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Brain networks of affective mentalizing revealed by the tear effect: The integrative role of the medial prefrontal cortex and precuneus

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ABSTRACT

Affective mentalizing involves the integration of various social signals in order to infer the affective states of others. Previous neuroimaging studies have shown that the medial prefrontal cortex, the precuneus/posterior cingulate cortex, and the temporo-parietal junction constitute the core affective mentalizing network. However, the relative contributions of these regions to affective mentalizing remain unclear. We used functional magnetic resonance imaging to investigate which of these nodes are involved in the integration of two social signals: emotional tears and facial expressions. We assumed that this integration would produce a supra-additive effect, indicated by greater activity than the sum of the effects of the individual social signals. Female subjects rated the sadness of faces with either tears or tear-like circles, and either sad or neutral expressions. We observed the supra-additive effect in the medial prefrontal cortex and precuneus/posterior cingulate cortex but not in the temporo-parietal junction. These results indicate that the medial prefrontal cortex and precuneus/posterior cingulate cortex play an important role in integrating tears and facial expressions during affective mentalizing.

1. Introduction

Social cognition involves psychological processes that allow humans to make inferences about other people. Among such processes, affective mentalizing (or cognitive empathy) is defined as the process of inferring another's affective state (i.e., "I understand how you feel") (Perry and Shamay-Tsoory, 2013). Previous neuroimaging and lesion studies have identified a number of brain regions involved in affective mentalizing (Frith and Frith, 2003; Samson et al., 2004; Saxe and Powell, 2006; Mitchell, 2008; Shamay-Tsoory et al., 2009; Atique et al., 2011; Corradi-Dell'Acqua et al., 2014). Among these regions, the medial prefrontal cortex (mPFC), the precuneus/posterior cingulate cortex (PCC), and the temporo-parietal junction (TPJ) are considered the core mentalizing network, because they have often been observed during affective (Atique et al., 2011; Corradi-Dell'Acqua et al., 2014) and non-affective (cognitive) (Goel et al., 1995; Van Overwalle, 2009; Van Overwalle and Baetens, 2009) contexts. However, the relative contributions of these nodes to affective mentalizing are not well understood.

One possible way to clarify the relative contributions of these nodes is to examine the brain regions that are involved in integrating multiple social signals to infer another's affective state. Here, we define the integration as a process in which social signals are combined to infer the most likely affective state. In the field of multisensory research, if two different types of social signal are integrated in a region, it is expected not only to be activated by each separately (convergence), but also to show interaction effects between them (Calvert et al., 2000; Raij et al., 2000; Stevenson et al., 2009). Previous neuroimaging studies have consistently found that the mPFC contains information about another's emotional state, regardless of whether the social signals involved facial, body, or vocal expressions (Peelen et al., 2010), or whether they involved facial expressions or situational information in the absence of

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observable expressions (Skerry and Saxe, 2014). These findings indicate that the mPFC plays a key role in representing others' affective states at the abstract level by receiving information about distinct social signals. However, each type of social signal was presented separately in previous studies, so it has remained unclear whether the mPFC is involved in the integration process.

Even less is known about the role of the PCC and TPJ in the integration of social signals. In particular, the function of the PCC in mentalizing is not well understood; hence, little attention has been paid to its role in integrating social signals. Furthermore, the function of the TPJ in mentalizing has been controversial (Decety and Lamm, 2007; Mitchell, 2008; Scholz et al., 2009; Cabeza et al., 2012), and its role in the integration of social signals has not been clarified. For instance, Peelen et al. (2010) showed that a region adjacent to the TPJ also contains information about another's emotional state across different types of emotional expression (face, body, and voice). However, a subsequent neuroimaging study by Skerry and Saxe (2014) utilizing facial expressions and situational information (e.g., social exclusion) showed that the TPJ did not represent another's emotional state at an abstract level; more specifically, their work showed that a classifier, which was trained to discriminate the valence of one social signal within the TPJ, did not successfully classify that valence for the other social signals. Understanding another person's affective state based on situational information is critically different from interpreting emotional expressions (produced by the face, body, and voice), in that situational information can be interpreted in multiple ways and presents an ill-posed inverse problem (e.g., a person might feel happy *or* sad when he or she is separated from others). Thus, understanding situational information in a socially-appropriate manner requires knowledge of the social event (e.g., that separation from others should be considered a sad event; Barbey et al., 2009; Krueger et al., 2009). Thus, we anticipate that the TPJ plays a minor role in the integration of social signals that involve social event knowledge.

Given this background, we focused our investigation on the integration of two social signals from facial stimuli: tears and facial expressions. To the best of our knowledge, neither the neural mechanisms underlying the processing of tears as social stimuli nor the neural bases of the integration of tears and facial expressions has been identified. Emotional tears appear to be unique to humans and are of considerable interest in the field of evolutionary psychology (e.g., Murube et al., 1999; Provine et al., 2009; Balsters et al., 2013). Like social situations, understanding another's affective state from tears is an ill-posed inverse problem, because tears can be shed in response to many different emotions (e.g., anger, happiness, and sadness; Murube et al., 1999). Therefore, tears are similar to social situations in that they require social event knowledge in order to achieve the most appropriate interpretation. In the absence of contextual information, humans tend to interpret tears as a symbol of sadness (i.e., the tears effect; Provine et al., 2009), possibly because such an interpretation is the most socially appropriate. As the mPFC can represent others' emotions at an abstract level across different social signals (Peelen et al., 2010; Skerry and Saxe, 2014), we predicted that it would be involved in integrating tears and facial expressions.

The present study used functional magnetic-resonance imaging (fMRI) to test the hypothesis that the mPFC, but not the TPJ, integrates tears and facial expressions during the evaluation of others' sadness. We also explored the role of the PCC in this integration process without a specific hypothesis. We manipulated two factors: tears (tears, tear-like control objects, and no object) and facial expressions (sad and neutral). We initially tested our assumption that the core mentalizing network is activated by the presence of tears, and then examined whether this network shows interaction effects between tears and facial expressions. We predicted that the mPFC would show a supra-additive effect, providing evidence of the integration of information on tears and facial expressions (Meredith and Stein, 1983; Calvert et al., 2000; Raij et al., 2000; Stevenson et al., 2009). In other words, these regions should show stronger activation in response to a sad facial expression with tears than the sum of the activity in response to individual presentations of a sad facial expression without tears and a neutral facial expression with tears. By contrast, we predicted that the TPJ would not show the same effect.

2. Materials and methods

2.1. Subjects

Sixty-one healthy subjects aged 18–44 years (mean age = 22.1 years; standard deviation [SD] = 4.7 years) participated in the study. We recruited only female participants because they tend to react to crying people with more sympathy and support than males (Cretser et al., 1982). All subjects were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). None of the volunteers had a history of symptoms requiring neurological, psychological, or other medical care. All subjects gave written informed consent. The study was approved by the ethical committee of the National Institute for Physiological Sciences of Japan. Thirty-eight subjects participated in the main fMRI experiment. The rest of the subjects ($n = 23$) participated in a separate experiment to define the regions of interest (ROIs). None of the subjects participated in both experiments.

2.2. Data acquisition

fMR images were acquired using a 3T scanner (Verio; Siemens Erlangen, Germany) with a 32-element phased-array head coil. Tight but comfortable foam padding was placed around each subject's head to minimize movement. T2*-weighted gradient-echo echo-planar imaging (EPI) was used to obtain the functional images. The sequence parameters were as follows: repetition time (TR), 3000 ms; echo time (TE), 30 ms; flip angle, 83°; 39 slices of 3.0 mm thickness with a 17% slice gap, which covered the entire cerebral and cerebellar cortices; field of view, 192 mm; and in-plane resolution, 3.0 mm × 3.0 mm. Oblique scanning was used to exclude the eyeballs from the images. For anatomical imaging, a T1-weighted three-dimensional (3D) magnetization-prepared rapid-acquisition gradient echo (MP-RAGE) sequence was obtained (TR = 1800 ms; TE = 2.97 ms; flip angle = 9°; field of view = 250 mm; and voxel dimensions = 0.9 mm × 0.9 mm × 1.0 mm).

2.3. Stimuli

We used six types of face: those portraying sad facial expressions with tears, with tear-like circles, and without tears; and those portraying neutral facial expressions with tears, with tear-like circles, and without tears (Fig. 1A). Stimuli were produced as described below.

2.3.1. Stimuli production

We followed the same procedure as Provine et al. (2009) to produce the stimuli. We initially obtained 90 images of faces with tears (Tears images) from the online image archives Flickr (www.flickr.com) and Google (www.google.co.jp). We limited our search to images of female adults in order to eliminate gender differences between the subjects and stimuli. In addition to facial images, we also collected 45 landscape images from Flickr to use as controls.

We removed the tears from the 90 face images using photo-editing software (Adobe Photoshop, Adobe Systems Inc., San Jose, CA) and defined them as NoTears images. We then produced new