BATS AND THE COMPARATIVE NEUROBIOLOGY OF VOCAL LEARNING

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1. Comparative research into vocal learning and human spoken language

The capacity to communicate with one another through spoken language is a uniquely human ability. However, certain components underlying our capacity for spoken language, such as vocal production learning (from here on: vocal learning), are shared with other animals. Vocal learning is the ability to modify vocalizations based on experience (Janik & Slater, 2000). Humans use their vocal learning abilities when they are learning the phonemes and spoken words of their native language. Evidence for vocal learning in non-human animals has been found in birds, cetaceans, elephants, pinnipeds, and bats, but not in non-human primates (Fitch & Jarvis, 2013). Neurobiological research into vocal learning has mainly focused on songbirds and has taught us a great deal about the neural basis of avian vocal learning. However, as avian brains differ significantly from mammalian brains, we must also study the neurobiology of mammalian vocal learning, especially if we want to better understand the evolution and neural basis of vocal learning and human spoken language.

Bats are particularly well-suited for the study of mammalian vocal learning as bat species across the evolutionary tree show evidence of vocal learning, and numerous bat species are gregarious animals that live in social groups and employ a wide range of vocalizations (Vernes, 2017). Moreover, certain species, such as the vocal learning, pale spear-nosed bat *Phyllostomus discolor*, can be kept successfully in a laboratory setting, enabling controlled experiments (Esser, 1994; Lattenkamp, Vernes, & Wiegrebe, 2018).

2. Examining the neurobiology of bat vocal learning

Our work investigates the *P. discolor* brain using molecular and neuroimaging approaches, to facilitate testing of key hypotheses related to the neurobiology of vocal learning in a mammalian model.

In humans and songbirds, a cortical/pallial vocal motor region – the laryngeal motor cortex (LMC) in humans and the robust nucleus of the arcopallium (RA) in songbirds – is responsible for uttering voluntary vocalizations (Jürgens, 2002). It has been hypothesized that a core feature of a vocal learning brain is a direct neural connection from this area to the vocal motor neurons that control the vocal apparatus (Jürgens, 2002; Kuypers, 1958). The axon guidance genes *Robo1* and *Slit1* have been implicated in the formation of this direct connection, and in humans and songbirds, a comparatively low amount of *Slit1* expression can be found in the LMC and RA compared to the surrounding brain areas (Pfenning et al., 2014; Wang et al., 2015). In our research, we are examining the expression patterns of *Robo1* and *Slit1* across the cortex of *P. discolor* brains in order to locate a potential LMC in these vocal learning bats. This area can be a future target for tracing experiments to test whether a direct connection from this area to the brainstem motoneurons innervating the larynx exists in *P. discolor*.

We have also conducted magnetic resonance imaging and diffusion tensor imaging of an adult, female *P. discolor* brain. As increased connectivity between different brain regions involved in vocal communication has been found in humans compared to non-human primates, we are exploring the connectivity of the *P. discolor* brain to see if similar enhanced connectivity profiles can be observed (Kumar et al., 2016; Rilling et al. 2008).

By locating brain regions involved in vocal learning in *P. discolor* and studying the connectivity between these regions, we will increase our understanding of the different and shared neurobiological mechanisms that make animals capable of vocal learning.

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