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Shifting the focus of attention modulates amygdala and anterior cingulate cortex reactivity to emotional faces

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ABSTRACT

Functional neuroimaging studies have largely established the prominence of amygdala during emotion processing and prefrontal areas such as anterior cingulate cortex (ACC) during attentional modulation. In general, emotion processing paradigms known to probe amygdala have not been adapted to recruit prefrontal areas. In this study we used a well-known perceptual face matching paradigm, designed to elicit amygdala response, and asked volunteers to shift their focus in order to recruit regions responsible for attentional control. Stimuli comprised a trio of geometric shapes (circles, rectangles, triangles) presented alongside a trio of emotional faces (angry, fear, or happy) within the same field of view, and subjects were instructed to Match Faces or Match Shapes, as a means of attending to and away from the emotional content, respectively. We observed greater amygdala reactivity to Match Faces (>Match Shapes), and greater rostral ACC response to Match Shapes (>Match Faces). Results indicate that simply and volitionally directing attention toward or away from emotional content correspondingly modulates amygdala and ACC activity.

1. Introduction

Facial expressions convey salient information and their motivational influence naturally captures attention [13]. Though among types of expressions, threat signals are thought to be most readily captured given their significance in responding to danger [17]. Much of the work delineating neural mechanisms of face processing can be traced to: (1) studies regarding the emotional influence of expressions and (2) those concerning the effects of emotion on attentional control.

The former includes the examination of task-relevant face effects—that is, basic perceptual matching paradigms serve to isolate the influence of facial expressions by contrasting a matching face task with a sensorimotor control task (i.e., matching shapes) [11,12]. In support of amygdala as a key emotion processing region [15], perceptual assessment paradigms have, for nearly a decade, consistently demonstrated robust amygdala responses (for review see [22]).

In contrast, attentional control paradigms are based on a biased competition model, in which top-down control is needed to supersede task-irrelevant distractors (e.g., emotional faces) to carry out cognitive goals [19]. Frequently used spatial tasks such as modified dot probe detection [3,20] and "faces/houses" [2,24] have in common a very brief temporal window of information processing. Namely, relevant and irrelevant stimuli (e.g., neutral versus threat faces) are rapidly presented (e.g., 250 ms or less) in the same field of view. Data showing enhanced anterior cingulate cortex (ACC) to task-irrelevant threat faces [2,24] is consistent with findings of prefrontal recruitment when higher-order control is required (e.g., ACC, dorso- and ventrolateral prefrontal cortex areas [2–5,16,19,24,25].

In addition to prefrontal engagement, some of these paradigms also show amygdala response to threat faces [3,24], which supports the function of amygdala in mediating attention to crude threat cues [15]. However, these paradigms are not well-validated probes of amygdala due to inconsistencies in amygdala results [2,20].

In summary, simple perceptual matching paradigms reliably elicit amygdala response whereas more challenging attentional control paradigms are known to recruit prefrontal areas. Not well understood is prefrontal response over task-irrelevant emotional faces when the information processing window extends beyond very brief stimuli presentation. Hypothetically, prefrontal areas associated with sustained goal-directed attention should engage given neurophysiological evidence demonstrating emotional cues not only capture but also sustain visual attention [10]. Yet, few paradigms exist that permit the evaluation of continued

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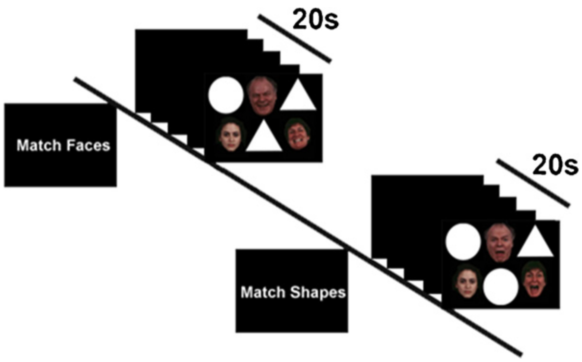

Fig. 1. Schematic of an exemplar Match Faces and Match Shapes blocks in the functional magnetic resonance imaging (fMRI) paradigm.

attentional control in the context of stimuli that robustly elicit emotion processing circuitry.

Accordingly, we modified the well-known perceptual face processing paradigm by configuring the traditional faces-only and shapes-only images to be in the same field of view. Here, subjects were instructed to "Match Faces" to engage emotion processing or "Match Shapes" to alter the focus of attention by shifting it *away* from faces. Over each 4 s trial, the emotional faces are still in full view and should regain attentional focus once the simple shapes matching task is successfully completed (Fig. 1). Based on the literature, we predicted: (1) amygdala reactivity when attending to emotional faces, (2) prefrontal (e.g., ACC, dorsolateral and ventrolateral prefrontal cortex) response when attending to shapes, and (3) attention–emotion interactions, specifically, threat versus happy expressions would enhance amygdala response during "Match Faces", however, threat would enhance prefrontal areas for "Match Shapes".

2. Methods

2.1. Participants

There were 21 right-handed healthy adults (38% male; χ^2 test for gender $p = 0.14$) with a mean age 24.5 ± 5.3 years who were physically, neurologically, and psychiatrically healthy, as confirmed by a physician-conducted medical exam and psychiatric evaluation that included the Structured Clinical Interview for DSM-IV [6]. All participants provided written informed consent, as approved by the local Institutional Review Board.

2.2. Experimental task

During fMRI participants performed our "Emotional Faces Shifting Attention Task" (EFSAT) comprising a trio of geometric shapes (circles, rectangles, triangles) alongside a trio of faces within the same field of view. For "Match Faces", participants selected one of two bottom faces (neutral versus emotional) that matched the emotion of the top target face, and similar instructions were used for "Match Shapes". Consequently, "Match Shapes" was a baseline to "Match Faces" as opposed to a less cognitive, more ambiguous baseline (e.g., fixation) [23]. Face stimuli were from a validated stimulus set [9], the identities were always different, and an equal number of male and female faces were presented.

The paradigm comprised 36 blocks: 18 blocks of matching shapes interleaved with 18 blocks of matching emotional faces, counterbalanced across 2 runs. Each target face condition (angry, fear, happy) was presented for an entire block 6 times without repetition. Each 20 s 'task' block contained four sequential matching trials, 4 s each, preceded by a 4-s instruction image to either "Match Faces" (attend *to* faces) or "Match Shapes" (attend *away* from faces). Participants responded by pressing response buttons.

2.3. Functional imaging: acquisition and analysis

Functional imaging was performed with blood-oxygen-level-dependent (BOLD) sensitive whole-brain fMRI on a 3.0 Tesla GE Signa System (General Electric; Milwaukee, WI) using a standard radio frequency coil. Images were acquired from 30 axial, 5-mm-thick slices using a standard T2*-sensitive gradient echo reverse spiral acquisition sequence (repetition time, 2000 ms; echo time, 25 ms; 64×64 matrix; 24 cm field of view; flip angle, 77). A high-resolution, T1-weighted volumetric anatomical scan was also acquired for anatomical localization. High quality and scan stability with minimum motion corrections was set at <3 mm displacement in any one direction. Conventional preprocessing steps were used in Statistical Parametric Mapping (SPM5) software package (Wellcome Trust Centre for Neuroimaging, London; www.fil.ion.ucl.ac.uk/spm) [7]. Briefly, images were temporally corrected to account for differences in slice time collection, spatially realigned to the first image of the first run, normalized to a Montreal Neurological Institute (MNI) template, and smoothed with an 8 mm isotropic Gaussian kernel.

A general linear model was applied to the time series, convolved with the canonical hemodynamic response function and with a 128 s high-pass filter. Task effects of Match Faces (shapes in 'background') and Match Shapes (faces in 'background') and emotion effects of angry, fear, and happy faces were modeled with boxcar regressors representing the occurrence of each block type, and effects were estimated at each voxel for each participant and taken to the second level for random effects analysis. In addition, six movement parameters obtained during realignment were included in the model as regressors to account for motion-related effects in BOLD signal.

Whole-brain voxel-wise analysis of variance (ANOVA) was conducted to evaluate main effects of Task (Match Faces versus Match Shapes), Emotion (angry, fear, happy), and Task by Emotion interactions. A stringent threshold for significance was set at $p < 0.05$, corrected for multiple comparisons across the entire brain using a false discovery rate with a cluster size of at least 10 contiguous voxels. Significant main effects and interactions were followed by post hoc *t*-tests to clarify the direction of effects.

3. Results

Whole-brain ANOVA revealed a robust main effect for Task in the right amygdala and right rostral anterior cingulate cortex (ACC). As expected, the post hoc *t*-test showed amygdala activity was greater for Match Faces than for Match Shapes (Fig. 2A), whereas rostral ACC activity was greater for Match Shapes than for Match Faces (Fig. 2B). The Match Faces > Match Shapes contrast also revealed activation of the primary visual (fusiform gyrus) and paralimbic (medial prefrontal gyrus and orbital frontal gyrus) areas whereas Match Shapes > Match Faces showed activation of visual association cortices (middle occipital, middle temporal gyrus, supramarginal gyrus) and prefrontal areas (middle and superior frontal gyrus). See Table 1 for all results. However, the main effect of Emotion or interaction between Task and Emotion were both non-significant.

4. Discussion

To date, the delineation of emotional face processing networks primarily corresponds to basic perceptual paradigms or cognitively demanding attentional modulation paradigms, which may tap into relatively distinct networks. Therefore, it is unclear to what extent