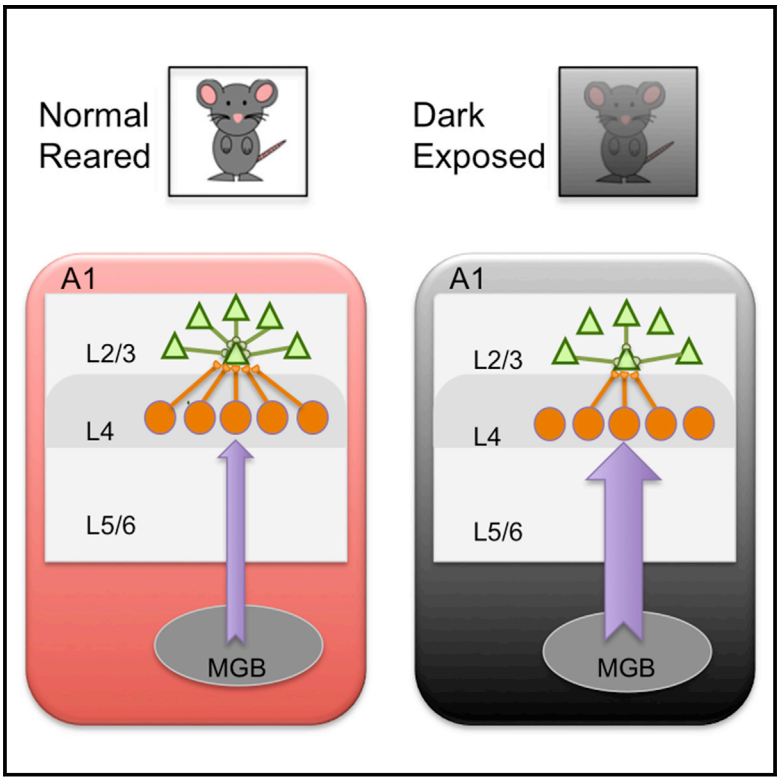
Article

Cell Reports

Visual Deprivation Causes Refinement of Intracortical Circuits in the Auditory Cortex

Graphical Abstract



Authors

Xiangying Meng, Joseph P.Y. Kao, Hey-Kyoung Lee, Patrick O. Kanold

Correspondence

pkanold@umd.edu

In Brief

Meng et al. find that after dark exposure both the excitatory and inhibitory connections from L4, and from within L2/3, to L2/3 neurons are refined. Mathematical modeling shows that the observed refinements can improve the reliability of sound-evoked responses.

Highlights

- Dark exposure (DE) after critical period refines circuits in auditory cortex (A1)
- DE alters intra- and inter-laminar excitatory and inhibitory circuits to L2/3 cells
- DE does not change the balance of excitation and inhibition
- Modeling shows that the altered circuits give more reliable evoked responses

Meng et al., 2015, Cell Reports *12*, 955–964
August 11, 2015 ©2015 The Authors
http://dx.doi.org/10.1016/j.celrep.2015.07.018

Cell Reports
Article

Visual Deprivation Causes Refinement of Intracortical Circuits in the Auditory Cortex

Xiangying Meng,[1] Joseph P.Y. Kao,[2] Hey-Kyoung Lee,[1,3] and Patrick O. Kanold[1,*]
[1]Department of Biology, University of Maryland, College Park, MD 20742, USA
[2]Center for Biomedical Engineering and Technology and Department of Physiology, University of Maryland School of Medicine, Baltimore, MD 21201, USA
[3]Department of Neuroscience, Mind/Brain Institute, Johns Hopkins University, Baltimore, MD 21218, USA
*Correspondence: pkanold@umd.edu
http://dx.doi.org/10.1016/j.celrep.2015.07.018

SUMMARY

Loss of a sensory modality can lead to functional enhancement of the remaining senses. For example, short-term visual deprivations, or dark exposure (DE), can enhance neuronal responses in the auditory cortex to sounds. These enhancements encompass increased spiking rates and frequency selectivity as well as increased spiking reliability. Although we previously demonstrated enhanced thalamocortical transmission after DE, increased synaptic strength cannot account for increased frequency selectivity or reliability. We thus investigated whether other changes in the underlying circuitry contributed to improved neuronal responses. We show that DE can lead to refinement of intra- and inter-laminar connections in the mouse auditory cortex. Moreover, we use a computational model to show that the combination of increased transmission and circuit refinement can lead to increased firing reliability. Thus cross-modal influences can alter the spectral and temporal processing of sensory stimuli by refinement of thalamocortical and intracortical circuits.

INTRODUCTION

The loss of a sensory modality can lead to functional enhancement of the remaining senses in a process often termed "cross-modal plasticity" (Bavelier and Neville, 2002). For example, blind individuals can display better tactile acuity (Grant et al., 2000; Van Boven et al., 2000; Goldreich and Kanics, 2003), sound localization (Lessard et al., 1998; Röder et al., 1999), and pitch discrimination (Gougoux et al., 2004) than sighted individuals. These results suggest that the absence of vision may trigger a refinement and/or sharpening of the remaining senses. There is accumulating evidence that even primary sensory cortices receive subthreshold modulatory information from other sensory systems. These inputs are thought important for multisensory integration under normal conditions (Schroeder and Foxe, 2005; Ghazanfar and Schroeder, 2006) and mainly activate the superficial layers of a primary sensory cortex (Lakatos et al., 2007; Iurilli et al., 2012).

We recently showed that depriving mice of vision by dark exposure (DE) for about 1 week alters the sound-evoked responses in layer 4 (L4) of primary auditory cortex (A1) in that cells responded more robustly to sounds but also showed increased frequency selectivity (Petrus et al., 2014). Whereas some of these changes in the responsiveness to sound can be attributed to increased thalamocortical transmission following DE (Petrus et al., 2014), increased frequency selectivity and spiking reliability cannot be accounted for by increased gain at the thalamocortical synapse but likely requires refinement of thalamocortical as well as intracortical excitatory or inhibitory synapses, which can alter the spectral tuning of A1 cells (Li et al., 2013, 2014). DE also causes changes to miniature excitatory postsynaptic current (mEPSC) amplitudes in the superficial layers in A1 as well as in primary somatosensory cortex (S1) (Goel et al., 2006; He et al., 2012). Layer 2/3 (L2/3) neurons receive excitatory and inhibitory inputs from the superficial and granular layers, and refinement of these connections can give rise to increased frequency selectivity. We therefore investigated whether DE causes a refinement of intracortical circuits in A1.

Although mEPSC and miniature inhibitory postsynaptic current (mIPSC) recordings enable an investigation of changes in the strength of individual synapses onto a neuron, they do not reveal which synapses are affected. Moreover, changes in synapse numbers between cells or the strength of unitary connections will not be revealed. Thus, to identify which microcircuits in A1 are affected by visual experience, we here use laser-scanning photostimulation (LSPS) to spatially map the connectivity of excitatory and inhibitory inputs to A1 neurons to determine whether visual deprivation alters their circuit topology. To assess changes in both intra- and inter-laminar connections, we record from L2/3 neurons. We find that 6–8 days of dark rearing does not affect the intrinsic excitability of L2/3 neurons but does alter the spatial pattern of both excitatory and inhibitory intra- and inter-laminar connections. Moreover, our results indicated that, in general, inter-laminar excitatory inputs originating from L4 were confined to a smaller area, indicating refinement of ascending connections. Furthermore, inhibitory inputs were also refined. To investigate the effects of circuit refinement, we implemented a computational model and found that refinement also resulted in more-reliable responses. Together, our results show that DE