

The neural mechanisms for understanding self and speaker's mind from emotional speech: an event-related fMRI study

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Abstract

Using linguistically positive and negative words uttered either pleasantly or unpleasantly by four speakers, we examined the brain regions that mediate speech communication through event-related functional magnetic resonance imaging (fMRI) analyses. Subjects were adult listeners who evaluated either speakers' mind, their own mind, or (as a control condition) the number of letters for spoken stimuli, which were randomly presented through earphones. In both the self and speaker-mind judgment tasks, the dorsal medial prefrontal cortex (dMPFC), that has been implicated in theory of mind or self-referential processing, is significantly activated, in addition to the classical cortical regions involved in processing linguistic semantics and emotional prosody of speech. These results suggest that the mental state attribution accomplished by the dorsal medial prefrontal cortex plays an important role to understand our own and speaker's mind in speech communication.

1. Introduction

How do we know the mind of a speaker who says, "you are on time" with unpleasant prosody to her friend who is very late? How do we aware of our own minds when we are addressed with such utterances? In speech communication, the ability to correctly infer interlocutors' minds from emotional and linguistic information of utterances is a very important social ability to establish smooth communication. The neural mechanisms responsible for this communication skill, however, have not yet been made clear enough.

The purpose of the present study is to examine the neural mechanisms responsible for reading interlocutors' minds in speech communication based on an event-related fMRI analysis, and to examine whether a common neural system exists or not to read mental states of speakers and addressees, or of others and self.

Functional brain imaging studies are attempting to identify neural pathways to support mental state inference in healthy volunteers. A number of studies using tasks that refer to self or other mental states reveal the medial prefrontal cortex activity [1-8]. These results suggest that common neural mechanisms for mental state inference of self and other may exist. Moreover, some studies found MPFC activation both when judging one's own mental state and when judging another individual's mental state [9-11]. Ochsner et al (2004) and Ochsner et al (2005) suggest that activation in MPFC may depend upon the meta-cognitive judgments common to both self and other mental state inference, which require explicit representations of what one knows. Other studies suggests,

however, greater MPFC activation is associated with judging another's beliefs or emotions as compared to judging one's own beliefs or emotions [12] or non-mentalistic baseline judgments [9]. On the other hand, some studies found greater MPFC activation for self than for other judgment [13, 14]. As mentioned above, it is unsure that specific role of MPFC in mental state attribution for self and others.

Most previous studies relied on tasks such as inferring mental states using stories [e.g. 7, 8], judging whether trait adjectives apply to self or other familiar person [e.g. 4, 10, 14]. However, these experimental situations are rarely observed in our daily communication scenes. Although these tasks are sufficient to elaborate on mental state inference processing for self and others, it is not sufficient to investigate how the neural resources to understand the mental states of self and others function in speech communication. That is, these experimental paradigms are not appropriate to investigate how the MPFC contributes to verbal communication.

To identify the neural system supporting the evaluation of self and other mental states in communication behavior, the present study employed an experimental paradigm we often experience in our daily communication scenes, which infer speaker's mind and our own minds from emotional speech. In this task, subjects judged their own emotional responses to each utterance as well as speakers' emotional states, taking into account of emotional meanings mainly conveyed by emotional prosody and literally-conveyed linguistic meanings of the utterance. As a baseline condition, subjects also judged whether the number of letters needed to describe the utterance was even or odd. We assumed that the MPFC in addition to multiple brain regions involved in analyzing and integrating the acoustic, emotional and linguistic aspects of utterances would be activated when subjects judged the mental states of speakers and of subjects as addressees.

2. Method

2.1. Subjects

Six right-handed native Japanese speakers participated in the experiment (mean age = 24.2 years). Informed consent was obtained from all subjects after explaining the purpose and the outline of the method for this research and the advantaged expected for the subjects.

2.2. Speech material

The speech material consisted of frequently used spoken phrases with 48 positive and 48 negative linguistic meanings. Half the 48 positive phrases were uttered pleasantly, other half were uttered unpleasantly. Likewise, half the 48 negative

phrases were uttered pleasantly, other half were uttered unpleasantly. The phrases were consisted of 2-7 morae and were uttered by four speakers (2 men and 2 women). These spoken phrases were divided into two lists such that each phrase appears only once. Thus, each list was consisted of 12 positive and 12 negative phrases uttered with pleasant prosody and 12 positive and 12 negative phrases uttered with unpleasant prosody.

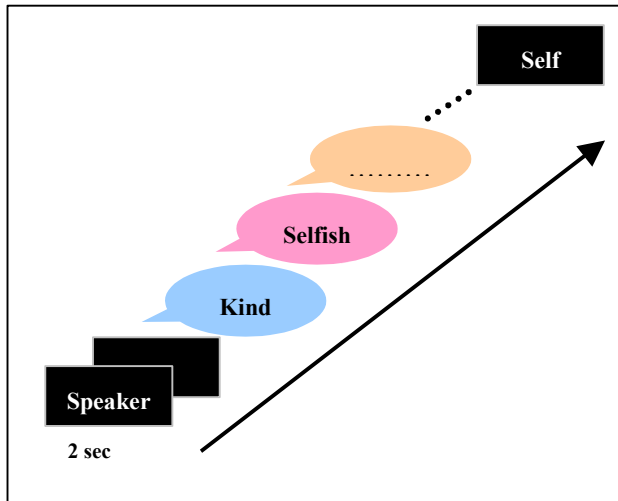


Figure 1: Examples of the behavioral paradigm. Square black screens with white characters indicate the visually presented instructions for each task, while circles indicate auditory presented phrases including an empty event or silence.

2.3. Behavioral paradigm

Subjects were imaged using fMRI during two runs while making judgments on the spoken phrases stimulated through earphones. Three different types of blocks were randomly presented. Prior to the onset of each block, one of three instruction cues was visually presented in the center of the screen for 2 sec. Under “speaker” blocks, subjects were instructed to judge whether the speaker of each stimulated phrase felt pleasant or unpleasant. Under “self” blocks, subjects were instructed to judge whether subjects themselves felt pleasant or unpleasant for each stimulated phrase. Under “letter” blocks, subjects were instructed to judge whether the number of letters needed to describe each stimulated phrase was even or odd. Subjects responded with their right hand by pressing one of two buttons on a response box as fast and correctly as possible. On each trial, stimulus onset asynchrony varied from 7 to 10 s to obtain measures at various points of the hemodynamic response. To insure that subjects would be experiencing all combination of both linguistic meanings (positive, negative) and emotional prosody (pleasant, unpleasant), each block included two positive phrases with pleasant prosody, two positive phrases with unpleasant prosody, two negative phrases with pleasant prosody, two negative phrases with unpleasant prosody, and four empty/null events as a control condition. Eight phrases and four empty events were randomly intermixed within each

block, and six blocks per each instruction type were presented in a randomized order.

2.4. Functional brain imaging

Brain imaging was conducted using a 1.5T scanner (Siemens, Magnetom Symphony). The scanning parameters were as follows: TE = 60ms; TR = 3000ms; FA = 90°; acquisition matrix = 64 x 64; FOV = 192mm. Twenty-four slices of the brain were acquired axially (5mm thickness, gapless). The image data were analyzed using Statistical Parametric Mapping (SPM2, Wellcome Department of Imaging Neuroscience, <http://www.fil.ion.ucl.ac.uk/spm/>).

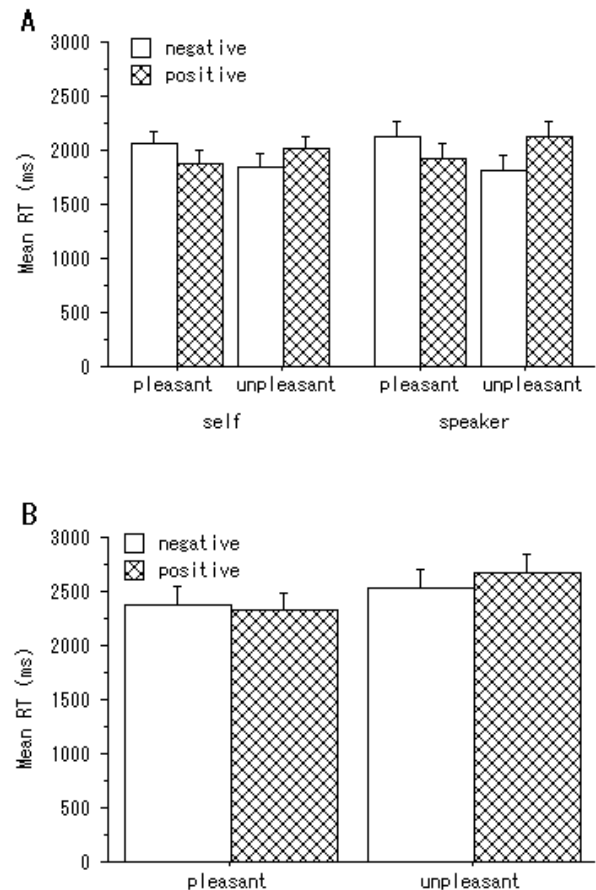


Figure 2: Behavioral data for speaker, self, letter judgments. (A) Response time of the speaker and self judgments. (B) Response time of the letter judgments. The error bars indicate standard errors.

3. Results

3.1. Behavioral results

The response time was analyzed by ANOVA with three factors of *Prosody* (pleasant, unpleasant), *Meaning* (positive, negative), and *Task* (speaker, self) as a repeated measure. As shown in Figure 2 (A), there was a significant interaction of *Prosody* and *Meaning* ($F = 5.39$, $p = 0.02$). The reaction time was shorter for positive phrases with pleasant prosody than those with unpleasant prosody, while it was shorter for negative phrases with unpleasant prosody than those with

pleasant prosody. Analysis of the reaction time data in letter trials was conducted separately. As shown in Figure 2 (B), there were no significant main effects and interactions in the letter trials.

3.2. Brain imaging results

To identify the brain regions associated with the evaluation of subjects' own and speaker's mental states, we contrasted each self or speaker blocks with the resting baseline (null events). Both contrasts revealed the brain activity in the left inferior frontal gyrus (IFG), the bilateral cerebellum, the left motor area, the right basal nuclei, the left temporal cortex including anterior and posterior parts of the middle temporal gyrus, the superior temporal sulcus/gyrus, as well as the temporoparietal region (anterior STS) and the temporal pole ($p < 0.05$, corrected). The right occipital cortex was activated only in speaker blocks ($p < 0.05$, corrected). While deactivation was found in the ventral medial prefrontal cortex (vMPFC), the paracentral lobule, the precuneus, the bilateral superior frontal sulcus, the right insula, the bilateral angular gyrus, the fusiform gyrus ($p < 0.05$, corrected).

The common regions associated with both judgments of self and speaker's minds were extracted by using within ANOVA of spm2. As shown in Figure 3, the activations were found in the dorsal medial prefrontal cortex (dMPFC), the right TPJ/anterior STS, the left TP, the left IFG, the right cerebellum ($p < 0.001$, uncorrected). The direct comparison between self and speaker blocks did not reveal any significant activation.

4. Discussion

The dorsal MPFC activation was found as a common region contributing to judgments of mental states of subjects themselves and of speakers. The contrast of each self or speaker blocks with the resting baseline revealed the activation in the IFG, the STS, the temporal pole, the temporoparietal region/anterior STS. These results suggest that the speech communication behavior of inferring speaker's real intention and understanding our own mental states from emotional speech consists of neural resources distributed across these brain regions.

In these regions, the STS has been reported to be involved in the processing of acoustic characteristics of speech sounds [15]. Primary analyses of emotional speech are supposed to be made in this region. Another area, the IFG has been reported to activate when emotional and linguistic information of the speech was not congruent (i.e. Speaker said, "you are nice" with unpleasant prosody) [16, 17]. These findings indicate that the IFG may be associated with the integration process of two competing information [16].

The MPFC, which commonly activated by inference of both subject's own and speaker's mental states, has been frequently reported to be activated during mental state attribution tasks (i.e. Theory of Mind tasks) [6-8]. These findings implicate that MPFC is a key part of understanding other people's belief and mental state [18]. The MPFC activation is known not to be activated for individuals with Asperger syndrome, who have difficulties for Theory of Mind tasks [19]. While, the MPFC has reported to be activate when subjects attend to themselves and reflect on their own mental states [1-4]. Such tasks include reflecting on one's emotional reaction to the stimuli [1, 4], hearing own name [2], judging whether trait adjectives apply to self [3, 10, 12]. Thus

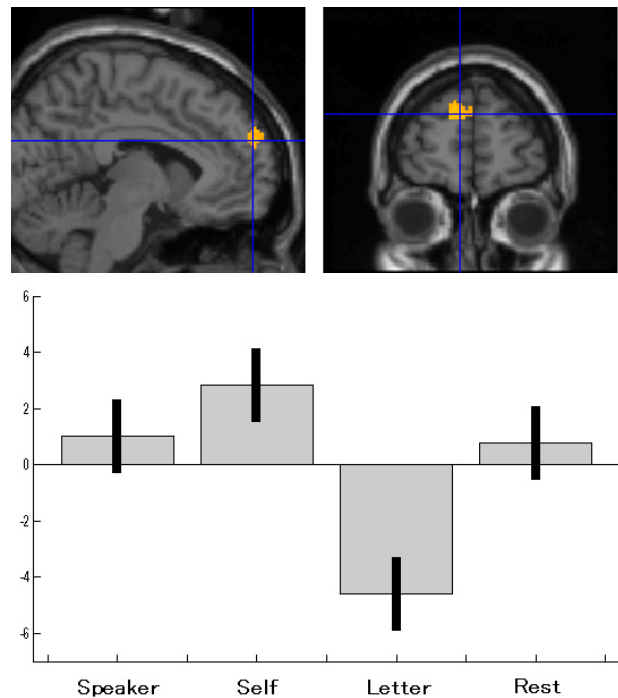


Figure 3: Dorsal medial prefrontal activation, which was commonly activated when subjects infer their own and speaker's mental states. Top low: the dorsal MPFC ($x=-6$, $y=58$, $z=26$; $p < 0.001$, uncorrected), Bottom low: Activation level for each block type

monitoring of own mental states may engage the MPFC.

Moreover, the studies that directly compared brain regions involved in judging one's own and other people's mental states revealed the MPFC activation overlapped in both judgments. These findings indicate that the possibility of a common function (i.e. meta-cognitive function) in the MPFC for the general processing of understanding our own and other people's mental states [9-11].

In the present study, the dorsal MPFC activation was also observed as a common region in self and speaker tasks, furthermore, the direct comparison between these two tasks did not reveal any significant differences in the brain activity. These results suggest that it is highly possible that understanding own and speaker's mind from speech is processed by a common mechanism accomplished by the MPFC. The activation level, however, was higher in the self task than in the speaker task. Although this finding indicates that the stronger MPFC activation is needed in understanding own mental state, it does not necessarily indicate that the MPFC play a role specific only for the self. For the speaker task, it is possible that subjects judge the speaker's mind by relying mainly on emotional prosody, that is the speaker is pleasant if emotional prosody sounds positive and vice versa, without any use of linguistic contents of spoken phrases. We assume that the MPFC activation is stronger in the self task than the speaker task, because the weight of mind reading is reduced by the use of relatively simple cues for the speaker task. On the other hand, the weight of mind reading is increased in the self task because not only emotional but also linguistic aspects of spoken phrases should affect addressee's mind, and therefore the listening subjects have to judge the

value of speakers intention by integrating various aspects of spoken phrases with their own mental states.

5. Conclusions

The present study sought to identify the neural processes supporting inference about one's own and speaker's emotional state based on an event-related fMRI measurement. The result showed the significant activation in the dorsal MPFC when judging both subject's own and speaker's mental state. These results indicate that the dorsal MPFC plays an important role for the communication behavior by inferring speaker's real intention and understanding our own mental states taking into account of both emotional and linguistic aspects of utterances. There may be a common function in the dorsal MPFC for the general processes of understanding our own and other people's mental states, and therefore the function of MPFC supports the important social skill of establishing smooth speech communication.

6. References

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