The inversion effect for neutral and emotional facial expressions on amygdala activity

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Abstract

Neuroimaging studies have reported activation of the amygdala in response to faces and emotional facial expressions. The way in which visual facial information is processed in the amygdala remains, however, unknown. The face inversion effect, a deficit in the processing of inverted compared to upright facial stimuli, has provided an important clue with regard to the visual processes that might be involved. Here we investigated amygdala activity during the presentation of upright and inverted facial expressions of neutral and fearful emotions by measuring functional magnetic resonance imaging (fMRI) while healthy subjects passively viewed these stimuli. The right amygdala was found to be more active in response to upright compared to inverted faces displaying both neutral and fearful emotions. These results suggest that the amygdala is involved in configural/holistic visual processing for faces and emotional facial expressions.

Keywords

Amygdala; Face; Fear; Emotional facial expressions; Inversion effect.

1. Introduction

Faces and facial expressions play an important role in social interaction in humans (Burrows, 2008). Neuroscientific studies indicate that the human amygdala is critically involved in processing faces and emotional facial expressions. A number of neuroimaging studies have reported that the amygdala is more active when neutral faces are viewed compared to when control stimuli, such as houses and mosaics, are viewed (e.g., Blonder et al., 2004; Ishai et al., 2005). Other studies have reported that the amygdala is more active when subjects view emotional compared to neutral expressions, especially in the case of negative emotions such as fear (e.g., Breiter et al., 1996; Fitzgerald et al., 2006). Some neuropsychological studies have shown that the amygdala is indispensable in the appropriate recognition of faces and emotional expressions (e.g., Adolphs et al., 1994; Sato et al., 2002; Young et al., 1995).

Despite the consensus that the amygdala is involved in the processing of faces and facial emotional expressions, the way in which visual facial information is processed by the amygdala remains unclear. Such knowledge would deepen our understanding of the neurocognitive processing of faces and facial expressions. Because even newborn infants efficiently process faces and emotional expressions, it has been speculated that the amygdala is involved in facial stimuli processing even at developmentally early stages (Johnson, 2005) and conducts face recognition using innate visual representations like templates (Emery and Amaral, 2000). In the cognitive science literature, visual representations are generally thought to specify either features or configurations (Treisman and Kanwisher, 1998). Several behavioral studies with adults (e.g., Purcell and Stewart, 1988) and infants (e.g., Goren et al., 1975) have shown that configurations, compared with features, are specifically important in processing facial stimuli (for a review, see Maurer et al., 2002). Collectively, these data suggest that the amygdala conducts configuration-based visual processing for faces and facial emotional expressions, but this remains unresolved.

Behavioral studies have shown that one useful strategy for investigating the visual processing of facial stimuli involves presenting inverted stimuli (e.g., Yin, 1969; for a review, see Bartlett et al., 2003; Valentine, 1988). The studies have indicated that inverted presentations impair face processing due to the difficulty associated with configural or holistic effects (Farah et al., 1995; Mondloch et al., 2002). For example, Farah et al. (1995) instructed subjects to process faces either holistically or partially, and asked them to recognize faces presented in an upright or inverted position. The results showed that inversion impaired the recognition of faces only when subjects processed faces holistically.

Some functional magnetic resonance imaging (fMRI) studies have tested the face inversion effect and have reported inconsistent findings. In response to upright versus inverted neutral faces, such studies have reported activation not only in the visual cortices, including the fusiform gyrus (Yovel and Kanwisher, 2004, 2005) and superior temporal gyrus (Epstein et al., 2006; Haxby et al., 1999; Leube et al., 2003; Yovel and Kanwisher, 2005), but also in the amygdala (Epstein et al., 2006). However, other studies that analyzed the entire brain found no significant differences in amygdala activity in response to upright versus inverted faces (Joseph et al., 2006; Leube et al., 2003). The question of whether the amygdala is related to the face inversion effect therefore continues to remain undecided. It should be noted, however, that a null finding does not generally lead to any definitive conclusion in relation to inductive statistics. This applies specifically to the amygdala, where measuring blood-oxygenation level-dependent (BOLD) signals is difficult (cf. Breiter et al., 1996). Although the previous studies that reported null findings for the inversion effect on amygdala activity acquired images using transverse sections (Joseph et al., 2006; Leube et al., 2003), a previous technical study indicated that coronal sections were preferable for measuring amygdala activity (Merboldt et al., 2001). Hence, one can speculate that data obtained subsequent to the optimization of scanning methods may provide clear evidence for the face inversion effect on amygdala activity.

Another line of inquiry with respect to behavioral studies indicates that inverted presentations can disrupt processing involved in emotional facial expressions (Fallshore and Bartholow, 2003; Kestenbaum and Nelson, 1990; McKelvie, 1995; Prkachin, 2003). For example, McKelvie (1995) presented upright or inverted photographs showing facial expressions of six basic and neutral emotions. The subjects were asked to identify the emotion by label matching. The results of a series of experiments consistently showed that inversion impaired recognition of all negative facial emotions, specifically including fear, sadness, anger, and disgust. Based on this behavioral evidence, it can be hypothesized that inverted presentations of emotional facial expressions may have an influence on the amygdala. As far as we are able to tell, no neuroimaging study has yet tested this issue.

Hemispheric functional differences may be an interesting topic in the investigation of the face inversion effect. A number of neuropsychological studies have shown hemispheric asymmetry in visual processing. Specifically the right and left hemispheres are dominant in the global- and local-based processing, respectively (for a review, see Hellige, 1996). Consistent with the notion that the face inversion effect is related to non-local processing (e.g., Farah et al., 1995), some prevous behavioral studies have shown that the difference in performance between upright and inverted faces was more evident when stimuli were processed in the right hemisphere (e.g., Leehey et al., 1978; Young, 1984). Some neuroimaging studies also suggest the existence of functional asymmetry in amygdala activity in the processing of emotional facial expressions, such as greater involvement of the left versus the right amygdala in conscious versus subconscious (Morris et al., 1998) and slow versus rapid (Wright et al., 2001) processing of facial expressions. Based on these data, it may be possible that the right, as compared with the left, amygdala shows a more evident inversion effect for faces and emotional facial expressions.

To investigate the inversion effect of faces and emotional facial expressions on the amygdala, we measured amygdala activity using fMRI during presentation of both upright and inverted facial expressions showing neutral and fearful emotions. We used fear as a representative emotion, because the facial manifestation of this emotion has been shown to activate the amygdala (e.g., Breiter et al., 1996) and to give rise to an inversion effect in facial expression recognition (e.g., McKelvie, 1995). We acquired echo planar images (EPI) of the amygdala using coronal sections (Fig. 1), which are preferable for measuring amygdala activity (Merboldt et al., 2001). We also focused on the amygdala with relatively thin fMRI images because voxel size reduction results in a reduction of susceptibility artifacts (Merboldt et al, 2001). Based on the aforementioned neuroimaging (Epstein et al., 2006) and behavioral evidence (e.g., McKelvie, 1995), we predicted that inverted presentations of both neutral and fearful facial expressions would elicit reduced amygdala activity compared to upright faces. Based on previous behavioral evidence (e.g., Young, 1986), we also expected that such face inversion effects would be more evident in the right, as compared with the left, amygdala.

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Insert Fig. 1 here
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2. Results

The contrast for the main effect of presentation (upright versus inverted) revealed significant right amygdala activation (x 18, y -6, z -18, $T(10) = 5.47$, extent threshold corrected $p < 0.05$; Fig. 2 upper). We also found a small activation in the left amygdala, which failed to reach significance in extent (x -22, y -10, z -24, $T(10) = 4.68$, extent threshold corrected $p = 0.13$). The significant main effect of expression (fearful versus neutral) was confirmed for the right amygdala (x 30, y -10, z -12, $T(10) = 5.30$, extent threshold corrected $p < 0.05$). Using a more liberal height threshold (uncorrected $p < 0.005$), significant activations were also found in the left amygdala (x –20, y 0, z –12, $T(10) = 3.24$). The interaction between presentation and expression revealed no significant effect on activation.

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Insert Fig. 2 here
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3. Discussion

Our results indicated that an inverted, as compared with upright, presentation of neutral faces induced lower amygdala activity, which is consistent with the results of a previous study examining the same issue (Epstein et al., 2006). Although some earlier studies failed to detect any differences in amygdala activity between the upright and inverted presentation conditions (Joseph et al., 2006; Leube et al., 2003), we suspect that the metholodogy employed during image acquisition may account for the disparity in these results. Those studies acquired images using transverse sections, which often results in signal dropout over the medial temporal regions, including the amygdala, due to susceptibility to incidental artifacts (Merboldt et al., 2001). In the present study, EPI images were aquired using coronal orientations, which are optimal for the purpose of carrying out fMRI studies of the amygdala (Merboldt et al., 2001). A reduction in susceptibility to incidental artifacts improved the BOLD sensitivity and thereby allowed the subtle differences in BOLD under the different presentation conditions to be detected. Taken together with the evidence from the behavioral literature (e.g., Farah et al., 1995), our results suggest that the amygdala is involved in the configural/holistic processing of neutral faces.

More importantly, our results indicated that the inversion of fearful expressions leads to a reduction in amygdala activity. This result is in line with previous behavioral evidence indicating that such inversion impairs the recognition of fearful facial expressions (Fallshore and Bartholow, 2003; McKelvie, 1995; Prkachin, 2003), suggesting that configural/holistic processes are important for processing emotional facial expressions. The notion that configural/holistic processes are important with regard to emotional expressions has been supported by several studies employing alternative methods, for example, where facial parts were subjected to misalignment (Calder et al., 2000). Because previous neuropsychological studies have shown that expression recognition is impaired in amygdala-damaged patients (e.g., Adolphs et al., 1994; Sato et al., 2002; Young et al., 1995) and also due to the fact that neuroimaging studies have demonstrated that the amygdala is active during the observation of emotional expressions (e.g., Breiter et al., 1996), it is reasonable to assume that the amygdala is affected by inverted presentations of emotional expressions. However, this notion was inconclusive, because some studies have shown that expression recognition was accomplished by part-based processing (Baron-Cohen et al., 1997), and the amygdala was active in response to parts of emotional facial expressions (Whalen et al., 2004; Hardee et al., 2008). The present study, as far as we are aware, is the first to demonstrate that inverting a face containing an emotional expression leads to a reduction in amygdala activity, suggesting its relation to configural/holistic visual processing.

Our results showed that the inversion effects of neutral and fearful facial expressions were more evident in the right, as compared with the left, amygdala. This result is in line with previous behavioral studies indicating that the inversion effect of facial stimuli was more evident when the stimuli were processed in the right hemisphere (e.g., Young, 1984). The functional asymmetry of the amygdala has also been suggested in some neuroimaging studies (e.g., Morris et al., 1998). Our findings extend the literature indicating that the right, as compared with the left, amygdala is more related to configural/holistic processing of neutral and emotional facial expressions. However, it must be noted that the left amygdala also showed a presentation effect when a more liberal threshold was used, and therefore, the inversion effect of neutral and fearful expressions appears not to be qualitatively different across right and left amygdalae.

Visual inspection of amygdala activities across conditions (Fig. 2 lower) suggests that only the inverted neutral facial expressions decreased amygdala activity. The results may suggest that the inversion of neutral facial expressions elicits qualitatively different neural processing in the amygdala. However, it must be noted that we did not present any visual stimuli or tasks to participants under the resting condition. It is difficult to determine the psychological processing under such conditions, and the interpretation of the decreasing signal under the experimental, relative to the resting, condition may be problematic (Morcom and Fletcher, 2007). Further studies are necessary to clarify the increase/decrease of neural activity due to the inversion of neutral faces, as compared with other types of baseline conditions.

Our findings can provide some interesting behavioral predictions. For example, because the amygdala has been demonstrated to show rapid activation in response to facial stimuli, even without awareness (e.g., Morris et al., 1998), the inversion effect for facial stimuli may occur rapidly, even subconsciously. Although some previous behavioral studies confirmed that facial stimuli could be processed without awareness (e.g., Sato and Aoki, 2006), to our knowledge, the subconscious face inversion effect remains untested. Second, because the amygdala has been shown to be involved in the recognition of some personality traits, such as trustworthiness, as well as emotional expressions (Adolphs et al., 1998; Winston et al., 2002), and certain relationships have been suggested between these types of recognition (Todorov et al., 2008), the inversion effect may occur even in the recognition of personality traits from faces. It would be interesting to explore such new behavioral phenomena based on the characteristics of amygdala activity we found in the present study.

Previous neuroimaging studies have shown an inversion effect for facial stimuli in the posterior superior temporal sulcus (Haxby et al., 1999; Leube et al., 2003; Epstein et al., 2006; Passarotti et al., 2007) and the posterior fusiform gyrus (Yovel and Kanwisher, 2004; Passarotti et al., 2007). Some neuroimaging studies have suggested that these regions send functional connections to the amygdala during the processing of facial stimuli (e.g., Fairhall and Ishai, 2007). Anatomical studies in monkeys have confirmed that the monkey homologue of these regions projects to the amygdala (Amaral et al., 1992). It is therefore possible that these regions are involved in the configural/holistic processing of faces and emotional facial expressions and that altered activity in these regions then modulates amygdala activity. Due to the fact that the image acquisition in the present study focused on the amygdala, we lack the necessary data to examine the complete neural network. Future neuroimaging studies and related analyses of functional connectivity would be useful in revealing the neural network associated with the amygdala in implementing the configural/holistic processing for faces and facial expressions.

Some limitations to this study should be acknowledged. First, because we tested a small sample, generalization to other subjects is unproven. Specifically, we only tested right-handed subjects and found right-hemispheric dominance in the face inversion effect on amygdala activity. Previous studies have reported that the degree of hemispheric functional difference in face processing could differ between right- and left-handers (e.g., Badzakova-Trajkov et al., 2010). The investigation of left-handers using the present paradigm could be an important matter for future research.

Furthermore, as we only tested neutral and fearful facial expressions, the generalizability of the present results remains to be established. Previous behavioral studies have shown that the inversion effect was elicited by facial expressions of other emotions, including anger (Fallshore and Bartholow, 2003; McKelvie, 1995; Prkachin, 2003), disgust (McKelvie, 1995; Prkachin, 2003), happiness (Fallshore and Bartholow, 2003; Prkachin, 2003), sadness (Fallshore and Bartholow, 2003; McKelvie, 1995; Prkachin, 2003), and surprise (McKelvie, 1995;

Prkachin, 2003). Previous neuroimaging studies have reported that the amygdala also undergoes activation in response to facial expressions involving these emotions (e.g., Fitzgerald et al., 2006). Taken together, these findings suggest the possibility that the amygdala shows the inversion effect for facial expressions of other emotions. Furthermore, because previous studies have shown that non-facial stimuli elicited the inversion effect (Diamond and Carey, 1986) and that the amygdala was active for non-facial objects (Britton et al., 2006), the amygdala may also show activity changes in response to the inversion of non-facial stimuli. Future research using facial expressions of other emotions and non-facial stimuli would provide further evidence about the visual processing of the amygdala.

In summary, our results demonstrated that the right amygdala was more active in response to upright than to inverted faces for both neutral and fearful emotions. These results suggest that the amygdala is involved in configural/holistic visual processing for both faces and emotional facial expressions.

4. Experimental procedure

4.1. Subjects

Eleven volunteers (four women and seven men; mean ± SD age, 22.0 ± 2.6 years) participated in the experiment. All subjects were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971), and had normal or corrected-to-normal visual acuity. All subjects gave informed consent to take part in the study, which was approved by the local ethics committee.

4.2. Experimental design

The experiment consisted of a within-subjects two-factorial design, with presentation (upright, inverted) and expression (neutral, fear) as factors.

4.3. Stimuli

The stimuli consisted of grayscale photographs of 10 models' faces depicting 10 neutral and 10 fearful expressions chosen from a standard set (Ekman and Friesen, 1976).

4.4. Presentation apparatus

The events were controlled by SuperLab software version 2.0 (Cedrus) implemented on a computer (Inspiron 8000, Dell) running Microsoft Windows. The stimuli were projected from a liquid crystal projector (DLA-G11, Victor Company) to a mirror that was positioned in a scanner in front of the subject. The stimuli subtended a visual angle of about 15.0° vertical x 10.0° horizontal.

4.5. Procedure

The session lasted 12 min and consisted of 12 30-sec blocks with 30-sec rest periods between blocks, during which a fixation point was presented at the center of the screen. In each block, the 10 stimuli (each lasting 1500 ms) were presented twice. Each of the four conditions was presented in three different blocks. The order of the stimuli within each block and the order of blocks within a session was initially randomized and then fixed for all the remaining subjects.

Subjects were instructed to observe the images carefully while fixating on the center of the screen (i.e., where the fixation point was presented during the rest periods). To avoid activation due to intentional evaluation of the stimuli, working memory, or response selection, subjects were asked to view the stimuli passively without making a response.

4.6. Image acquisition

Image scanning was performed with a 1.5-T scanning system (MAGNEX ECLIPSE 1.5T Power Drive 250, Shimadzu Marconi) using a standard radio-frequency head coil for purposes of signal transmission and reception. A forehead pad was used to stabilize the head position. The functional images consisted of 20 consecutive coronal slices centering on the amygdala (Fig. 1). The T2*-weighted gradient echo-planar imaging sequence was used employing the following parameters: repetition time (TR)/echo time (TE) = 2000/60 ms; flip angle (FA) = 90°; matrix size = 64 x 64; and voxel size = 4 x 4 x 3 mm. Before the acquisition of the functional images, a T2-weighted anatomical image was obtained in the same plane as the functional images using a fast spin echo sequence (TR/TE = 5104/80 ms, FA = 90°; matrix size = 256 x 256; voxel size = 1 x 1 x 3 mm; number of echoes = 16). After functional image acquisition, we acquired the additional T2-weighted anatomical image covering the whole cerebral cortex using an oblique-transverse orientation to correctly normalize the coronal images (TR/TE = 5104/80 ms, FA = 90°; matrix size = 256 x 256; voxel size = 0.75 x 0.75 x 4 mm; number of echoes = 16). An additional high-resolution T1-weighted image for anatomical localization was obtained for a number of subjects using a 3D RF-FAST sequence (TR/TE = 12/4.5 ms; FA = 20°; matrix size = 256 x 256; voxel dimension = 1 x 1 x 1 mm).

4.7. Image analysis

Image and statistical analyses were performed using the statistical parametric mapping package SPM5 (http://www.fil.ion.ucl.ac.uk/spm) implemented in MATLAB version 7.3 (Mathworks, Inc.). Functional images of each run were realigned using the first scan as a reference to correct for head movements. Data from all subjects showed a small motion correction (<2 mm). Both T2- and T1-weighted anatomical images were preprocessed by intensity inhomogeneity correction. Then, the coronal T2-weighted anatomical image was coregistered to the first volume of the functional images. We also coregistered the coronal and transverse T2-weighted anatomical images. Following this, the coregistered transverse T2-weighted anatomical image was normalized to a standard T2 template image as defined by the Montreal Neurological Institute (MNI) using linear and nonlinear three-dimensional transformations (Ashburner and Friston, 1999; Friston et al., 1995). The parameters from this normalization process were then applied to each of the functional images. The spatially normalized functional images were finally resampled to a voxel size of 2 x 2 x 2 mm and smoothed with an isotopic Gaussian kernel of 8-mm full-width at half-maximum to compensate for any anatomic variability among subjects. The high-resolution T1-weighted image was also normalized to MNI standard space.

We used random effects analyses (Holmes and Friston, 1998) to search for significantly activated voxels that displayed effects of interest. A single-subject analysis was carried out first (Friston et al., 1995; Worsley and Friston, 1995). The task-related neural activities for each condition were modeled with a boxcar function, convoluted with a canonical hemodynamic response function. We used a high-pass filter composed of a discrete cosine basis function with a cutoff period of 128 to eliminate the artifactual low-frequency trend. To reduce any motion-related effects, realignment parameters were included in the model. Serial autocorrelation, which assumes a first-order autoregressive model, was estimated from the pooled active voxels with a restricted maximum likelihood procedure and was used to whiten the data and the design matrix (Friston et al., 2002).

A planned contrast was subsequently performed with respect to the main effect of presentation (upright versus inverted) to test our specific prediction. We also tested the main effect of expression as well as the interaction between presentation and expression. For these analyses, contrast images were generated for each contrast and then analyzed using a one-sample t-test to create a random effect SPM{T}. We focused on the amygdala as our region of interest (ROI) and conducted a small volume correction with an anatomical mask (Worsley et al., 1998). The search region in the amygdala was determined by tracing strict anatomical borders defined by the cytoarchitectonic map derived from the data of human postmortem brains using the Anatomy Toolbox version 1.5 (Amunts et al., 2005; Eickhoff et al., 2005). This amygdala volume of interest comprised a search volume of 1010 voxels (8080 mm^3). Voxels were regarded as significantly activated when they reached an extent threshold of $p < 0.05$, corrected for multiple comparisons, with a height threshold of $p < 0.001$ (uncorrected).

To depict amygdala activities, parameter estimates for each condition were extracted at the peak voxel of the random effects analyses and averaged over subjects.

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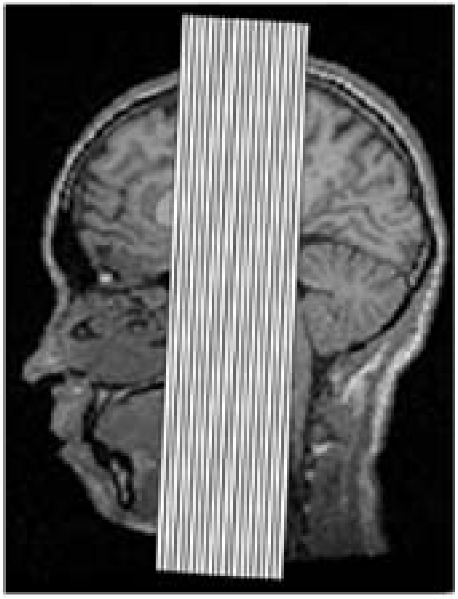

Fig. 1. Illustration of functional image acquisition. Twenty slices were acquired with a coronal section centering on the amygdala.

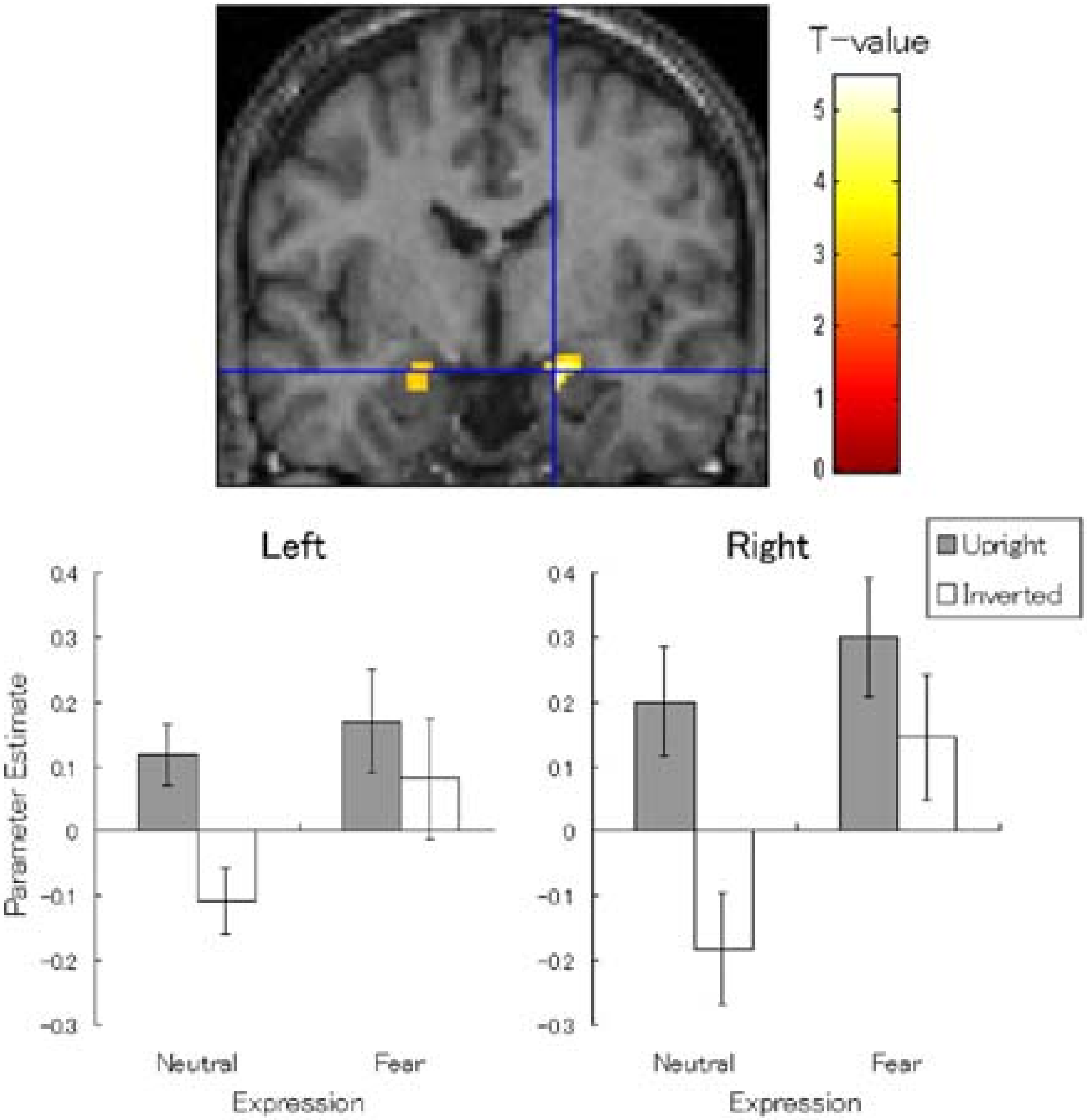

Fig. 2. (Upper) Statistical parametric map showing amygdala activity for the main effect of presentation (upright versus inverted). The area is overlaid on the MRI scan of a subject involved in the present study. For purposes of display, a height threshold was set at $p < 0.01$ (uncorrected). (Lower) Mean (±SE) parameter estimates of the amygdala activation foci.