Auditory selectivity for species and self recognition in the zebra finch brain: new insights from spin-echo BOLD fMRI.

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Introduction: The neurobiology of birdsong, as a model for human speech, is a growing area of research in the neurosciences. Until now, the neural substrates of song perception received less attention than song production and our knowledge about discrimination properties of the different auditory nuclei remains incomplete. The goal of this study was to investigate the neural substrates of auditory species recognition and self recognition.

Material and Methods: By opposition to electrophysiology and molecular approaches that allow to investigate either different stimuli on few neurons, either one stimulus in large parts of the brain, BOLD fMRI allows to combine both advantages, i.e. to compare the neural activations induced by different stimuli in the whole brain. Until now, gradient-echo (GE) fMRI successfully developed in starling (1) and zebra finches (2, 3). However, at high magnetic filed, GE fMRI does not allow to investigate neural activity in boundary parts of the brain because of susceptibility artifacts and is not spatially accurate. Because we were interested to study species and self recognition on the whole brain, including the auditory pathway (Fig. 1) and the song control system, and wanted a good spatial accuracy, we have developed spin-echo fMRI. Twelve anesthetized male zebra finches were tested in our Pharmascan 7 Tesla MRI system with five different auditory stimuli: random tones (RT), familiar heterospecific songs (fHS, songs from canaries and starlings), unfamiliar conspecific songs (ufCS, song from unknown zebra finches), familiar conspecific songs (fCS, songs from zebra finches housed in the same cage) and the bird's own song (BOS). Data were realigned, co-registered to an MRI atlas developed in our lab, and smoothed. Statistical results were then assessed with the General Linear Model implemented in SPM software. An ANOVA was first performed to identify voxels were differential activations occurred. Then different paired t-tests were computed to identify these differential activations. P values were corrected for multiples comparisons with the Family Wise Error method.

Results: **Auditory species recognition** was assessed by the comparison of neural substrates of familiar conspecific song perception with those of familiar heterospecific song perception. This comparison revealed a greater activation by conspecific song perception of two distinct brain regions: left MLd, the auditory midbrain nucleus (equivalent to the inferior colliculus in mammals) ($t = 2.84$, $p= 0.034$) and a region located in the right globus pallidus ($t = 3.93$, $p = 0.035$). These results were comforted by the comparison of neural substrates of bird's own song perception with those of heterospecific song perception (BOS minus fHS: $t = 2.75$, $p = 0.023$ for MLd; $t = 2.82$, $p = 0.036$ for the globus pallidus). Whereas MLd is a well-known auditory nucleus, the global pallidus does not make part of the traditional auditory pathway. To test if the cluster specifically involved in species recognition presents auditory properties, the map of regions activated by random tones, the only auditory non-significant stimulus, was computed and revealed significant activation of this cluster ($t = 2.47$; $p = 0.042$). **Auditory self recognition** was assessed by the comparison of neural substrates of bird's own song perception with those of familiar conspecific song perception. This comparison revealed the specific activation of right HVC ($t = 4.6$, $p = 0.001$), an important nucleus of the song control system well known to be specifically involved in self recognition (3), but also of right MLd ($t = 2.83$, $p = 0.035$) (Fig. 2). These results were comforted by the comparison of neural substrates of bird's own song perception with those of heterospecific song perception (BOS minus fHS: $t = 3.25$, $p = 0.005$ for HVC and $t = 3.59$, $p = 0.003$ for MLd). Finally, because bird's own song and familiar conspecific songs differed by their degree of familiarity, we tested if these two nuclei made part of the memory pathway. This pathway was identified by the comparison of neural substrates of familiar conspecific song perception with those of unfamiliar conspecific song perception. This comparison revealed no differential activation in both these regions ($p > 0.1$).

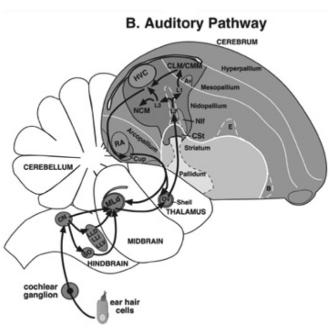

Figure 1: Schematic representation of the auditory pathway: main auditory nuclei include MLd that projects to Ovoidalis that projects to the primary auditory cortex Field L (L1, L2 and L3) that projects to the secondary auditory regions, namely NCM and CLM/CMM. Note that the primary auditory subregion L3 and the secondary auditory region CLM/CMM connect to the song control system at HVC level.

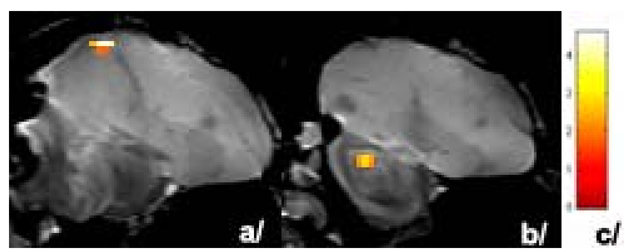

Figure 2: Regions more activated by bird's own song perception than by familiar conspecific song perception superimposed to sagittal slices of the atlas used for co-registration. a/ HVC activation (x = 2.2 mm to midline); b/ MLd activation (x = 3 mm to midline); c/ color scale of t values.

Discussion and Conclusion: Whereas recognition of bird's own song was only attributed to regions in the song control system, including HVC (4), our results reveal that self recognition already occurs at MLd level, in the midbrain, a very early stage of the auditory pathway. Species recognition also occurred at this level, but whereas self recognition occurred in right MLd, species recognition occurred in left MLd, demonstrating a clear functional lateralization of this structure. Our results also reveal a new auditory region in the globus pallidus involved in species recognition. This study thus presents the first SE fMRI results obtained in songbirds. It demonstrates the feasibility of spin-echo fMRI in small songbirds and reveals new insights about auditory selectivity of the zebra finch brain.

References

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