Journal Club

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Birdsong and the Brainstem

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Review of Ashmore et al. (<http://www.jneurosci.org/cgi/content/full/25/37/8543>)

Introduction

As the oscine song system gained prominence as a model for studying motor control and learning, more attention focused on the specific contributions to singing made by the various components of the song system motor pathway. Initially, that pathway appeared to be a simple circuit consisting of a telencephalic nucleus HVC projecting to the RA that then directly innervates vocal motor neurons and brainstem respiratory centers (Fig. 1). This perhaps suggested a simple hierarchical division of labor wherein HVC issues general “commands” specifying the overall sequence of song components that are subsequently translated into increasingly specific motor instructions by the successive components of the pathway. A microstimulation study in the zebra finch (Vu et al., 1994) supported this view by showing that unilateral stimulation within HVC during singing affected the sequence of song syllables, whereas stimulation lower in the pathway, in RA, caused brief distortion of ongoing syllables without changing syllable order or timing. That, and other work, promoted the idea that HVC functions as the central pattern generator (CPG) for song and that subsequent components of the pathway merely execute these commands.

This simple picture was clouded by the realization that feedback pathways from

brainstem vocal–respiration circuits could affect HVC (Wild, 1997). Furthermore, the neural activity in HVC of each hemisphere is synchronized (Schmidt, 2003), and stimulation in one HVC can “reset” the pattern of activity in the contralateral HVC (Vu et al., 1998). The only anatomical pathways that could mediate synchronization and signaling between the HVC nuclei pass through the brainstem, implying that feedback from the brainstem can in fact influence activity in HVC under some circumstances. In light of this, Ashmore et al. (2005) reexamined the functional roles of the various song motor nuclei, again using microstimulation, but now stimulating brainstem structures as well as HVC and RA and measuring air sac pressure in addition to acoustic output.

Ashmore et al. (2005) divided the effects of microstimulation into two classes: syllable level, including syllable distortion and truncation, and song level, including restarting or terminating motifs (the stereotyped sequence of syllables comprising song bouts). Unilateral HVC stimulation evoked song- or syllable-level effects [Ashmore et al. (2005), their Figs. 2 (<http://www.jneurosci.org/cgi/content/full/25/37/8543/FIG2>) and 3 (<http://www.jneurosci.org/cgi/content/full/25/37/8543/FIG3>)], often in tandem. Syllable truncation in particular was almost always accompanied by song-level effects. This in itself could be consistent with a model that ignores brainstem feedback, but the authors’ careful examination of the latency from stimulation to the behavioral effect raises some doubts. The average

latency from HVC stimulation to syllable truncation was ~75 ms [Ashmore et al. (2005), their Fig. 4 (<http://www.jneurosci.org/cgi/content/full/25/37/8543/FIG4>)], yet the respiratory pattern as measured by air sac pressure could be affected in <20 ms [Ashmore et al. (2005), their Fig. 5 (<http://www.jneurosci.org/cgi/content/full/25/37/8543/FIG5>)]. This suggests that syllable truncation may not simply result from a disruption in the stimulated HVC transmitted directly to brainstem circuits; the extra time may reflect a requirement for disruption of the contralateral HVC before the full behavioral effects are manifest. Comparing their results to Vu et al. (1998), the authors note that the mean latency to resetting activity in contralateral HVC (36 ms) was longer than that to the first measurable changes in air sac pressure but was much shorter than the latency to syllable truncation [Ashmore et al. (2005), their Fig. 6 (<http://www.jneurosci.org/cgi/content/full/25/37/8543/FIG6>)], consistent with propagation down to the brainstem and back to the contralateral HVC.

In contrast to the results of Vu et al. (1994), Ashmore et al. (2005) reported that even weak (15 μ A) unilateral stimulation in RA could trigger song-level effects. In fact, low-intensity stimulation of RA was just as effective as stimulation in HVC [Ashmore et al. (2005), their Fig. 7 (<http://www.jneurosci.org/cgi/content/full/25/37/8543/FIG7>)]. This undermines the notion that RA only follows the pattern set by HVC, but given these data alone, it is still possible that the song-level effects of RA microstimulation are attrib-

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utable to antidromic disturbance of HVC activity rather than orthodromic effects propagating through normal feedback pathways. However, the authors go on to show that stimulation of nucleus paraambigualis within the brainstem respiratory network could also trigger song-level effects, in addition to the expected syllable-level effects [Ashmore et al. (2005), their Fig. 8 (<http://www.jneurosci.org/cgi/content/full/25/37/8543/FIG8>)]. Because HVC does not project directly to the brainstem, the song-level effects cannot be explained by antidromic disturbance of this putative CPG. In contrast, stimulation of the tracheosyringal portion of the hypoglossal nucleus that lacks ascending feedback projections did not evoke song-level effects [Ashmore et al. (2005), their Fig. 8 (<http://www.jneurosci.org/cgi/content/full/25/37/8543/FIG8>)].

These data demonstrate that feedback from the brainstem can affect the motor program that drives song production. This raises the intriguing possibility that the song motor pathway, not just HVC, collectively functions as the song CPG. However, that is just one possibility; these data do not exclude the hypothesis that HVC plays a privileged role in generating the song motor pattern. *In vitro* studies have shown that HVC can generate rhythmic activity patterns in isolation (Solis and Perkel, 2005), and brainstem feedback may do little more than coordinate activity patterns generated by HVC. Reliance on unilateral stimulation may have obscured this possibility if song-level effects require the transmission of disruptive stimulation-induced activity to the contralateral HVC. Bilateral stimulation in HVC might have demonstrated a lower threshold for inducing song-level effects than bilateral stimulation in RA, supporting a more hierarchical division of labor like that implied by the pioneering study of Vu et al. (1994). Nevertheless, the au-

Figure 1. Schematic of the song system motor pathway with feedback from the brainstem. HVC and the robust nucleus of the archipallium (RA) are a part of the telencephalic pallium and are analogous to mammalian motor/premotor cortex, although specialized for vocal control. The ventral two-thirds of RA projects to the tracheosyringal portion of the hypoglossal nucleus (nXIIIts), containing motor neurons that innervate the avian vocal organ, the syrinx. RA, especially dorsal RA, also directly innervates three interconnected components of a brainstem respiratory control network: the dorsomedial nucleus of the intercollicular complex (DM), nucleus retroambigualis (RAm; innervating expiratory motor neurons), and nucleus paraambigualis (PAm; innervating inspiratory motor neurons). Two of these nuclei (DM and PAm) project to the thalamic nucleus uvaformis (Uva) bilaterally, providing feedback to HVC on both sides of the brain. In addition, DM projects to the contralateral DM, and RAm projects to the entire contralateral brainstem vocal-respiratory network, providing a rich substrate for bilateral coordination. Regions subjected to microstimulation in this study are marked with a lightning bolt.

thors conclusively demonstrate that feedback from the brainstem can affect song motor pattern and alert us to the possibility that brainstem circuitry actively participates in generating complex learned behaviors rather than merely following orders sent from the telencephalon.

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