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Article

Sensory Cortical Control of a Visually Induced Arrest Behavior via Corticotectal Projections

Highlights

- Flash light induces a transient suspension of locomotion in running mice
- The arrest of locomotion is critically dependent on superior colliculus (SC) activity
- V1 enhances the arrest behavior and SC responses via corticotectal projections
- V1 directly drives the behavior via activation of corticotectal projections to the SC

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In Brief

Sensory stimuli can induce innate behaviors of animals important for their survival. Liang et al. show that via a corticotectal projection, visual cortex not only modulates flash light induced transient suspension of locomotion, but also can directly drive the behavior.

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Sensory Cortical Control of a Visually Induced Arrest Behavior via Corticotectal Projections

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SUMMARY

Innate defense behaviors (IDBs) evoked by threatening sensory stimuli are essential for animal survival. Although subcortical circuits are implicated in IDBs, it remains largely unclear whether sensory cortex modulates IDBs and what the underlying neural pathways are. Here, we show that optogenetic silencing of corticotectal projections from layer 5 (L5) of the mouse primary visual cortex (V1) to the superior colliculus (SC) significantly reduces an SC-dependent innate behavior (i.e., temporary suspension of locomotion upon a sudden flash of light as short as milliseconds). Surprisingly, optogenetic activation of SC-projecting neurons in V1 or their axon terminals in SC sufficiently elicits the behavior, in contrast to other major L5 corticofugal projections. Thus, via the same corticofugal projection, visual cortex not only modulates the light-induced arrest behavior, but also can directly drive the behavior. Our results suggest that sensory cortex may play a previously unrecognized role in the top-down initiation of sensory-motor behaviors.

INTRODUCTION

Innate defense behaviors invoked by natural threatening sensory stimuli (Bordi and LeDoux, 1992; LeDoux, 2012; Motta et al., 2009; Yilmaz and Meister, 2013) are essential for animal survival. In nocturnal rodents, an expanding dark visual stimulus above the animal, which is analogous to a looming shadow indicating an approaching aerial predator, triggers two types of protective behavior: the animal either dashes for cover underneath an opaque nest (Wallace et al., 2013; Yilmaz and Meister, 2013) or stops moving and stands completely motionless for an extended period of time (Yilmaz and Meister, 2013). The latter behavior, called "freezing," may render the detection of the prey animal more difficult. Simpler visual stimuli such as increasing illumination can also evoke a variety of behaviors that may indicate fear or anxiety. For instance, lighting differentials evoke a preference for dark, whereby rats tend to avoid brightly illuminated places (Godsil and Fanselow, 2004; Williams, 1971). Bright illumination evokes thigmotaxis (a tendency to stay near walls), a behavior that can reduce detectability and threats of attack from behind and above (Godsil and Fanselow, 2004; Valle, 1970). In an open-field arena, the onset and termination of bright light temporarily increase locomotion in rats (Godsil and Fanselow, 2004). This has been thought as an exploratory response geared at investigating surroundings—protective behavior before encountering predators. These studies suggest that bright light may be a danger signal for rodents.

Midbrain structures including the superior colliculus (SC), inferior colliculus (IC), and periaqueductal gray (PAG) have been implicated in the production of unconditioned or innate defense behaviors (Brandão et al., 2005; McHaffie et al., 2005; Sahibzada et al., 1986; Schenberg et al., 2005; Sudré et al., 1993). Anatomically midbrain colliculi receive abundant corticofugal projections from sensory cortices (Comoli et al., 2012; McHaffie et al., 1993; Oh et al., 2014; Wang and Burkhalter, 2013). The superficial layers of SC receive massive inputs from the primary visual cortex (V1), and visual inputs to the deeper layers of SC arise predominantly from the secondary visual cortices (Comoli et al., 2012; Harting et al., 1992; Harvey and Worthington, 1990). It is natural to speculate that sensory cortex may relay processed information (e.g., contextual information and information on the evaluated threatening nature of stimuli), to the colliculi. However, the role of sensory cortex in naturally induced innate behaviors and the neural circuits underlying the cortical impacts on these behaviors have remained poorly understood.

In this study, we intended to develop a behavioral assay that is amenable to easy quantification of response levels. This allowed us to investigate the neural pathways underlying an identified visually induced innate behavior (i.e., temporary suspension of locomotion upon a sudden flash of light). By combining optogenetic manipulations of activity of different neural structures, we revealed that the behavior depended on intact SC activity and that specific corticofugal circuits played a critical role in modulating and driving this behavior.