Hemispheric lateralization of sentence intonation in left handed subjects with typical and atypical language lateralization: an fMRI study

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Abstract

Prosody (as the melody of speech) is an important component of human social interactions. More specifically, linguistic prosody conveys meaning of speech through syllable, word, or sentence level stress and intonation. In the modern neuroimaging era the hemispheric representation of sentence intonation is widely investigated. Most of these studies suggest bilateral activations predominantly in the perisylvian language areas and in the subdominant homologues. However, there are some inconsistencies about the hemispheric representation and lateralization of linguistic prosody. These inconsistencies could be due to the lack of attention on the language lateralization of the subjects. The present study aims to investigate the hemispheric representation and lateralization of linguistic prosody with a sentence intonation task in two groups of left handed subjects with typical and atypical language lateralization. Functional MRI was used to test the assumption that - according to the functional lateralization hypothesis - the representation of sentence intonation is predominantly lateralized within the language dominant hemisphere and the lateralization of sentence intonation is associated with language lateralization in both groups.

Left handers were examined to create two groups of subjects with typical and atypical language lateralization. In all, 32 healthy subjects were evaluated with a standard verbal fluency task with fMRI in order to assess functional hemispheric language lateralization. In our final investigation the atypical group consisted of 8 subjects with right hemispheric language dominance (LI<-0.2) and the typical group also consisted of 8 subjects with left hemispheric language dominance (LI>0.2).

Sentence intonation task was utilized to test linguistic prosody skills with fMRI. 49 pairs of sentences (18 pairs of neutral-neutral sentences, 10 pairs of interrogative-interrogative sentences, and 1 pair of interrogative-neutral sentence) were presented with an event-related design. Sentences were matched in terms of syntactic structure, semantic complexity and length and all were affectively neutral. In the fMRI data analysis interrogative pairs were compared to neutral pairs.

One of the main findings of our study is that subjects with typical language lateralization activated the middle temporal gyrus (MTG) on the right side. The activation of the MTG in the right hemisphere is classically associated with the encoding of prosodic information. Furthermore, both groups recruited the frontal and temporal language areas predominantly in the language-dominant hemisphere. Moreover, between-group comparison showed significantly stronger activations in subjects with typical language lateralization only in left sided language areas: pars triangularis of the inferior frontal gyrus, the superior frontal gyrus and the inferior parietal lobule.

This finding is in accordance with the functional lateralization hypothesis of prosody, and suggests a correlation between linguistic prosody lateralization and language lateralization.

Index Terms: sentence intonation, language lateralization, left-handers, fMRI

Introduction

Prosody is an important component of everyday discourse and thus, of social interaction. It conveys different pieces of linguistic information at the word and sentence level (also known as linguistic prosody), and expresses information about the speaker's emotional state (called emotional prosody) [1,2]. More specifically, linguistic prosody conveys meaning through syllable, word, or sentence level stress and intonation. Currently, there are four general hypotheses about the hemispheric localization of speech prosody. (1) Acoustic lateralization hypothesis posits that both linguistic and emotional prosody are processed in the right hemisphere through the extraction of suprasegmental information [3]. (2) Functional lateralization hypothesis proposes that linguistic prosody, like word stress, sentence focus and sentence modus, engages neural mechanisms in the left hemisphere, while emotional prosodic information (such as emotions and personality) are encoded in the right hemisphere [2,4]. (3) Several findings claim that the lateralization of speech prosody and the division of labor of the two hemispheres depend on different acoustic cues, such as temporal vs. spectral cues, high frequency vs. low frequency cues and rapidly changing vs. slowly changing acoustic cues [5,6]. (4) However, some clinical studies posit that prosody processing is not lateralized at all, but is rather subserved by subcortical regions [7,8].

Relatively few fMRI studies have been published that specifically focus on prosody based language processing [6,9,10,11] and hence, there are still some inconsistencies about the hemispheric representation and lateralization of subjects. Most of these fMRI studies suggest bilateral

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activations predominantly in the perisylvian language areas and in the subdominant homologues. The mentioned inconsistencies could be due to the fact that these studies did not take into consideration the language lateralization of the examined subjects.

The present study aims to investigate the hemispheric representation and lateralization of linguistic prosody with a sentence intonation task in two groups of left-handed subjects with typical and atypical language lateralization. Functional MRI was used to test the assumption – held by the functional lateralization hypothesis - that the representation of sentence intonation is predominantly lateralized within the language dominant hemisphere and thus the lateralization of sentence intonation is associated with language lateralization in both groups.

Methods

2.1. Verbal fluency task

Left-handers were examined to create two groups of subjects with typical and atypical language lateralization. In the modern neuroimaging era it is believed that among left handers the incidence of atypical language lateralization is higher (15-30%) than in right handers (4-6%) [12], hence, in the present study, 32 healthy, left-handed subjects were evaluated with a standard verbal fluency task with fMRI in order to assess functional hemispheric language lateralization. The paradigm included seven cycles of 30-second-long rests alternating with 30-second-long internal word generation tasks. During the active conditions, the subjects were asked to silently generate different words starting with a particular letter. During the rest periods, the subjects were instructed to stop the active task and relax. In our final investigation the atypical group consisted of 8 subjects with right hemispheric language dominance (LI (lateralization index)<-0.2), while the typical group, also formed by 8 subjects, was characterized by left hemispheric language dominance (LI>0.2).

2.2. Linguistic prosody task:

A sentence intonation task was utilized to test linguistic prosody skills with fMRI. 33 pairs of sentences (see examples) were presented by a professional actress with an appropriate intonation: 18 pairs of neutral-neutral sentences, 10 pairs of interrogative-interrogative sentences, and 5 pairs of interrogative-neutral sentences. As we can see in the examples below, in Hungarian each sentence pair was based on the same syntactic structure with either the same (interrogative-interrogative pairs and neutral-neutral pairs) or different (neutral-interrogative pairs) intonation. (The neutral-interrogative pairs were not used for contrasts in the fMRI analysis, they were used to keep subjects' attention during the paradigm instead). In other words, in one sentence pair, neutral and interrogative sentences were syntactically exactly the same, only sentence intonation differentiated the semantic meaning. Since Hungarian uses variations in pitch to signal different sentence intonations, the syntactic form of questions and statements are identical, and there is no transformation from one to another as in English. (In this study, neutral sentences with monotonic intonation could be statements from a syntactic viewpoint, only intonation differentiates them from questions.) It is important to note that in Hungarian the fundamental frequency of interrogative sentences appears to start high and generally move upward through the duration of the sentence. Besides, the fundamental frequency of the used neutral sentences of monotonous intonation in our design starts much lower and stays flat through the whole sentence. Also, sentences were strictly matched in terms of syntactic structure, semantic complexity and length, which is important from a methodological point of view, in order to make sure, that the neutral and interrogative sentences differ only in prosody. All of the pairs were presented in a randomized order, which was the same across subjects. We used an event-related design. Between sentence pairs an inter-trial interval of 4-6 s (jittered) was used. Participants were asked to press an answer button when the two sentences sounded different, e.g.in the case of neutral-interrogative sentence pairs. As mentioned earlier, the neutral-interrogative pairs were not used for contrast in the fMRI analysis, they were only used to keep subjects' attention focused during the paradigm.

2.3. Functional data analysis

Functional data sets were analyzed using FSL 4.1.3. In the fMRI data analysis of the linguistic prosody task the question "Where is the response to the interrogative sentences greater than the response to the neutral sentences?" was asked by defining contrast of regressors: interrogative pairs compared to neutral pairs (interrogative>neutral). Since we hypothesized that the neutral and the interrogative sentences differ only in sentence intonation, analyzing the above mentioned contrast shows neural circuitry underlying pitch perception associated with sentence intonation. LIs were calculated using the LI toolbox available as part of the SPM8. Because most areas of the frontal cortex are activated during verbal fluency task, language lateralization analysis was focused on the frontal lobe. Language dominance was classified as left hemispheric (LI>0.2), bilateral (-0.2≤LI≤0.2) or right-sided (LI<-0.2).

2.4. Examples

Neutral-neutral pair:

János a könyvtárban tanul./John is studying in the library.
János a könyvtárban tanul./John is studying in the library.
Interrogative-interrogative pair:

Péter a konyhába megy?/Is Péter going to the kitchen?
Péter a konyhába megy?/Is Péter going to the kitchen?
Neutral-interrogative pair:

Mária a szobában sír./Mary is crying in the room.
Mária a szobában sír?/Is Mary crying in the room?*
*In the original Hungarian examples no structural change signals sentence type, only prosody and intonation distinguishes declarative and interrogative sentences.

Discussion

As far as we know, this is the first fMRI study investigating the relationship of hemispheric representation and functional lateralization of sentence intonation with both atypical and typical language lateralization in a preliminary sample of healthy, left-handed subjects. During the sequential analysis of fMRI data, we found that the two groups had markedly distinct neural activation patterns. The 'atypical group' (AG) – in the interrogative versus neutral sentence contrast – recruited language related brain areas only in the right hemisphere, such as the posterior division of the right middle temporal cortex and the right anterior paracingulate gyrus. On the other hand the 'typical group' (TG) activated language related areas mainly in the left hemisphere, such as the left frontal operculum reaching the left middle temporal gyrus, the left superior temporal gyrus, the left inferior parietal lobule and the pars triangularis of the left inferior frontal gyrus. Moreover, the left superior frontal gyrus, the left gyrus lingualis, the left thalamus was also recruited by the TG. Even more, the TG activated brain regions in the right hemisphere as well, such as the posterior division of the middle temporal gyrus and the insula. Between-group comparison showed significantly stronger activations in subjects with typical language lateralization than in subjects with atypical language

lateralization only in left sided language areas: the pars triangularis of the inferior frontal gyrus, the superior frontal gyrus and the inferior parietal lobule. This finding is consistent with our previous data [13], which found that a reduced microstructural integrity of the left hemisphere was associated with atypical language lateralization.

Results in the sentence intonation processing task revealed activations mostly in the dominant hemisphere in both groups. Interestingly, the AG showed a much poorer activation pattern than the TG. Considering the AG poorer activation pattern, we can speculate that this finding may potentially be the result of a neurodevelopmental disorder behind atypical language lateralization [14,15]. In contrast, the typical group recruited a more widespread brain activation network including language areas in the dominant hemisphere and also in the right (subdominant) middle temporal gyrus - which is classically associated with the encoding of prosodic information - and in the right insula.

Like most of the higher-order cognitive functions, it is very likely that linguistic prosody is processed within a neural network mainly in the frontal, temporal and parietal cortex [6,9,2,11]. Our fMRI data demonstrate that during the sentence intonation task the TG recruited the fronto-temporo-parietal activation network predominantly in the language-dominant hemisphere. This predominantly dominant hemispheric activation pattern is supposedly due to the processing of the modality (i.e. the semantic meaning) of the interrogative sentences. This finding is in line with the functional lateralization hypothesis which proposes that linguistic prosody is processed within the language-dominant hemisphere. Besides, for the processing of non-linguistic acoustic signals subdominant temporal activations were also observed in the TG.

Conclusions

Our finding is in harmony with the functional lateralization hypothesis, since we have found that the representation of sentence intonation is predominantly lateralized within the language-dominant hemisphere in both investigated groups.

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