КОГНИТИВНАЯ НАУКА В МОСКВЕ

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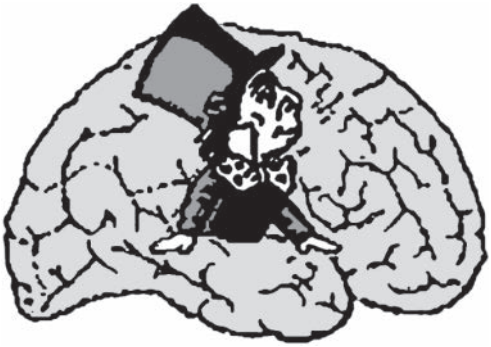

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Deactivation in auditory cortex evoked by affective pictures and revealed by fMRI as a potential neural signature of inattentional deafness

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Abstract. This paper explores in more detail the phenomenon of deactivation of the auditory cortex evoked by the presentation of the affective pictures that we accidentally found in one of our recent studies (Litvinova et al., 2016). Data from two previous studies employing affective pictures (Litvinova et al., 2016 and Rozovskaya et al., 2014, 2016) were re-analyzed and demonstrated a similar pattern of results. Emotionally negative scenes elicited significant deactivation in the auditory cortex in passive viewing and during encoding of pictures into memory. Emotional valence (positive, negative or neutral) significantly affected BOLD signal change in the auditory cortex under conditions of passive viewing (with the most pronounced deactivation evoked by mutilation pictures), but not in the memory task condition. However, mere presentation of an affective picture is not enough to induce deactivation in the auditory cortex. Unlike encoding, retrieval of the affective pictures from working memory evokes a significant positive BOLD response. A pronounced leftward hemispheric asymmetry of this response suggests that it may reflect a role of verbal processes in the retrieval of information from the working memory. Overall, our results suggest that the observed phenomenon may reflect a neural signature of inattentional deafness (ID): a failure to perceive auditory stimuli which manifests under high visual perceptual load. Therefore, we predict that passive viewing and memorization of negative affective pictures, but not their retrieval from WM, would be accompanied by the ID effect at the behavioral level.

Keywords: inattentional deafness, auditory cortex, ROI analysis, affective pictures, IAPS, GAPED, fMRI

Introduction

Inattentional deafness (ID) is a failure to perceive the auditory stimuli which manifests under high visual perceptual load (MacDonald, Lavie, 2011). So far, not many studies have addressed the possible neural correlates of this recently discovered phenomenon. An MEG study by Molloy et al. (2015) revealed that an increase of the task-relevant visual load results in a decrease of auditory cortex

responses to task-irrelevant stimuli. An EEG study by Giraudet et al. (2015) also found that ID is accompanied by a decrease in the auditory P300 ERP component. To our knowledge, no fMRI study has yet explored possible changes in the activation of the auditory cortex during ID. However, we may expect that ID may also manifest as an evoked deactivation (BOLD-signal drop below the baseline level) in the auditory cortex.

In a recent fMRI study involving perception of affective pictures (Litvinova et al., 2016), we unintentionally observed a phenomenon that may represent such a possible neural signature of ID. The study was focused on the effects of a memory task and the emotional content of stimuli on activation of the amygdala. Control regions of interest (ROI) in the visual and auditory cortices were used in order to account for possible global variations of the BOLD signal induced by task or arousal. The auditory cortex was selected as a control ROI since initially we considered the effect of viewing and memorizing emotional visual stimuli on the auditory cortex to be unlikely. However, we found that affective pictures evoked a significant reduction of the BOLD signal in the auditory cortex compared to the baseline level. The magnitude (percentage) of this negative BOLD signal change was comparable to the positive BOLD signal change in the amygdala. We also found an interaction between the emotional valence of the pictures and the task: image category affected the BOLD signal change in the auditory cortex under conditions of passive viewing (with the most pronounced deactivation evoked by mutilation pictures), but not in memory task condition.

Although we did not explicitly test the ability of our participants to detect acoustic stimuli during the presentation of the affective pictures, and therefore were not able to make a strong claim for the neural correlates of ID, we nevertheless hypothesized that the pattern of activation observed in our study may indicate involvement of the same mechanism. The observed decrease in the BOLD signal may partially reveal how reallocation of attentional resources between sensory modalities is implemented in the brain under the high perceptual or mental load that emerges when participants attend to highly biologically significant visual stimuli (erotica or mutilation) or when they are engaged in a demanding cognitive task.

Here we present two pieces of evidence for the presence of such a neural signature of ID during the perception of affective pictures. First is a more detailed analysis of our initial finding from Litvinova et al. (2016), and second are the results of the ROI analysis of the data from another project devoted to working memory (WM) on affective pictures (partially published in Rozovskaya et al., 2014; 2016). Since the second study only employed a WM task and no passive viewing condition, we expected the results from the second dataset to confirm the results of the memory task condition in Litvinova et al. (2016).

Method

In Study 1, an original fMRI experiment (Litvinova et al., 2016) was designed to test the effect of the memory task (vs. passive viewing) on the BOLD-signal change evoked in the amygdala by affective pictures. Here we consider data from

all 44 participants who were included in the final analysis in the original study: 22 in the experimental group (15 females) and 22 in the control group (11 females), mean age 26 ± 5 years in each group. All participants viewed the same set of 54 International Affective Picture System (IAPS) pictures, with 18 images of scenes from each category: emotionally neutral, negative emotional valence (mutilation) and positive emotional valence (erotica). Each image remained onscreen for six seconds. Participants in the control group performed passive viewing and were asked to attend to the screen while the experimenter recorded their brain activity. Participants in the experimental group performed a memory task and were instructed to memorize the stimuli. A short recognition test was introduced after the end of the functional scanning session in this group. Regions of interest (ROI) in the auditory cortex were constructed as spheres around the spot manually selected in each participant's structural image within the Sylvian fissure of the right and left hemispheres in a gray matter concentration between the transverse temporal gyrus and the planum temporale. Sphere volume corresponded to amygdala volume in the matching hemispheres of the same participant.

Study 2 (Rozovskaya et al., 2014; 2016) was a part of a complex project that involved both fMRI and EEG and was devoted to the developmental changes in the functional system of the brain underlying WM for emotionally neutral and emotionally charged (and thus potentially distracting) information. Participants performed a change detection task with emotionally neutral, positive and negative IAPS and GAPED images (40 pictures in each emotional modality) and responded whether the two stimuli were identical or different with a button press. Within each of the 120 trials, the offset of the first display (standard stimulus) was followed by the onset of the test image after a delay period, so that the first image had to be maintained in memory during the delay which varied from 9 to 11.5 seconds. On half of the trials the test display was identical to the standard display, but on the other half of the trials some minor aspects of the image changed (such as background color, detail color, rotation, brightness, contrast, presence or absence of some details, etc.). The original image from the database was always used as the standard image, which guaranteed the required emotional coloring of the image representation during the WM retention period. Every standard stimulus was presented for 4 seconds, and every test image appeared for 3 seconds. Data from 36 adult participants (15 females, mean age 30) who performed all four functional runs (120 trials) were included in the present analysis. The same ROI in the auditory cortex were used for all participants, constructed as two spheres with centers and radii corresponding to the average of those from the ROIs used in Study 1 (MNI coordinates {53, −22, 14}, radius 6 mm in the right hemisphere; MNI coordinates {−53, −24, 13}, radius 7 mm in the left hemisphere). BOLD signal changes were extracted separately for two types of events involving picture presentation: at the stage of encoding the information into WM (picture presented as the standard stimulus) and at the stage of information retrieval (picture presented as the test image).

In both studies, structural and functional MRI data were acquired with a Siemens 1.5T Avanto MR scanner located at the Federal Center of Medicine and Rehabilitation in Moscow. Functional data were preprocessed with SPM software

(SPM8 for Study 1 and SPM12 for Study 2; Wellcome Institute of Cognitive Neurology, www.fil.ion.ucl.ac.uk) with the spatial smoothing step excluded from the pipeline. ROI were built and the BOLD signal percent changes were extracted with Marsbar toolbox for SPM. Further details on the materials, experimental procedures and imaging details are available in respective papers.

Results

The average percent BOLD signal change evoked in the auditory cortex by each type of stimuli in each group in Study 1 is presented in Table 1. According to the design of the original study, two 2-way rmANCOVAs were performed in Litvinova et al. (2016), which found the described above interaction of image category with task and no effects of task or hemisphere or their interaction. Here we also performed a 3-way rmANOVA to test a possible 3-way interaction between *Task* (memory task vs. passive viewing), affective *Image Category* (mutilation, erotica or neutral) and *Hemisphere* (left or right) on the percent BOLD signal change in the auditory cortex and a 2-way interaction between image category and hemisphere. Neither the 3-way interaction ($F(2,84) = 0.232$, $p = .793$) nor the *Image Category* × *Hemisphere* interaction ($F(1,84) = 0.729$, $p = .696$) was significant.

The average percent BOLD signal change evoked in the auditory cortex by each type of stimuli during encoding and retrieval stages of the WM task in Study 2 is presented in Table 2. A 3-way rmANOVA revealed significant effects of *Stage* ($F(1,35) = 60.61$, $p < .001$), *Hemisphere* ($F(1,35) = 16.83$, $p < .001$)) and a *Stage* × *Hemisphere* interaction ($F(1,35) = 6.84$, $p = .013$)). Separate pairwise comparisons for the encoding and retrieval stages with values averaged across emotional valence revealed a significant effect of *Hemisphere* on retrieval ($t(1,35) = 4.43$, $p < .001$) but not on encoding ($t(1,35) = 1.90$, $p = .066$).

Discussion and Conclusions

Data from the encoding stage of Study 2 replicated the general structure of results from the memory task group in Study 1. Emotionally negative scenes elicited significant deactivation in the auditory cortex. At the same time, there were no significant effects of either picture valence or hemisphere. The difference in image categories used in the two studies may explain some discrepancies between the two patterns of results. While Study 1 employed arousing erotic images, the positive images used in Study 2 were more similar to neutral as may be seen from both IAPS arousal scores and behavioral data from this study (Rozovskaya et al., 2016).

Although the initially observed phenomenon were replicated across the two studies, Study 2 has also shown that the mere presentation of an affective picture is not enough to induce deactivation in the auditory cortex. Unlike encoding, retrieval of the affective pictures evokes a significant positive BOLD response. A pronounced leftward hemispheric asymmetry of this response suggests that it may reflect a role of verbal processes in the retrieval of information from WM. However, it is not clear why the same verbal processes do not manifest during encoding. Nevertheless, the idea that the relative deactivation of the auditory cor-

Table 1. Mean (with standard deviation) percent BOLD signal change in auditory cortex in Study 1.

	Erotica		Mutilation		Neutral scenes	
	L	R	L	R	L	R
Passive viewing	−0.21 (0.28)*	−0.14 (0.28)	−0.34 (0.24)*	−0.28 (0.27)*	0.02 (0.30)	0.08 (0.28)
Memory task	−0.11 (0.28)	−0.12 (0.31)	−0.14 (0.26)*	−0.20 (0.28)*	−0.08 (0.29)	−0.10 (0.28)

Note: *Mean value is significantly different from zero at $p < .05$ (FDR-corrected).

Table 2. Mean (with standard deviation) percent BOLD signal change in auditory cortex in Study 2.

	Positive scenes		Negative scenes		Neutral scenes	
	L	R	L	R	L	R
Encoding	−0.06 (0.49)$^{n.s.}$	−0.20 (0.42)	−0.16 (0.31)	−0.27 (0.43)	−0.10 (0.43)$^{n.s.}$	−0.18 (0.38)
Retrieval	0.55 (0.52)	0.22 (0.41)	0.50 (0.60)	0.16(0.43)	0.57 (0.54)	0.28 (0.40)

Note: All mean values are significantly different from zero at $p < .05$ (FDR-corrected) except $^{n.s.}$

tex may reflect a neural signature of ID suggests several interesting implications that would guide our future research. The first of them is a prediction that passive viewing and memorization of negative affective pictures, but not their retrieval from WM, would be accompanied by the ID effect at the behavioral level. If this prediction holds true, enough evidence would be provided for the statement that the relative deactivation in the auditory cortex evoked by demanding visual tasks is the neural signature of ID.

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Деактивация в слуховой коре при просмотре эмоционально окрашенных изображений как потенциальный нейрофизиологический коррелят глухоты по невниманию

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Аннотация. В данной работе более детально анализируется явление деактивации слуховой коры, вызванной предъявлением эмоционально окрашенных изображений, которое мы случайно обнаружили в ходе недавнего исследования (Litvinova et al., 2016). Мы повторно проанализировали данные, полученные в двух экспериментах, в которых в качестве стимулов использовались эмоционально окрашенные изображения (Litvinova et al., 2016 и Rozovskaya et al., 2014, 2016). Общий паттерн результатов, обнаруженный в двух исследованиях, был сходным. Пассивный просмотр и запоминание негативно эмоционально окрашенных изображений вызывали значимую деактивацию слуховой коры. При пассивном просмотре эмоциональная валентность изображений (позитивная, негативная или нейтральная) значимо влияла на BOLD-сигнал в слуховой коре, причем наиболее значительная деактивация в слуховой коре вызывалась изображениями увечий. Влияния валентности на степень деактивации не наблюдалось, если изображения было необходимо запомнить. Однако как такового предъявления эмоционально окрашенных изображений недостаточно для того, чтобы вызвать деактивацию слуховой коры. Оказалось, что в отличие от стадии запечатления материала в рабочую память, на стадии извлечения материала эмоционально окрашенные изображения вызывают значимый положительный прирост BOLD-сигнала в слуховой коре. Выраженная левосторонняя асимметрия этого ответа свидетельствует о том, что он может отражать роль вербальных процессов в извлечении информации из памяти. В целом полученные результаты позволяют предположить, что наблюдаемый феномен может представлять собой нейрофизиологический коррелят эффекта глухоты по невниманию — ухудшения восприятия слуховых стимулов, которое проявляется при увеличении зрительной загрузки. Таким образом, мы предсказываем, что пассивный просмотр или запоминание негативно окрашенных эмоциональных изображений, но не их извлечение из рабочей памяти, могут сопровождаться эффектом глухоты по невниманию, который может быть зарегистрирован на поведенческом уровне.

Ключевые слова: глухота по невниманию, слуховая кора, анализ по зонам интереса, эмоционально окрашенные изображения, IAPS, GAPED, фМРТ