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Gender Differences in the Functional Organization of the Brain for Emotional Prosody Processing

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Abstract

Using spoken phrases with positive or negative linguistic meanings uttered by a woman with two emotions, warmhearted and coldhearted, we analyzed gender differences in the brain activity based on a functional MRI measurement when subjects judged linguistic or emotional meanings of the phrases. Significant interaction effects of language and emotion were observed on the acoustic characteristics of utterances, such as F0 range, and also on the perceptual behavior evaluated by response time and judgment correctness. When compared to the female subjects, the male subjects showed significantly stronger activation in only the right frontomedian cortex, which can be hypothesized to construct and maintain the theory of mind to understand speaker's hidden but true intensions. These results suggest that emotion modulates linguistic processes not only in speech production but also in speech perception, and such modulations may differ between the genders at least in perceptual processes.

1. Introduction

Humans powerfully and flexibly interpret the speaking behavior of other people based on an understanding of their minds: that is, we use a "theory of mind [1, 2]." Mind understanding from speech, however, is not necessarily easy task between men and women. The theory of women's mind could be an enigma to men, and the theory of male mind could be an enigma to women.

The purpose of this study is to investigate how the functional organization of the male brain for emotional prosody interpretation differs from the female brain. Using spoken phrases with positive or negative linguistic meanings uttered by a female with two emotions, warmhearted and coldhearted, we analyzed gender differences in the brain activity based on a functional MRI measurement when subjects judged linguistic and emotional meanings of the phrases.

A much debated question is whether sex differences exist in the functional organization of the brain for language and prosody [3-10]. A long-held hypothesis posits that language functions are more likely to be highly lateralized in males and to be represented in both cerebral hemispheres in females, but attempts to demonstrate this have been inconclusive. Some data indicate that language primarily lateralizes to left in males, and approximately half have left lateralization and the other half have bilateral representation in females [9], while other results suggest that men and women show very similar, strongly left lateralized activation patterns [5].

While some data indicate that both emotional and linguistic prosody are processed in the right hemisphere, other results suggest that only emotional prosody or only linguistic prosody is processed in the right hemisphere. Some results imply that sentence-level linguistic prosody is processed in the left hemisphere. Alternatively, it has been proposed that the lateralization of prosodic processing may vary as function of the acoustic parameters of prosody, such as fundamental frequency, intensity or duration under study [12]. Some others suggest that the lateralization of prosodic and phonetic processing may vary depending on the subjective attention [13]. It has also been suggested that emotional prosody modulates word processing and that the time-course of this modulation differs for males and females, that is, women make an earlier use of emotional prosody during word processing as compared to men [3, 6].

As this brief review of the literature shows, neither behavioral nor brain imaging studies have yet provided a clear picture of the functional organization of the brain for language and prosody processing, and their gender differences.

The primary purpose of this study is to clarify the gender differences in the functional organization of the brain for emotional prosody processing.

1. Method

All experiments in this study were conducted in accordance with Declaration of Human Rights, Helsinki 1975 and the research ethics regulations by the authors' affiliate. Written informed consent was obtained from each subject after explaining the purpose and the outline of the method for this research and the advantages and disadvantages expected for the subjects.

1.1. Speech material

Frequently used 40 phrases with positive linguistic meanings, such as "I love you," and 40 phrases with negative linguistic meanings, such as "I hate you," were uttered by a female speaker of Tokyo dialect with two emotions, warmhearted and coldhearted (Table 1). The warmhearted utterances were made with strong pleasure, while the coldhearted ones were made with strong hatred. These utterances were digitized and analyzed to extract prosodic characteristics such as F0 contour, and then used for listening tests under functional brain imaging.

Table 1: *Speech materials used for the experiments.*

Emotional Content / Linguistic Meaning	Warmhearted	Coldhearted	Total
Positive	40	40	80
Negative	40	40	80
Total	80	80	160

1.1. Acoustic analyses

Fundamental frequency at various characteristic timing points and total length of utterances were measured and analyzed by ANOVA with two factors of Emotion (Warmhearted vs. Coldhearted) as a within-subject measure and Language (Positive vs. Negative) as a between-subject measure.

1.1. Listening tasks

The listening subjects were 24 right-handed healthy adults (12 males and 12 females aged 24.7 in average). Two listening tasks were imposed, the language task and the emotion task. For the language task, the listening subjects were instructed to judge whether the linguistic meaning of a presented speech sample is positive or negative as fast as possible. For the emotion task, they were instructed to judge whether the emotional prosody of a presented speech sample is warmhearted or coldhearted as fast as possible.

The response time and the percent correct were analyzed by ANOVA with three factors of Emotion (Warmhearted vs. Coldhearted), Language (Positive vs. Negative), and Sex (Female vs. Male).

For the control task used in brain imaging, tones with a rising pitch or a falling pitch were prepared. The length and the presentation level of the tones were adjusted as same as those of the speech samples. The control task was to judge whether the pitch of a tone raises or falls.

1.1. Functional brain imaging

With the subject in the fMRI system (Siemens, Magnetic Symphony 1.5T), one of the listening tasks and the control task were performed alternately at 30-second intervals, 4 times each, and this block design, which took 4 minutes to complete, was performed under the 2 listening tasks.

The speech and tone stimuli were presented at the most comfortable level of individual subjects once per 3 seconds. Pressing two buttons by the right index and middle fingers, the judgment and the response time were measured.

The scanning conditions were: The interscan interval (TR), 6 seconds; acquisition time (TA), 4.4 seconds; flip angle, 90°. The image data obtained were analyzed using a statistical parametric mapping (SPM2) [14].

1. Results

1.1. Acoustic characteristics

As illustrated in Figure 1, F0 range varied depending on Emotion and Language. ANOVA on F0 range revealed that the main effects of Emotion ($F=63.21$, $p<0.0001$) and Language ($F=9.979$, $p<0.005$) were significant. The interaction effect of Emotion and Language ($F=4.971$, $p<0.05$) was also significant. The warmhearted utterances had significantly wider F0 range than the coldhearted utterances, and the warmhearted utterances of negative phrases showed significantly wider F0 range than the warmhearted utterances of positive phrases. Similar tendency was observed for other F0 measures.

1.1. Behavioral results

As shown in Figure 2, significant differences in the correct responses were detected depending on the factors analyzed. There was no gender difference in the correctness scores. The coldhearted utterances were more correctly judged than the warmhearted utterances ($F=12.465$, $p<0.001$). The percent correct of the negative phrases were slightly higher than the positive phrases only in the emotion task. The coldhearted utterances of the negative phrases and the warmhearted utterances of the positive phrases were more correctly judged than the coldhearted utterances of the positive phrases and the warmhearted utterances of the negative phrases (F=7.766_p<0.01). This tendency was observed in both the tasks.

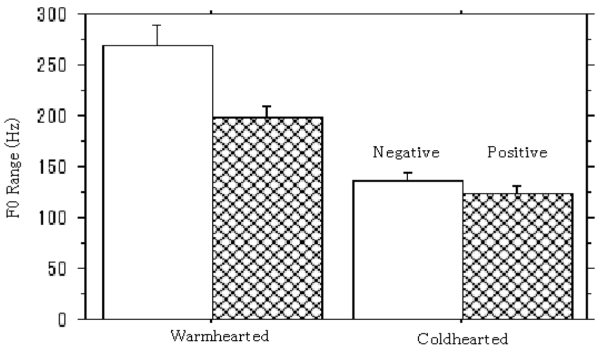


Figure 1: *F0 range with error bars.*
Empty bar: Negative linguistic meanings
Meshed bar: Positive linguistic meanings
Cold: Coldhearted, Warm: Warmhearted

As shown in Figure 3, significant differences in response time, RT, were detected depending on Sex ($F=98.713$, $p<0.0001$). The male subjects needed longer response time than the female subjects. The interaction effect of Emotion

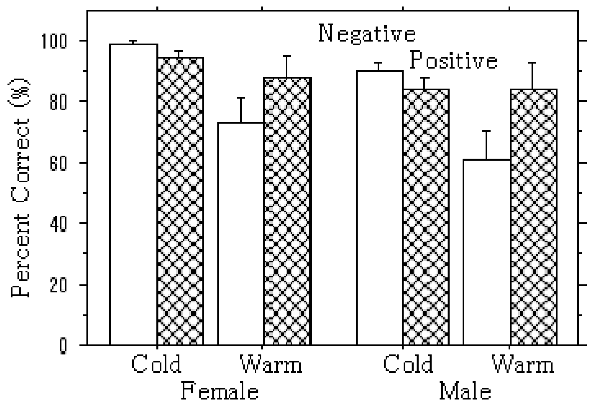


Figure 2: *Percent correct with error bars of the emotion task.*
Empty bar: Phrases with negative linguistic meanings
Meshed bar: Phrases with positive linguistic meanings
Cold: Coldhearted, Warm: Warmhearted

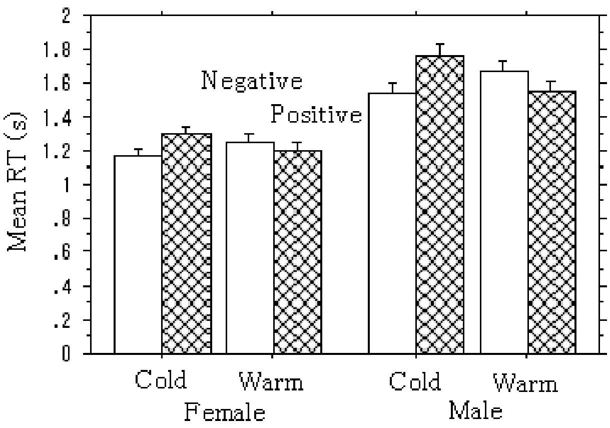


Figure 3: *Response time of the emotion task with error bars.*
Empty bar: Phrases with negative linguistic meanings
Meshed bar: Phrases with positive linguistic meanings
Cold: Coldhearted, Warm: Warmhearted

and Language on RT was significant (F=10.659, $p<0.005$). RT was shorter for warmhearted utterances of positive phrases than those of negative phrases, and was shorter for coldhearted utterances of negative phrases than those of positive phrases.

1.2. Brain imaging results

As shown in Figure 4, the male subjects showed significant activation in more cortical areas than the female subjects for the both tasks. For the male subjects, significant activation ($P_{PWE\text{-}corr}<0.05$) was found in the bilateral middle temporal gyri including the superior temporal sulci, the bilateral superior frontal gyri, the left posterior cerebellar lobe and the left inferior frontal gyrus. On the other hand, for the female subjects, the left posterior cerebellar lobe was the only area, the activity of which was significant at $P_{PWE\text{-}corr}<0.05$ corrected for multiple comparison.

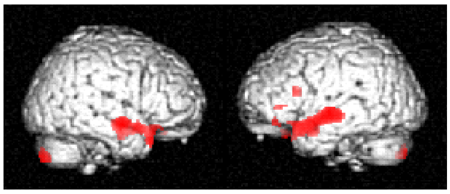
When compared to the female subjects, the male subjects showed significantly stronger activation in only one cortical area in the right frontomedian cortex ($P_{PWE\text{-}corr}<0.05$).

As shown in Figure 5, the activated cortical areas were similar between the male and female subjects for the language task when compared to the control task. There was no cortical area activated significantly when comparison was made between the male and female subjects for the language task.

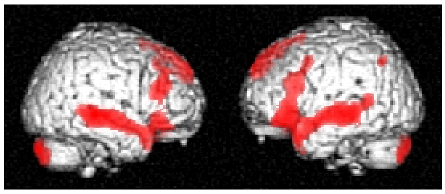
2. Discussion

When compared to the female subjects, the male subjects showed significantly stronger activation in only one cortical area in the right frontomedian cortex only under the emotion task. The frontomedian cortex has been shown to be important for theory-of-mind processes, i.e., during the attribution of other people's actions to their motivations, beliefs, or emotions [1]. It has also been suggested that the right-hemisphere-damaged but not the left-hemisphere-damaged patients have difficulties for theory-of-mind processes [2]. Therefore, the present results may suggest that the right frontomedian area of the male brain may contribute to construct the theory of female mind when the male subjects try to understand the female speaker's mind from her utterances.

The male subjects showed significant activation in more cortical areas than the female subjects, although there were no

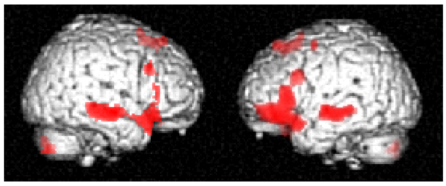


(a) Female brain

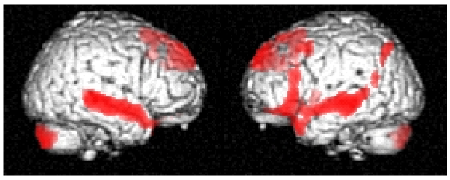


(b) Male brain

Figure 4: *Brain activity pattern revealed in the emotion task-the control task ($p<0.001$ uncorrected for multiple comparison).*



(a) Female brain



(b) Male brain

Figure 5: *Brain activity pattern revealed in the language task - the control task ($p<0.001$ uncorrected for multiple comparison).*

significant differences in judgment scores between the male and female subjects. The present results suggest that the male brain need stronger efforts requiring higher brain activities than the female subjects to understand the female speaker's mind from the utterances.

As shown in Figures 1, 2 and 3, significant interaction effects of language and emotion were observed on the acoustic characteristics of utterances, such as F0 range, and also on the perceptual behavior evaluated by response time and judgment correctness. These results obtained in our experiment suggest that emotion modulates linguistic processes not only in speech production but also in speech perception, and such modulations may differ between the genders particularly in perceptual processes. These results support, in part, previous studies suggesting that emotional prosody modulates perceptual word processing and that the time-course of this modulation differs for males and females, that is, women make an earlier use of emotional prosody during word processing as compared to men [3, 6].

Although several previous studies have suggested, neither the right-hemisphere predominance in the emotion task nor the left-hemisphere predominance in the language task was observed in this study. One possible interpretation of the present results is that the linguistic as well as emotional processes may automatically be induced as cooperative processes, and the differences may exist only at a high processing stage to integrate the linguistic and emotional processes to generate a coherent interpretation of the speaker's mind. The present results suggest that female listeners need less neural resources to process and interpret the female speaker's mind than the male listeners. This may be due to that the female brain fully equips the theory of female mind, while the male brain has to construct the theory of mysterious female mind through inference processes. This may also explain why the male subjects show significantly longer response time to judge the speaker's hidden but true emotional states, although they spend more neural resources than the female subjects.

3. Conclusions

Gender differences in the brain organization for emotional prosody processing are analyzed based on a functional MRI measurement during judgments of linguistic or emotional meanings of phrases spoken by a woman. Significant interaction effects of language and emotion were observed on the acoustic characteristics of utterances, such as F0 range, and also on the perceptual behavior evaluated by response time and judgment correctness. These results obtained in our experiment suggest that emotion modulates linguistic processes not only in speech production but also in perception processes, and such modulations may differ between the genders at least in perceptual processes. When compared to the female subjects, the male subjects showed significantly stronger activation in only right frontomedian cortex, which may concern to construct and maintain the theory of mind for proper interpretation of emotional prosody.

4. References

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