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Activation of Striatal Neurons Causes a Perceptual Decision Bias during Visual Change Detection in Mice

Highlights

- Activation of basal ganglia biases perceptual choices in a visual detection task
- Direct pathway stimulation biases choices in favor of expected contralateral events
- Effects on perceptual choice require the presence of task-relevant visual stimuli
- Choice-related GCaMP activity also requires the presence of task-relevant stimuli

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In Brief

Using a visual change detection task in mice, Wang et al. demonstrate that the direct and indirect pathways in the basal ganglia contribute to perceptual decision-making by biasing choices in favor of expected or valued visual events.

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Activation of Striatal Neurons Causes a Perceptual Decision Bias during Visual Change Detection in Mice

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SUMMARY

The basal ganglia are implicated in perceptual decision-making, although their specific contributions remain unclear. Here, we tested the causal role of the basal ganglia by manipulating neuronal activity in the dorsal striatum of mice performing a visual orientation-change detection (yes/no) task. Brief unilateral optogenetic stimulation caused large changes in task performance, shifting psychometric curves upward by increasing the probability of "yes" responses with only minor changes in sensitivity. For the direct pathway, these effects were significantly larger when the visual event was expected in the contralateral visual field, demonstrating a lateralized bias in responding to sensory inputs rather than a generalized increase in action initiation. For both direct and indirect pathways, the effects were specific to task epochs in which choice-relevant visual stimuli were present. These results indicate that the causal link between striatal activity and decision-making includes an additive perceptual bias in favor of expected or valued visual events.

INTRODUCTION

The basal ganglia are a set of subcortical nuclei that play a central role in regulating actions (Dudman and Krakauer, 2016; Hikosaka et al., 2014). The complete basal ganglia circuit is astonishingly complex, but the basic backbone is well established. The striatum, the main input nucleus of the basal ganglia, contains distinct classes of projection neurons that give rise to pathways with complementary roles—a direct pathway through the substantia nigra that facilitates desired actions and an indirect pathway through the globus pallidus that inhibits unwanted actions (Albin et al., 1989; DeLong, 1990; Gerfen et al., 1990; Mink, 2003). There is also a "hyperdirect" pathway through the subthalamic nucleus that rapidly alters basal ganglia output (Nambu et al., 2002). Studies using genetic targeting of striatal neurons in mice have mostly confirmed these functional arrangements and clarified how the direct and indirect pathways work together during the initiation of orienting movements and action sequences (Cui et al., 2013; Jin et al., 2014; Kravitz et al., 2010; Tecuapetla et al., 2014, 2016).

Whether an action should be facilitated or not depends on the expected value of the action given the behavioral context, and there is growing evidence that the functional scope of the basal ganglia includes these more cognitive aspects of action selection. In the primate striatum, the activity of many neurons is related to the value of specific actions, such as making a saccade in a particular direction (Lau and Glimcher, 2008; Lauwereyns et al., 2002a, 2002b) or turning a handle left or right (Samejima et al., 2005). In mice, optogenetic stimulation of striatal neurons can bias orienting choices toward the response port associated with higher rewards (Tai et al., 2012).

The basal ganglia are also implicated in perceptual decision-making tasks (Ding and Gold, 2013), in which action value depends on judging sensory signals, as often happens during natural behavior. In the classic visual motion discrimination task, when the subject decides how to move their eyes based upon the direction of motion in a visual stimulus (Shadlen and Kiani, 2013), neurons in the primate striatum exhibit activity related to several aspects of the decision process (Ding and Gold, 2010) and electrical stimulation of the primate striatum biases perceptual choices as well as the saccades (Ding and Gold, 2012). These results are consistent with clinical findings in humans that basal ganglia dysfunction causes not only motor impairments, but also deficits in sensory and cognitive functions (Botha and Carr, 2012; Brown et al., 1997).

The possible involvement of the basal ganglia in perceptual decision-making raises several important questions. Is there a causal link between the activity of striatal neurons and perceptual decision-making? The results from applying electrical stimulation in the primate caudate nucleus provide compelling evidence in favor of a causal role (Ding and Gold, 2012) but leave some key points unresolved. Given the widespread inputs to the striatum from the cortex, including projections from areas known to be involved in decision-making (Haber et al., 2006; Selemon and Goldman-Rakic, 1985), changes in performance with electrical stimulation could be caused by antidromically activating cortical neurons rather than orthodromically activating circuits through the basal ganglia. Are both the direct and indirect pathways involved? Because electrical stimulation affects neural tissue