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Short communication

Task-dependent modulation of regions in the left temporal cortex during auditory sentence comprehension

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HIGHLIGHTS

- The left lateral temporal cortex is sensitive to sentence intelligibility.
- The anterior and posterior STS/MTG regions are involved in both passive and active sentence comprehension.
- The middle STS/MTG regions respond to sentence intelligibility only during the active task.

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ABSTRACT

Numerous studies have revealed the essential role of the left lateral temporal cortex in auditory sentence comprehension along with evidence of the functional specialization of the anterior and posterior temporal sub-areas. However, it is unclear whether task demands (*e.g.*, active *vs.* passive listening) modulate the functional specificity of these sub-areas. In the present functional magnetic resonance imaging (fMRI) study, we addressed this issue by applying both independent component analysis (ICA) and general linear model (GLM) methods. Consistent with previous studies, intelligible sentences elicited greater activity in the left lateral temporal cortex relative to unintelligible sentences. Moreover, responses to intelligibility in the sub-regions were differentially modulated by task demands. While the overall activation patterns of the anterior and posterior superior temporal sulcus and middle temporal gyrus (STS/MTG) were equivalent during both passive and active tasks, a middle portion of the STS/MTG was found to be selectively activated only during the active task under a refined analysis of sub-regional contributions. Our results not only confirm the critical role of the left lateral temporal cortex in auditory sentence comprehension but further demonstrate that task demands modulate functional specialization of the anterior–middle–posterior temporal sub-areas.

1. Introduction

Recent neurolinguistic work has highlighted the critical role of the left lateral temporal cortex in auditory sentence comprehension [1,13,14,23,30]. Neural models for speech comprehension hold that the left lateral temporal cortex together with the left frontal areas such as par triangularis and par orbitalis forms the ventral pathway responsible for auditory-to-meaning processing [12,26]. However, there is evidence that sub-regions of the left lateral temporal cortex are functionally specialized, although the specific functions of the different areas in auditory sentence comprehension are still being debated. For example, the posterior areas are considered to be critical for semantic store at the lexical level, whereas the anterior regions are more involved in combinatorial semantic processes [3,16,23]. There may even exist subtle separation of functions within the left anterior temporal region, with the most anterior portion of the superior temporal sulcus and middle temporal gyrus (STS/MTG) primarily responding to syntactic

Abbreviations: fMRI, functional magnetic resonance imaging; GLM, general linear model; ICA, independent component analysis; ROI, region of interest; STS/MTG, superior temporal sulcus and middle temporal gyrus.

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structure and a region directly posterior to it reflecting the interaction of syntactic and semantic information [13].

The existing studies on functional heterogeneity of the left lateral temporal cortex have used stimulus manipulations in either a passive listening condition [1,25,30] or active anomaly detection/selective attention conditions [10,20,23]. These studies adopted the strategy of comparing activation across different types of stimuli or across active tasks to isolate semantic and syntactic processing in either passive or active listening conditions. While the results helped to disentangle functional divisions of the sub-regions in the left lateral temporal cortex and how they were associated with syntactic and sentence-level semantic processing, the previous studies have not successfully addressed how task demands may differentially affect the functional specificity of the sub-regions in this important brain area. To our knowledge, only one study has made direct comparison between passive and active sentence comprehension [11]. By use of sentence repetition paradigm, this study reported null findings on this issue as similar activation reductions were found in the lateral aspects of STS/MTG for the different tasks.

In the current study, we attempted to further address whether and how passive *vs.* active task-related effects contribute to different activation patterns in various sub-regions of the left temporal cortex during auditory sentence comprehension. Of these sub-regions, the middle area is of special interest because functions of this area in auditory sentence comprehension have not been clearly specified, although it is implicated as an important part of the ventral pathway subserving semantic processing [8]. We asked participants to listen to normal and time-reversed sentences in both passive and active task conditions. In the passive listening task, participants were told to listen to sentences carefully without overt responses, and in the active comprehension task, they were instructed to comprehend the sentences attentively and to press a button whenever they detected an anomalous sentence. We first adopted probabilistic independent component analysis (ICA) [2] to identify the functional regions of interest (ROIs) in order to avoid the issues of circularity that may characterize the traditional two-step model-driven identifications of ROIs [15,29]. And then anatomical parcellation masks from Freesurfer [7] were used to create sub-ROIs in order to examine the possible functional heterogeneity of the left lateral temporal cortex that is modulated by passive and active task demands.

2. Materials and methods

2.1. Participants

Twenty undergraduate and postgraduate students (11 females) with a mean age of 20.8 years (range 18–25) participated in this study. They were all native Chinese speakers, and were right-handed according to a modified Chinese version of the Edinburgh Handedness Inventory [21]. No participant reported a history of a hearing, neurological or psychiatric disorder. Written informed consent was obtained from all participants after they were given a complete description of the study and all received monetary compensation for their participation. The study was approved by the research ethics committee at Beijing Normal University's Imaging Center for Brain Research.

2.2. Stimulus material

Two types of stimuli were used: (1) 48 spoken sentences in Mandarin Chinese, half of which were presented in the passive listening task and the other half in the active comprehension task, and (2) time-reversed versions of the 48 sentences. For the first type, six sentences were semantically anomalous (*e.g.*, 太阳每天从西边升起来, "The sun rises from the west everyday") for both the passive and the active tasks, intermixed with the remaining normal sentences presented to participants. The sentences were produced by a female Chinese native speaker and recorded in an anechoic chamber at a sampling rate of 44.1 kHz. Each sentence consisted of 10 ± 1 Chinese syllables with an average duration of 2289 ms (SD = 115 ms). For the second type, the intelligibility of the speech was destroyed but the overall acoustic complexity was preserved, following an established method previously used by other researchers [17,24]. All stimuli were normalized for average root mean square intensity amplitude.

2.3. Functional magnetic resonance imaging (fMRI) procedure and data acquisition

Two runs of scanning were collected from each participant, one for the passive task and the other for the active task. The passive and active task runs were counterbalanced across participants. Each run consisted of six 36-s sentence blocks, half of which were normal sentence blocks and half time-reversed sentence blocks, interleaved with seven 12-s silent resting blocks. Each sentence block comprised eight sentences and before each sentence, a 500-ms pure tone was presented as a cue. The normal sentence blocks and time-reversed sentence blocks were arranged in random order within each run. The passive and active task runs each lasted 302 s.

During the passive task run, participants were required to listen to the stimuli carefully without any explicit response. During the active task run, they were instructed to comprehend the stimuli and make a judgment by pressing a button when they heard any semantically anomalous sentence. This anomaly detection paradigm was used to ensure that participants did comprehend each stimulus carefully. Semantically anomalous sentences occurred in 25% of the total trials and were not used in the analysis to avoid measuring activations associated with error detection [23].

Magnetic resonance images were obtained on a Siemens Magnetom Trio Tim 3-T scanner at the Beijing normal university's imaging center for brain research. Foam pads were used to keep participant's head still as far as possible within the head coil. We collected two sessions of fast echo planar imaging sequence with the following parameters: TR = 2 s, TE = 30 ms, FA = 90°, matrix size = 64×64, voxel size = $3.125 \times 3.125 \times 4\,mm^3$. Each session had 151 volumes and each volume had 33 slices to cover the whole brain. After two EPI scans, a high-resolution 3-dimension anatomical image was acquired using MPRAGE sequence in axial plane with the following parameters: TR = 2.53 s, TE = 3.45 ms, FA = 7°, matrix size = 256×256, voxel size = $1 \times 1 \times 1\,mm^3$. During the scanning, the auditory stimuli were presented binaurally *via* MRI-compatible headphone SereneSound (Resonance Technology Inc., Northridge, CA, USA), which reduced the background scanner noise to about 70 dB. A short pre-test scanning was administered to ensure that participants could hear the sentences clearly and the sound volume was adjusted to a comfortable level for each participant.

2.4. Data analysis

2.4.1. Preprocessing and independent component analysis

Functional image preprocessing was conducted using the AFNI software package [4], including the correction for slice timing and head motion, alignment between functional images and structural images, normalization, spatial smoothing and scaling. In order to increase the signal to noise ratio, the passive task run and active task run were concatenated together for each participant, and an average concatenated time series was calculated across all participants as the input data for the following ICA analysis.