Procedia Computer Science
Volume 88, 2016, Pages 282–287
7th Annual International Conference on Biologically Inspired Cognitive Architectures, BICA 2016

Neural Substrates of The Auditory Motion Aftereffect: a Functional MRI Study

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Abstract
The aim of this study was to identify cortical areas, which are responsible to perception of sound source approaching or withdrawing. Models of moving sound sources were presented to 7 healthy subjects while activity of their brain was traced by fMRI. It was found that during long-term 45 s sound stimulation additional areas of activation to that in control stimulation with pink noise were involved. There were frontal and parietal areas which perform the function of analysis of spatial information and also the region of the angular gyrus. Furthermore BOLD-signal in the areas remained to be enhanced after the end of adaptation to motion and decayed gradually within 30 s. Pilot experiments with use of sound recordings of human steps as auditory stimuli had shown the same areas of activation but with much stronger activation.

Keywords: sound localization, motion aftereffect, fMRI, SPM, auditory adaptation.

1 Introduction

The methods of neurovisualization demonstrated both the bilateral activation of the temporal cortex and the unilateral activation of the parietal cortex on the right side in response to signals simulating the sound source motion in different directions (Pavani, 2002), (Warren, 2002). The direction in which sound stimuli move can be decoded in responses of the neuronal ensembles in the dorsal parietal-temporal cortex area (Wolbers, 2011), (Alink, 2012). Auditory motion direction could not be decoded from activation patterns in hMT/V5+. These findings provide further evidence for the planum temporale playing a central role in supporting auditory motion perception. In addition, the data

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Selection and peer-review under responsibility of the Scientific Programme Committee of BICA 2016

doi:10.1016/j.procs.2016.07.436

suggest a cross-modal transfer of directional information to high-level visual cortex in healthy humans. Auditory adaptation to a sound source motion can cause noticeable changes in the spatial perception of subsequent sound stimuli, so called aftereffect. A hypothesis about the role of selective motion sensitivity of neural elements in the formation of the auditory motion aftereffect (Dong, 2000) suggests the presence of selectivity to motion direction (Warren, 2002). The auditory motion aftereffects (aMAE) of sound source upon presentation of approaching and receding sound images - signals changed in intensity and frequency, was shown (Malinina, 2012).The aim of the work was to identify areas of activation of human brain using functional magnetic resonance imaging (fMRI) during and after stimulation of the approaching and receding sound images.

2 Materials and Methods

Participants Seven healthy volunteers participated in the fMRI study (age range, 19–43 years; 3 females). All subjects had normal hearing. All subjects gave their informed consent after being introduced to the experimental procedure in accordance with the Declaration of Helsinki.

Stimuli Auditory stimuli were two sequences of 10 ms sound bursts with 15 ms pauses between them. The first sequence modeled sound source approach, it had 30 dB linear increase of the amplitude of the bursts and linear decrease of their frequency from 1800 to 1400 Hz, second sequence imitated withdrawal of a sound source and had 30 dB linear decrease of the bursts' amplitude and linear increase of frequency from 1400 to 1800 Hz. An unmoving stimulus had constant amplitude and was 6 s pink noise in the same frequency band. The spectral range of the stimuli was chosen in order to diminish an overlapping of spectral regions of the stimuli and the MR tomograph noise. An adaptation period lasted 45s, and included seven similar stimuli with 6 s duration, separated by 0.5 s pauses.

Task—fMRI Experiment The study was performed on MR tomograph Magnetom Verio 3T (Siemens, Germany) using a 32-channel MR head coil in two stages:

1. Collecting of anatomical data with high resolution based on T1-weighted sequence (TR 1900 ms, TE 2.21 ms, 176 slices, voxel size of 1x1x1 mm^3)
2. Recording data on the basis of functional EPI-sequence (TR 2000 ms, TE 30 ms, 42 slices, voxel size 2x2x2 mm^3).

The duration of experiment was about 50 minutes, during which the subjects were asked to rest with closed eyes. To increase the signal / noise ratio and improve the quality of stimulation compared with standard MR-compatible headphones were used optical OptoACTIVE (Israel) one with active noise cancellation for stimuli presentation.

The results were obtained using SPM8 software package (statistical parameter mapping http://www.fil.ion.ucl.ac.uk/spm/). It was carried out by combining structural and functional data MNI atlas in front of the anterior commissure, and then the data were normalized to the size of a template image voxel 2x2x2 mm^3. The magnetic field inhomogeneity was corrected for the fMRI data. Functional data were co-registered to structural ones (performed their superposition). After the co-registration in order to remove accidental releases for the functional data a smoothing procedure was performed with Gaussian kernel 8x8x8 mm^3.

In order to control stimuli audibility it was decided to compare activity level of the entire period of stimulation (45 seconds) and the thirty-second rest period prior to the stimulus using T-statistics. The testing was carried out for statistically significant activations in the primary auditory cortex. An example of such a map is shown at Figure1. The results of this comparison will be further referred to as "control condition".