ISRSA uncovers the impact of state anxiety on multivariate activation patterns in the human extrastriate cortex

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Abstract

We used functional magnetic resonance imaging and showed that state anxiety modulated extrastriate cortex activity in response to emotionally-charged visual images. State anxiety and neuroimaging data from 53 individuals were subjected to an intersubject representational similarity analysis (ISRSA), wherein the geometries between neural and behavioral data are compared. This analysis identified the extrastriate cortex (fusiform gyrus and area MT) to be the sole region whose activity patterns covaried with state anxiety. Importantly, we show that this brain-behavior association is revealed when treating state anxiety data as a multidimensional response pattern, rather than a single composite score. This suggests that ISRSA using multivariate distances may be more sensitive in identifying the shared geometries between self-report questionnaires and brain imaging data. Overall, our findings demonstrate that a transient state of anxiety may influence how visual information – especially those relevant to the valence dimension – is processed in the extrastriate cortex.

Introduction

Emotions constitute an inherent aspect of human nature, profoundly shaping how we navigate the world. Among the various emotions we experience on a daily basis, anxiety holds particular significance for our survival (Grupe & Nitschke, 2013). An adequate amount of anxiety can heighten our alertness and vigilance, facilitating the detection of threats and avoidance of dangerous situations (Davis & Whalen, 2001). Although previous research demonstrated emotional states can impact visual perception (Phelps et al., 2006), the manner in which transient states of anxiety influence neural representations of the visual world remains largely unknown. Emphasis on trait anxiety in previous studies (Etkin & Wager, 2007; Kim et al., 2011) created a noticeable gap in the neuroimaging literature exploring the link between state anxiety and evoked neural activity during experimental tasks. Moreover, previous functional magnetic resonance imaging (fMRI) studies employing task-based experimental designs have demonstrated its suitability in capturing individual differences in mental or emotional states, but not traits (Gratton et al., 2018). Therefore, the present study aims to utilize task-based fMRI, wherein participants will be presented with emotionally valenced pictures, to examine the association between state anxiety and brain activity patterns. To achieve this, intersubject representational analysis (ISRSA) will be employed as it is well-suited for comparing similarities in multivariate patterns across diverse measurements (Chen et al., 2020; Chen & Qu, 2021; Finn et al., 2020). Prior research has demonstrated that compared to univariate analysis, ISRSA is more sensitive in detecting shared geometries between the brain and behavior (Chen et al., 2020; Kim & Kim, 2022). As such, the present study incorporates ISRSA and a data-driven approach to investigate which brain regions might reveal significant associations between individual variations in state anxiety and multivariate brain patterns of the three valence conditions (e.g., positive, negative, or neutral). Here, we hypothesize that, compared to a single aggregate score, using a multidimensional representation might be better at capturing individual variations in state anxiety. Based on prior empirical work, we hypothesize that brain regions known to be responsive to emotionally valenced stimuli such as the amygdala, ventromedial prefrontal cortex (vmPFC), dorsomedial prefrontal cortex (dmPFC) (Bishop, 2007; Etkin & Wager, 2007; Kim et al., 2011), and the fusiform gyrus (Mattek et al., 2020; Morris et al., 1998; Vuilleumier & Pourtois, 2007) will reveal significant associations with state anxiety.

Method

Participants

Fifty-six participants with no history of mental or neurological disorders were recruited for this study. This study consisted of two phases, where all participants underwent functional magnetic resonance imaging (fMRI) scanning in the first phase, followed by the completion of a battery of psychological questionnaires in the second phase. Three

out of 56 participants failed to complete psychological questionnaires, resulting in a final sample size of 53 participants (12 males, 41 females, mean age = 20.02, age std = 1.82) for the subsequent analysis. All participants provided informed consent, adhering to the guidelines established by the Committee for the Protection of Human Subjects at Dartmouth College.

Experimental procedure

In this study, participants were instructed to complete an emotional reactivity task in the MRI scanner. Within this task, participants were instructed to judge each scene as either indoor or outdoor in a block design paradigm. Each block consisted of six scenes sharing the same valence (i.e., positive, negative, or neutral), with each scene displayed on the screen for a duration of 2.5 seconds, resulting in a total block duration of 15 seconds. Each emotional scene block was then alternated with a fixation block lasting for 15 seconds. Five positive, five neutral, and another five negative emotional blocks were presented in a counterbalanced order across participants.

Stimuli

A total of 90 emotional scenes were selected from the International Affective Picture System (Lang et al., 2008) to be used as stimuli in the emotional reactivity task. Among them, thirty scenes were classified as negative, meeting criteria of both unpleasant and high arousal (valence M = 2.8; arousal M = 5.1). Similarly, thirty scenes were categorized as positive, reflecting pleasant and high arousal (valence M = 7.2; arousal M = 5.0). Additionally, a set of thirty scenes, characterized by neither pleasant nor unpleasant and low arousal, were classified as neutral (valence M = 5.4; arousal M = 3.6). To prevent potential confounds arising from an imbalance in the presence of faces or people across emotional conditions, we ensured that the ratio of faces or people presence was equivalent across the three emotional conditions. This step aimed to rule out any biases that could attribute observed differences in response to a particular emotional condition due to an overabundance of faces or people, following the same procedure described previously (Wagner & Heatherton, 2012).

State anxiety

After the fMRI scanning session, participants were asked to complete the State-Trait Anxiety Inventory (STAI) (Spielberger & Gonzalez-Reigosa, 1971). The STAI is a widely-used scale to assess individual differences in both their state and trait anxiety. Specifically, the State Anxiety subscale, consisting of 20 items, measures the current and transient state of anxiety stemming from stress or other negative emotions.

Image acquisition and preprocessing

Imaging parameters

MRI scanning was conducted using a Philips Achieva 3T scanner with a 32-channel head coil. Structural images were acquired by using a T1-weighted MPRAGE protocol, consisting of 160 sagittal slices with a TR of 9.9 ms, TE of 4.6 ms, voxel size of 1 x 1 x 1 mm, and flip angles of 8 degrees). Functional images were acquired using a T2*-weighted echo-planar sequence, consisting of 36 axial slices, 3 mm thick with 0.5 mm gap, 3 x 3 mm in-plane resolution, and with TR of 2500 ms, TE of 35 ms, voxel size of 3 x 3 x 3 mm, flip angles of 90 degrees, as well as field of view of 240 mm^2.

fMRI data preprocessing

The fMRI data were analyzed utilizing SPM8. The first step in the analysis involved correcting for differences in acquisition time between slices. Subsequently, image realignment was performed using affine registration with 6 DOFs for motion correction. Following motion correction, the images underwent an unwarping procedure to decrease residual motion-related distortions that were not previously corrected. The next step involved normalizing the images to a standard stereotaxic space (3 x 3 x 3 mm isotropic voxels), SPM8 EPI template. Lastly, spatial smoothing was applied using a 6-mm full-width-at-half-maximum Gaussian kernel.

For each participant, a general linear model was computed, incorporating condition effects and covariates of no interest (a session mean, a linear trend to account for low-frequency drift, and six movement parameters derived from realignment corrections). The model was then convolved with a canonical hemodynamic response function. Subsequently, beta images were generated for the positive, negative, and neutral conditions, which were further used for the following analyses. To investigate potential associations between individual variations in state anxiety and corresponding variations in multivariate brain patterns for each emotion condition, the entire brain was divided into 50 functionally similar ROIs. These 50 non-overlapping ROIs were defined based on meta-analytic functional coactivations from the Neurosynth database (de la Vega et al., 2016). Multivariate brain activity patterns for each valence condition were then extracted from each ROI. All subsequent analyses were performed using these multivariate brain patterns obtained from these ROIs, with particular focus given to results from the fusiform gyrus, amygdala, vmPFC, and dmPFC. For completeness, exploratory analyses were performed on all other ROIs.

Intersubject representational similarity analysis (ISRSA)

We then employed intersubject representational similarity analysis (ISRSA; Chang et al., 2018) to explore which brain regions may reveal significant associations between individual variations in state anxiety and variations in multivariate neural activity patterns for each valence condition. ISRSA investigates how intersubject variability in self-reported measurements relates to variability in multivariate brain patterns. ISRSA

accomplishes this by utilizing second-order statistics similar to classical representational similarity analysis (Kriegeskorte et al., 2008; Nummenmaa et al., 2012).

The ISRSA procedure begins with computing subject-by-subject distance matrices based on self-reported data (i.e., state anxiety) and neural data, respectively. Regarding individual variability in state anxiety, in order to test whether compared to taking a single aggregate score, using a multidimensional representation would be better to capture individual variations in state anxiety, we conducted both multivariate distance and univariate aggregate score distance matrices for the state anxiety scores. For the multivariate distance matrix, cosine distance was utilized to calculate dissimilarity across all items in the state anxiety subscale between each pair of participants (Liao & Xu, 2015; Maharani et al., 2020). To obtain the univariate aggregated score distance matrix, we calculated the absolute difference between the composite state anxiety scores, thereby quantifying intersubject dissimilarity between each pair of participants. Regarding the neural data, within each valence condition, pairwise Euclidean distances between participants' multivariate brain patterns were computed per ROI, producing subject-by-subject distance matrices for each ROI. Spearman rank correlations were used to evaluate the associations between the intersubject dissimilarity of the behavioral multivariate and neural intersubject distance matrices, as well as the behavioral univariate aggregate score distance and neural intersubject distance matrices for each valence condition. To assess the significance of these correlations, Mantel permutation tests were utilized (Mantel, 1967; Nummenmaa et al., 2012), which is commonly employed to calculate one-tailed p values in ISRSA research (Chen et al., 2020; van Baar et al., 2019). Given the increased probability of Type I error with multiple tests, Bonferroni correction was applied to control the family-wise error rate (FWE) during multiple comparisons. Consequently, the thresholded *p*-value after the Bonferroni correction was set to 0.001.

Results

ISRSA results using multivariate distances of state anxiety consistently revealed significant associations between intersubject variations in state anxiety and multivariate patterns in the fusiform gyrus. This effect was persistent across valence conditions: positive, $r(1376) = 0.33$, $p < 0.001$ (Figure 1(A-1)), negative ($r(1376) = 0.32$, $p < 0.001$; Figure 1(A-2)), and neutral scenes ($r(1376) = 0.36$, $p < 0.001$; Figure 1(A-3); Table 1). Similarly, significant associations were observed in area MT for positive ($r(1376) = 0.36$, $p < 0.001$), negative ($r(1376) = 0.32$, $p < 0.001$), and neutral scenes ($r(1376) = 0.36$, $p < 0.001$; Table 1). However, no significant associations were found in the amygdala, vmPFC, or dmPFC during the viewing of positive, negative, or neutral scenes (Table 1). On the other hand, results from the ISRSA using univariate aggregate score distances of state anxiety indicated no significant associations in the fusiform gyrus for positive ($r(1376) = -0.01$, $p = 0.549$; Figure 1(B-1)), negative ($r(1376)$

= -0.05, p = 0.796; Figure 1(B-2)), and neutral conditions (r(1376) = -0.11, p = 0.959; Figure 1(B-3); Table 1). Similarly, no significant associations were found in area MT, amygdala, vmPFC, or dmPFC during the viewing of positive, negative, or neutral scenes (Table 1).

Table 1. Summary of ISRSA results using multivariate distances and univariate aggregate score distances for computing intersubject similarity in state anxiety. The values indicate the Spearman correlation from the ISRSA analysis and the values within the parentheses correspond to the *p* values.

ISRSA using multivariate distances

	fusiform gyrus	area MT	amygdala	vmPFC	dmPFC
Positive	0.33 (< 0.001)	0.36 (< 0.001)	0.09 (0.147)	0.04 (0.284)	0.08 (0.171)
Negative	0.32 (< 0.001)	0.32 (< 0.001)	0.20 (0.011)	0.01 (0.422)	0.02 (0.410)
Neutral	0.36 (< 0.001)	0.36 (< 0.001)	0.11 (0.108)	0.11 (0.083)	-0.09 (0.869)

ISRSA using univariate aggregate score distances

	fusiform gyrus	area MT	amygdala	vmPFC	dmPFC
Positive	-0.01 (0.549)	0.02 (0.375)	0.06 (0.205)	0.01 (0.444)	0.02 (0.371)
Negative	-0.05 (0.796)	0.03 (0.335)	0.04 (0.288)	0.01 (0.411)	0.04 (0.276)
Neutral	-0.11 (0.959)	-0.07 (0.882)	0.11 (0.058)	0.04 (0.234)	0.06 (0.167)

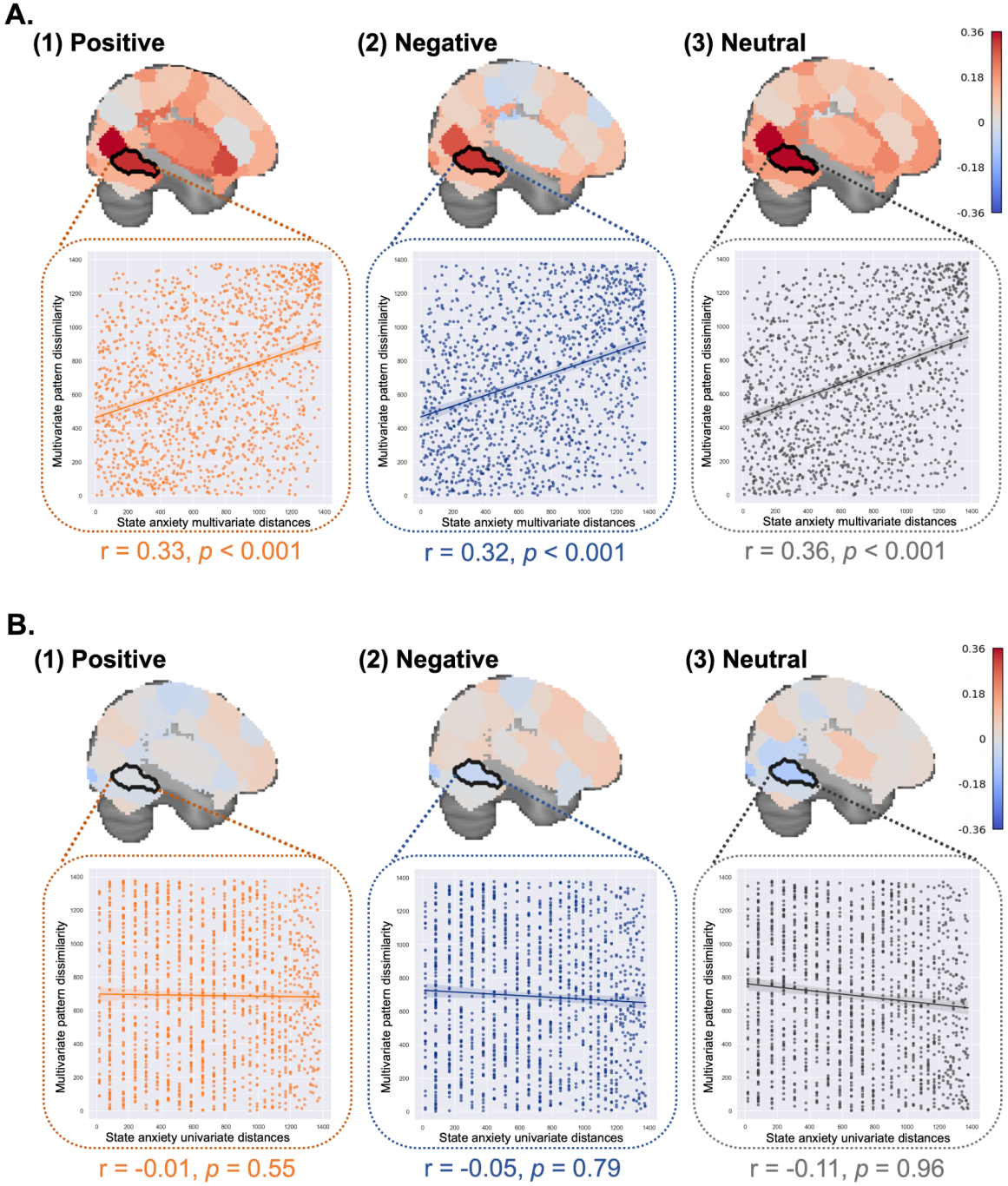

Figure 1. ISRSA using multivariate distances and univariate aggregate score distances in computing intersubject similarity in state anxiety. (A) ISRSA using multivariate distances revealed significant associations between individual variations in state anxiety and multivariate patterns in the fusiform gyrus across all three valence conditions. (B) In contrast, ISRSA using univariate aggregate score distances yielded no significant associations in the fusiform gyrus. Spearman rank correlations and Mantel permutation tests were used to test for statistically significant brain-anxiety associations. The color bar indicates the Spearman correlation value from the ISRSA for each ROI.

Discussion

In the present study, we demonstrate that intersubject similarity in neural representations of emotionally-charged and neutral stimuli was associated with similarity in their self-reported levels of state anxiety. Notably, these associations are primarily observed in the extrastriate cortex, specifically in the fusiform gyrus and area MT. Cognitive neuroscience research over the past two decades has emphasized the role of emotion in modulating stimulus representation in the visual cortex (Carretié et al., 2022; Kragel et al., 2019; Morris et al., 1998). By placing our results within this broader context, the present findings suggest that elevated state anxiety may influence perception by altering the neural representations of visual information in the extrastriate cortex (more so for the fusiform gyrus than the unexpected effect in the area MT). This proposition aligns with a recent study indicating that representations of valence are organized in a gradient within the fusiform gyrus (Mattek et al., 2020). It is likely that an anxious state, compared to a calm state, may bias individuals toward perceiving emotionally charged stimuli differently (Hirsch et al., 2016; Mathews & MacLeod, 1994), leading to alterations in neural representations within the fusiform gyrus. Furthermore, this effect may not only be limited solely to emotionally-charged scenes but could extend to neutral scenes as well. Interestingly, this suggestion finds support in previous research demonstrating that differential neural and behavioral responses to emotionally neutral stimuli are associated with individual differences in anxiety (Cooney et al., 2006; Yoon & Zinbarg, 2008). Overall, our study builds upon prior work that has focused on specific brain regions like the amygdala (Somerville et al., 2004) and proposes a potential candidate mechanism for how anxious states might alter the representations of visual stimuli at the level of the extrastriate visual cortex.

Somewhat unexpectedly, there was a notable absence of significant associations in either the amygdala or vmPFC. While previous studies found correlations between state anxiety and neural responses using univariate methods, they usually involved facial expressions of emotion (Bishop et al., 2004; Somerville et al., 2004) rather than emotional scenes. In cases where emotional scenes were used, such effects appear to depend on experimental design (passive viewing vs. cognitive reappraisal) or pre-existing mental health conditions (Denny et al., 2015). Our multivariate ISRSA approach expands on these findings to suggest that the extrastriate cortex is also impacted by state anxiety. That said, we do note that amygdala activity patterns to negative stimuli were marginally correlated with state anxiety ($p < 0.011$), but we are careful not to interpret this observation as this effect did not pass the corrected statistical threshold.

In sum, the present study examined the impact of a transient state of anxiety on neural representations of visual information. Rather than relying solely on a univariate aggregated score, we employed multivariate distances to capture individual differences in state anxiety. This approach considers the full spectrum of individual variations across all items, avoiding the reduction of the multivariate nature to a single

average score. In line with other recent work (Chen et al., 2020), the present findings provide further evidence that, compared to a single aggregated score, the existence of more nuanced and sensitive individual differences might be within a multi-dimensional space (Jolly & Chang, 2019). Collectively, our results demonstrate that a transient anxious state can indeed influence the neural representations of valence, with particular relevance observed in the fusiform gyrus. These findings underscore the critical role of an anxious state in shaping how we perceive and interpret the world around us.

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