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Trait Anxiety Influences Negative Affect-modulated Distribution of Visuospatial Attention

Gursimran Kaur, [a1] **Rakshita Anand** [b] **and Mrinmoy Chakrabarty** [a1*]

[a] *Dept. of Social Sciences and Humanities, Indraprastha Institute of Information Technology Delhi, New Delhi 110020, India*

[b] *Dept. of Human-Centered Design, Indraprastha Institute of Information Technology Delhi, New Delhi 110020, India*

Abstract—Visuospatial attention allows humans to selectively gate and prioritize visual (including salient, emotional) information for efficiently navigating natural visual environments. As emotions have been known to influence attentional performance, we asked if emotions also modulate the spatial distribution of visual attention and whether any such effect was further associated with individual differences in anxiety. Participants (n = 28) discriminated the orientation of target Gabor patches co-presented with distractors, speedily and accurately. The key manipulation was randomly presenting a task-irrelevant face emotion prime briefly (50 ms), conveying Neutral/Disgust/Scrambled (Null) emotion signal 150 ms preceding the target patches. We calculated attention gradient (change in negative inverse attentional efficiency with unit change in distance from the source of emotion signal) as a metric to answer our questions. Specifically, the Disgust signal modulated the direction of attention gradients differentially in individuals with varying degrees of trait - anxiety, such that the gradients correlated negatively with individual trait-anxiety scores. This implies spatial shifts in Disgust-signalled visual attention with varying trait - anxiety levels. Neutral yielded attention gradients comparable to Scrambled, implying no specific effect of this signal and there was no association with anxiety levels in both. No correlation was observed between state - anxiety and the emotion-cued attention gradients. In sum, the results suggest that individual trait - anxiety levels influence the effect of negative and physiologically arousing emotion signals (e.g., Disgust) on the spatial distribution of visual attention. The findings could be of relevance for understanding biases in visual behaviour underlying affective states and disorders.

Key words: anxiety, emotion, disgust, attention gradient.

INTRODUCTION

Visuospatial attention aids humans to deal with the onslaught of visual information from the complex natural environment by selectively isolating relevant stimuli for elaborate processing by the brain, towards serving the needs of perception and action in a time-critical manner. Deploying attention to the spatial loci of visual environmental stimuli is crucial for actively maneuvering in that environment in daily life, e.g., looking for objects, crossing roads, driving, playing sports, and approaching/avoiding an object, just to name a few (Carrasco, 2011). Indeed, studies support the role of attention in enhancing a range of visual functions, e.g., contrast sensitivity (Solomon et al., 1997; Liu et al., 2009; Barbot and Carrasco, 2018), orientation discrimination (Liu et al., 2005), shape and colour discrimination (Corbetta et al., 1991), spatial resolution (Yeshurun and Carrasco, 1998; Carrasco et al., 2006), amongst several others. Thus, attention confers the ability to parse the visual environment and focus on salient information.

Social visual environments especially are additionally replete with emotional information, such as those conveyed by human faces which are notable landmarks of these environments. Salient information believed to be conveyed by facial emotions orchestrates a wide spectrum of physiological reactions that impact various cognitive processes, flexibly adjusting people's behaviours in responding to the demands of a dynamically changing environment. Indeed, studies have shown that emotions can be extracted from either isolated faces (Alpert, 1993) or an ensemble of faces even within a visual snapshot (Chakrabarty and Wada, 2020), and generally impact a range of visual functions, e.g., visual search (Bendall et al., 2019), discrimination (Phelps et al., 2006; Bertini et al., 2019), identity judgements (D'Argembeau and Van der Linden, 2011) and visual temporal resolution (Chakrabarty et al., 2021). In this regard, the process by which the incidental evaluation of an emotional stimulus (task-irrelevant and to be ignored

*Corresponding author.
E-mail address: mrinmoy@iiitd.ac.in (M. Chakrabarty).
[1] These authors contributed equally to this research.
Abbreviations: DI, Disgust; NE, Neutral; Scr, Scrambled.

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'prime') influences the processing of subsequent task-relevant stimuli is known as emotional / affective priming (Klauer, 1997; Klauer and Musch, 2003), wherein a sizeable body of evidence has accrued suggesting an interaction between emotions conveyed by stimuli and attention in humans, for example, priming visual search of discrepant targets by highly arousing emotions (Lamy et al., 2008); enhancement in cueing effect exerted by threatening emotions on eye-gaze in a Posner-cueing task (Ishikawa et al., 2020); influences of emotional speech prosody on the visual attention to faces expressing matching emotions (Rigoulot and Pell, 2012); influences of underlying self-construal cultural primes on the scope of visual attention (Lin and Han, 2009); emotional potentiation of visual-spatial attention on task performance (Barbot and Carrasco, 2018) and perception (Phelps et al., 2006), including emotional valence and arousal of scenes enhancing overt visual attention as reflected by eye-gaze fixations (Schomaker et al., 2017).

Intriguingly, the effect of emotional information on visual processing and attention is additionally linked with the internal affective states of individuals. While reports suggest that trait-anxiety worsens fearful expression-related contrast sensitivity (Ferneyhough et al., 2013); accentuates affect-primed ratings of facial emotions (Li et al., 2008); potentiates affect-primed perceived contrast (Barbot and Carrasco, 2018); a recent study in a small sample of individuals with autism spectrum disorder has also found that state-anxiety modulates emotion-cued changes in visual temporal resolution (Chakrabarty et al., 2021). The literature on visual processing concurs with anxiety influencing specific biases of attention as well, e.g., allocation of greater attention to task-relevant information vs task-irrelevant (Osinsky et al., 2012); overt attentional orientation and maintenance towards a negative scene and threat information (Veerapa et al., 2020); emotional facial expressions (Bradley et al., 2000); delayed disengagement of attention from threatening words and facial cues leading to increased attentional dwell time on the cues (Fox et al., 2001; Georgiou et al., 2005) in healthy (subclinical) individuals. The nature of the aforementioned attentional biases is mirrored in patients with generalized anxiety disorder in that patients show selective biases of both covert and overt attention towards threatening facial emotions (Bradley et al., 1999; Mogg et al., 2000). These effects may be plausibly interpreted in the light of the evidence that the processing of emotions and the subsequent biases on attention are principally regulated in the brain by the amygdala (Phelps and LeDoux, 2005; Vuilleumier, 2005), which projects to sensory-processing regions of the brain (LeDoux, 2007) and also implicated in anxiety disorders, along with its reciprocally connected region-insula (Stein et al., 2007; Gogolla, 2017). Detection of environmental threats by the amygdala and top-down control of attention by prefrontal cortical regions, e.g., lateral prefrontal cortex and anterior cingulate cortex have been implicated as key players in the neural mechanism of threat-driven biases of attention in anxiety (Bishop, 2008, 2009).

Allocation of attentional resources to multiple disjoint locations of visual space is essential for efficiently performing visually guided cognitive tasks and in this connection, systematic differences in attentional performance across different locations inform the spatial distribution of the focus of visual attention (Handy et al., 1996), which is herein referred to as 'distribution of visuospatial attention. It is worth noting that the account in the above sections about the role of emotions on attention is predominated by studies that investigated exogenous attention (automatic, bottom-up, stimulus-driven) activated adaptively by salient (conspicuous) stimuli which are seemingly crucial for rapid processing from an evolutionary perspective (Klein and Shore, 2000). Of a few studies mentioned above and others have shown that exogenous attention is linked with emotions and anxiety, such as increased anxiety worsening negative emotion related visual attentional costs (Ferneyhough et al., 2013); anxiety potentiating selective visual attention (Barbot and Carrasco, 2018); attentional biases to threat-based stimuli (Putman et al., 2006; Moriya and Tanno, 2011) and negative-affect impaired attentional orienting in anxiety (Moriya and Tanno, 2009).

Given the account in the preceding section, there is a possibility that anxiety influences the distribution of exogenous visuospatial attention which has been primed by emotions, which to our knowledge has not been adequately clear in the extant literature. Specifically, a) the effect incidental emotional influences have on the deployment of exogenous visual attention to the space relative to the source of the emotion signals, i.e., the distribution of visuospatial attention, and b) whether the above influence (if any) is further biased by inter-individual differences in internal affective states, e.g., anxiety, remained to be directly addressed. We, therefore, investigated whether temporally unexpected facial emotion cues below conscious awareness (specifically Disgust and Neutral), known to be processed by the amygdala (Phelps and LeDoux, 2005; Chapman and Anderson, 2012), modulated the gradient of exogenous visuospatial attention and additionally, whether any such influence was conditioned by the individual severities of state and trait - anxiety of the participants. Here, the 'gradient of visuospatial attention' is calculated by a simple difference of an index of attentional efficiency (Townsend and Ashby, 1978) between two locations separated in space as measured from the centre of the emotion signal (Near and Far; see Data analysis). Thus, the gradient here reflects the relative extents of visual attentional resource allocation between two disjoint spatial locations, or distribution of visuospatial attention, with the sign of the gradient indicating the spatial locus receiving relatively greater attentional resources (Near > Far eccentricity/distance relative to the source of emotion signal at the screen centre or vice-versa). Disgust emotion cue was chosen as it is one of the basic, negatively valenced emotions; intimately linked with interoceptive processes; known to elicit physiological arousal below awareness and facial features conveying disgust across cultures are consistent (Chapman and Anderson, 2012; Tybur et al., 2013; Allen et al., 2016). Also noteworthy is that a Neutral emotion cue may be considered an emotion signal and not merely a null cue, considering earlier evidence suggesting Neutral is processed as ambiguous, threat-related information in the amygdala of individuals with social-emotional disorders (Cooney et al., 2006). It is pertinent to mention here that this study intended to evaluate the emotional cueing effects below explicit perceptual judgment and hence, did not require distinguishing the facial emotions. We here expected varying levels of subjective anxiety would bias the emotion signalled distribution of visuospatial attention across the disjoint spatial locations differentially in individuals. In line with our expectation, we found that individual attention gradient (indexing visuospatial attention distribution) is differentially modulated by Disgust compared to Null-emotion signal and this modulation is further conditioned by subjective trait - anxiety, such that the distribution of exogenous attention shifts spatially (implied by attention gradient flip), with increasing inter-individual severities of trait -anxiety. The findings suggest an emotion-cued spatial redistribution of individual exogenous attention that is biased by the subjective trait - anxiety of individuals.

EXPERIMENTAL PROCEDURES

Participants

A total of 28 healthy individuals (mean ± *SD*: 22.1 ± 3. 8 years, range: 18–35 years; nine females), naïve to the experimental goals were recruited for the study after due informed, written consent and were compensated with Amazon gift cards worth Indian Rupees. 250/- for their time to participate in the experiment.

We reached the requisite sample size based on the effect sizes in two earlier studies with human participants (Barbot and Carrasco, 2018; Veerapa et al., 2020) which were relevant to the background of our experiment. While the former (Barbot and Carrasco, 2018) demonstrated a significant correlation between trait - anxiety and the role of visual attentional modulation in low-level visual function, when precued by facial emotions (correlation coefficient $r = 0.53$), the latter (Veerapa et al., 2020) found that average eye-gaze fixation duration towards negative stimuli was biased by individual trait - anxiety (correlation coefficient $r = 0.51$; $R^2 = 0.26$). Based on the large effect sizes, i.e., correlation coefficients $r > 0.5$ (Cohen, 1988, 1992) reported in the above studies, we anticipated a similar strength of association between trait - anxiety and our outcome measure for attentional efficiency (see Data analysis) but used the lower effect size i.e., correlation coefficient = 0.51 for our calculation to estimate a sufficient sample size given the prior evidence. Thus, after entering the expected correlation coefficient = 0.51 (effect size), accepted two-tailed alpha level = 0.05 and power of detection = 0.8 (80% chance of correctly rejecting the null hypothesis) into a priori sample size calculation by the 'Exact' method in the G*power version 3.1.9.7 (Faul et al., 2009), we got a sample size of at least 27 participants to correctly reject the null hypotheses in a two-tailed, correlation analysis with 80% chance. We here report our results with 28 participants that agree with the above calculation and are comparable to similar peer-reviewed studies reported earlier (Fox, 1996; Bishop, 2009; Barbot and Carrasco, 2018; Chakrabarty et al., 2021). The above-recruited participants did not report any neurological and/or psychiatric diagnoses at the time of the experiment and had normal or corrected-to-normal (with spectacles) vision. The study and its procedures were approved by the Institutional Review Board of the Indraprastha Institute of Information Technology Delhi, INDIA.

Subjective ratings

All participants completed the English version of the State-Trait Anxiety Inventory (STAI) for assessment of self-reported severity of anxiety levels (Spielberger et al., 1983). After the participants were acquainted with the main task procedures in a few practice trials and the questionnaire was administered before beginning the main experimental task.

Procedures

Participants were seated at a distance of 57 cm from a 27-inch computer monitor (1920 × 1080 pixels; 144 Hz; ACER; edges subtending ~60 × 34°), with their heads stabilized using a chin and headrest to view stimuli presented on the monitor. The experiment was controlled with custom code written in PsychoPy (v2021.2.1). Each trial began with a central white fixation cross (1 × 1°), presented for a random duration of 300–500 ms. Fixation cross offset was immediately followed with a spatial attention cue (filled black circle of size 0.5°) centred at an eccentricity (distance) of 5° on the horizontal meridian from the screen centre, along with an image prime (7 × 7° visual angle) for 50 ms at the screen centre. This spatial attention cue was meant to orient the attention of the participant to either the right or left half of the screen (relative to the central fixation) for the upcoming task-relevant target. After an intervening blank (inter-stimulus interval, ISI) of 150 ms, the target (Gaussian Gabor patch; size = 1°, spatial frequency = 3 cycles/degree, contrast = 100%, luminance = 28.9 cd/m^2) visual stimulus was presented for ~40 ms, pseudo-randomly at three different vertical eccentricities (±2.9°, 4.3°, 6.5° measured from the position of the attention cue), either on the left or the right half of the screen with equal probability. A distractor (black open circle; size = 1°, contrast = 100%, duration ~40 ms) was co-presented with the target at 180° (diametrically opposite) from the target position. An instruction screen following the earlier event signalled the participants to respond by pressing the appropriate key on a PC keypad. The trial ended with keypress and the next trial started after a blank of 500 ms. The duration between the presentation of image prime + attention cue to the target was 200 ms to suppress saccadic eye movements (on an average every ~300 ms) and to probe covert attention. Participants were explicitly instructed to maintain fixation at the screen centre throughout the trial, covertly utilize the peripheral attention cue to prepare for the upcoming target while ignoring the central image prime, and accurately discriminate the angle of orientation (left/ right) of the target to finally indicate their decision speedily and accurately by the keypress. There was no emotion recognition step in the trial as the task performance was investigated under the awareness (explicit perceptual recognition) of the image primes, without orienting participants' attention to these primes.

Each participant performed six sessions of 90 trials each, with intermittent breaks (total = 540 trials) during a single visit to the lab. One session consisted of 30 trials each primed by emotion conveying images (i.e., Neutral and Disgust) and 30 trials primed by no emotion (Scrambled; control) conveying images (Scrambled; control), adding up to 90 trials. Trials primed by each image type were further, comprised of 10 trials each with spatial target eccentricity of 2.9°, 4.3°, and 6.5°. All other aspects of the trials were the same. Within each session, the trials primed by different image types and with different target eccentricities were randomized to rule out the element of predictability from upcoming trials. The key experimental manipulation was the unexpected presentation of task-irrelevant image prime (Neutral/Disgust/Scrambled) preceding the task-relevant visual target. If emotions influenced visual-spatial attention gradient, then the difference in attentional efficiency calculated across the nearest and farthest eccentricities of target presentation (see Data analysis) would vary between the pure emotion signals (Neutral/Disgust) and emotion-null signal (Scrambled). The experimental design is illustrated in Fig. 1. Participants performed 10–20 practice trials and the main experiment commenced only after the investigator(s) verbally confirmed the participants' full acquaintance with the task demands. A participant on average spent 70 min in the entire experiment.

Face images (Caucasian, Asian and African ethnicities) were sourced from academic, non-commercial databases: 64 different images (32 females, 32 males; all Caucasian) from Karolinska Directed Emotional Faces database – KDEF (Lundqvist et al., 1998) and 26 different images (13 females, 13 males; 16 Caucasian, seven African-American, three Asian-American) from NimStim facial expression database (Tottenham et al., 2009). Thus, there were 90 different images (45 females, 45 males) expressing each emotion type (Disgust and Neutral; total = 180 face images). The KDEF database has been rated by a different group (Goeleven et al., 2008), wherein the mean values reported on a scale of 1 (least) – 9 (most) are – valence = 6.23 (Disgust), 4.75 (Neutral); arousal = 3.71 (Disgust), 2.67 (Neutral). The NimStim database has been evaluated psychometrically for validity and reliability of recognition of the emotions of these images in untrained individuals (Tottenham et al., 2009). These scores are – mean validity: 0.76/1 (Disgust), 0.91/1 (Neutral) and test–retest reliability: 0.81 (Disgust), 0.94 (Neutral) respectively.

All images were converted to grayscale eliminating the hue and saturation and thereafter, their brightness was adjusted to the same level (mean = 128, range = 0–255). An equiluminant scrambled image was created from a grayscale face image by randomly permuting the pixels so that no face emotion was evident. There were a total of 90 different face images and each face image was shown twice to a participant in different sessions of the entire experiment.

Data analysis

Data from keypad responses were analyzed by custom codes. The steps of analysis in a single participant are explained here. Within one session the response data were first sorted by each of the three emotions (Neutral, Disgust, Scrambled) and thereafter, by three eccentricities (2.9°, 4.3°, 6.5°) for each emotion condition. The median reaction time (RT) of the trials wherein the participant discriminated the angle of target orientation correctly (correct trials) and the fraction of correct trials out of the total number of trials (accuracy) were used to calculate the negative inverse efficiency score (index of attentional efficiency), which is a variant of inverse efficiency score described earlier (Townsend and Ashby, 1978),

$$nIES = \left(\frac{median(RT)}{accuracy}\right) \times (-1) \tag{1}$$

The above metric of nIES was calculated by multiplying the original inverse efficiency score (Townsend and Ashby, 1978) by (-1), such that higher nIES scores indicated higher attentional efficiency, and are more straightforward to interpret. The inverse efficiency score is an integrated metric incorporating both the reaction time and accuracy of task performance to yield a single score popularly used as an index of speed-accuracy tradeoffs in attention studies (Townsend and Ashby, 1978; Chica et al., 2011; Robertson et al., 2013). This was done for each of the three eccentricities for all three emotion conditions. Further, session-wise nIES scores calculated as above for each of the six sessions were z-scored across those sessions for each emotion condition separately. Please note that the nIES calculated at three spatial locations relative to the source of the emotion signal at the screen centre, i.e., Near (2.9°), Intermediate (4.3°) and Far (6.5°). The ratio of eccentricities, i.e., Far / Intermediate and Intermediate / Near were both ~1.5°. The three spatial locations were to observe the trend of emotion cued visual attentional spread uniformly over space. The nIES score at the Intermediate eccentricity was not used in any further calculation. See Fig. 2(**A–C**) for an illustration. Next, the visuospatial gradient of attention (referred to as 'gradient' in the text hereafter) was calculated by subtracting the z-scored nIES of the farthest target eccentricity (6.5°; Far) from the nearest (2.9°; Near). The 'gradient' summarizes both the magnitude as well as direction. A positive value of the gradient, therefore, indicates greater attentional efficiency near the emotion signal relative to far (Near minus Far). This metric was used for all later statistical analyses. Two participants' task performance was less than the chance level (0.5) in one/more sessions and were excluded from further analyses. The number indicated under 'Participants' is the final sample size after exclusion. The average accuracy over all six sessions

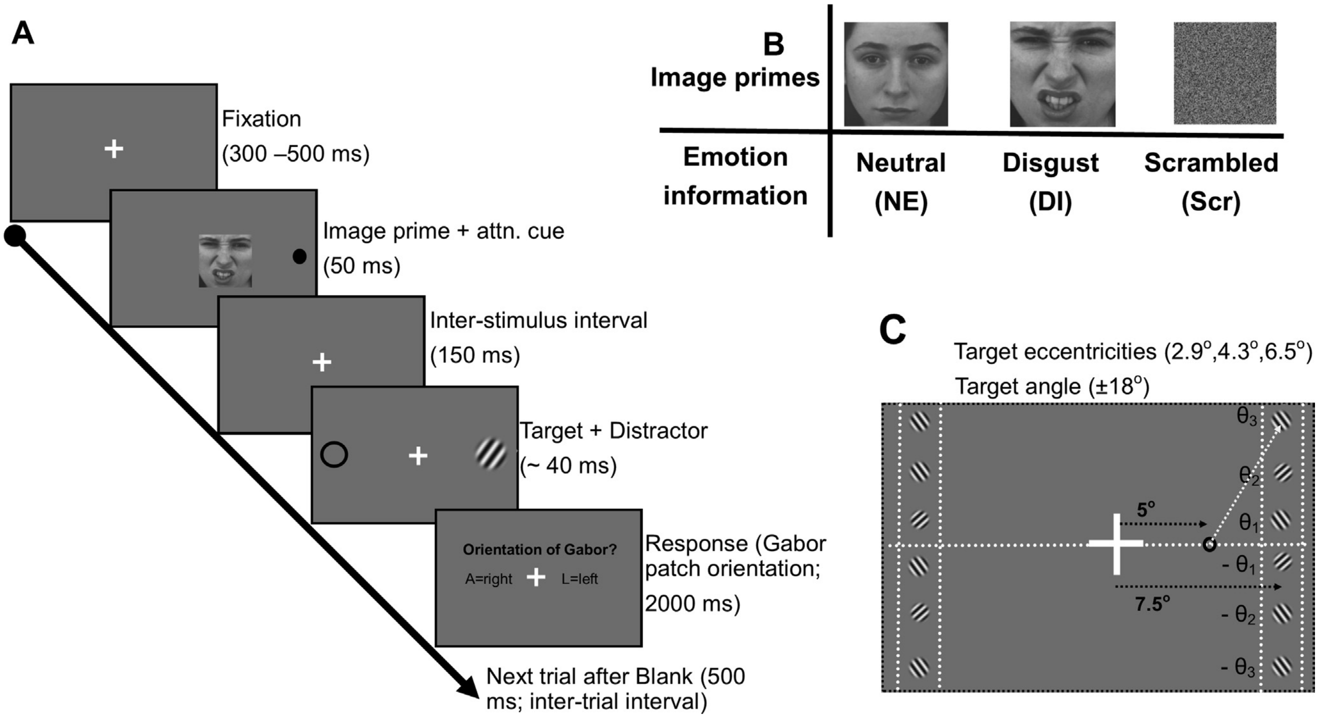

Fig. 1. Experimental Procedures. (A) The timeline of one trial of the behavioural task is shown. A fixation cross at the screen centre for a pseudorandom duration (300–500 ms) was immediately followed by a task-irrelevant image prime at the centre of the screen + an attention cue (black, filled circle; 5° eccentricity from screen centre on the horizontal meridian) for 50 ms. Following an inter-stimulus interval of 150 ms, the target (Gabor patch with an orientation of either +18°/−18° left/right randomized across trials) appeared for ~40 ms at different degrees of visual angle on the direction cued by the attention cue. A distractor (black, open circle) appeared for the same duration at a spatial location diametrically opposite (180°) from the target. Participants were asked to fixate at the centre of the screen throughout, ignore the task-irrelevant image prime while covertly attending to the half of the screen cued by the attention cue and indicate whether the target was oriented towards the left or to the right by pressing the appropriate keys. The next trial started after 500 ms from the key-press. **(B)** The two different types of image primes convey facial emotion information. KDEF image IDs: (Disgust - F05DI); (Neutral – F15NE). The KDEF images may be included in manuscripts as per the terms of the original authors (https://kdef.se/home/using%20and%20publishing%20kdef%20and%20akdef.html). **(C)** The six different vertical eccentricities/ spatial positions (±2.9°, 4.3°, 6.5°) were measured from the imaginary position (black, open circle) of the attention cue presentation on either half of the screen. Please note that the targets were randomly presented at each eccentricity, either above/below and left/right side, relative to the screen centre. The distractor was always presented at a position diametrically opposite to the target (180°).

per participant was ≥86.5%, and had an overall average across all participants with mean ± SD = 95.2 ± 0.06%, in the range = [86.5%, 99.6%]. Association of trait and state - anxiety scores with gradient values were tested by permutation-based Spearman's rank correlation coefficients separately, to examine for a monotonic relationship between the two variables. The distribution of the coefficients for the null hypothesis was estimated by 10,000 permutations as described earlier (Groppe et al., 2011) and the empirical coefficients are reported with their 95% bootstrap (10,000 samples) confidence intervals (*CI*). All statistical analyses were carried out with the Statistics and Machine Learning Toolbox (version 12.0) of MATLAB 2020b. For all purposes, $p < 0.05$ was considered statistically significant. Please note that the relevant analyses with nIES scores as detailed below were also repeated separately with its two constituent measures - RT and accuracy scores and the overall pattern is reported in the Supplementary Information file for a comparison with the actual nIES analyses (below) from which the main conclusions were drawn.

RESULTS

Effects of emotions on visuospatial attention gradient

To examine whether the image primes conveying different emotion signals modulated visuospatial attention gradients in participants, one-way repeated measures analysis of variance (ANOVA) was run on the gradient with a factor of emotion condition (levels: Neutral, Disgust, Scrambled). This test when run after confirming the adherence of the data to the assumptions of normality (Lilliefor's test for normality; all $ps \geq 0.07$) and homogeneity of variance (Mauchly's test for sphericity; Mauchly's W = 0.88, p = 0.054), returned a non-significant result ($F_{(2,54)}$ = 2.97, p = 0.059, partial η^2 = 0.10) but given the appreciable effect size (partial η^2), an effect of emotions on the overall gradient would possibly attain statistical significance with a larger sample size.

We had one main question of *a priori* interest – whether gradient modulation by pure emotion (Neutral and Disgust) differed from no emotion (Scrambled).

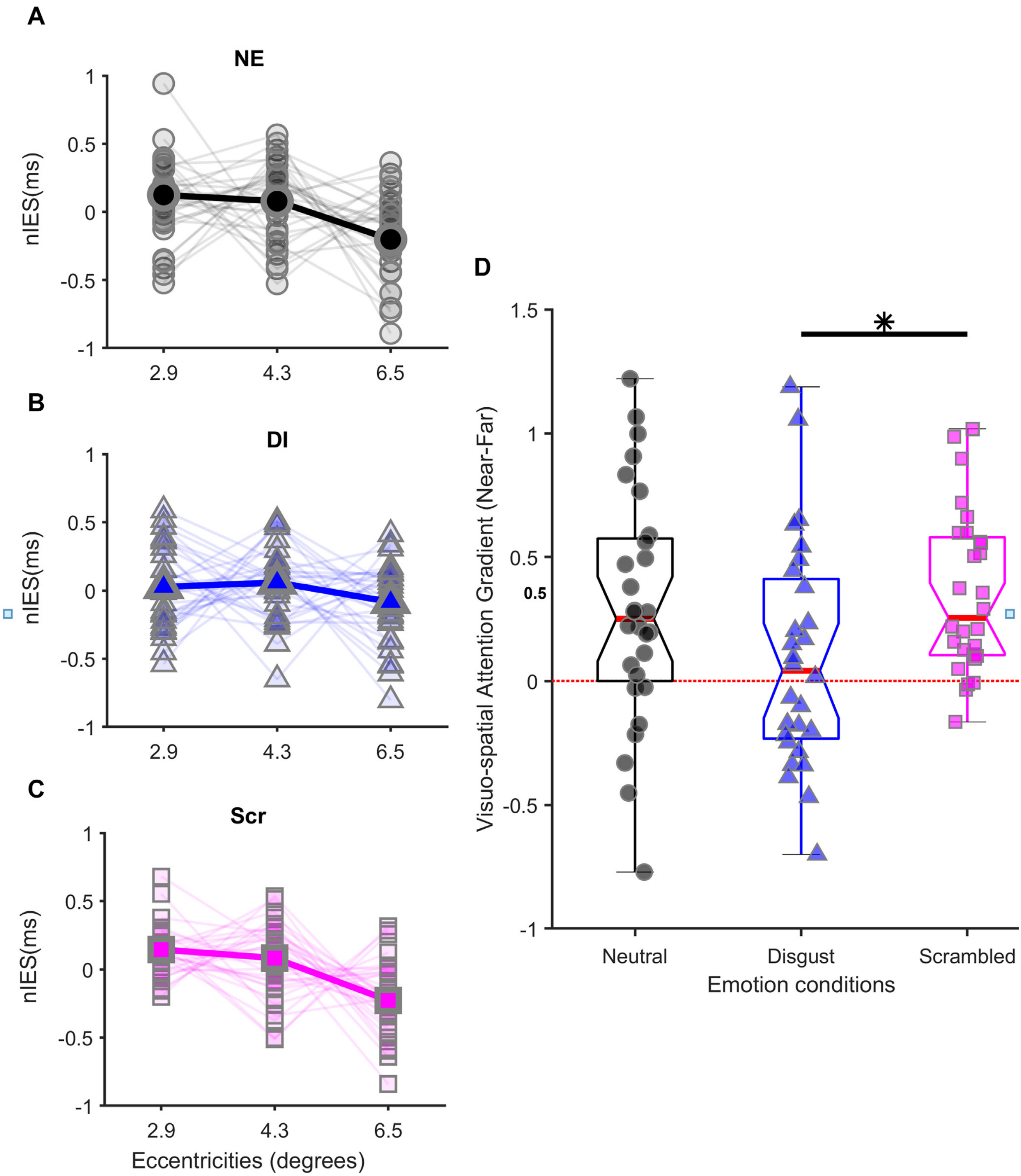

Fig. 2. Effects of emotions on visuospatial attention gradient (A-C) Plots showing the negative inverse efficiency scores (nIES) at three spatial target eccentricities for an individual participant (lighter markers and lines in the background) and mean across participants (darker markers and lines in the foreground) in Neutral (NE; black), Disgust (DI; blue) and Scrambled (Scr; magenta) image primes. **(D)** Boxplots with overlaid markers showing the distribution of participants' visuospatial attention gradients calculated with nIES scores (see *Data analysis*). The horizontal edges of the boxplots show the 25th, 50th (median; red), and 75th percentiles of the distribution. All other colour conventions are the same as **(A-C).** $^{*}p < 0.05$.

Thus, despite the non-significant ANOVA, it was followed up with posthoc comparisons as suggested earlier (Ruxton and Beauchamp, 2008). Consequently, a significant difference between the gradients modulated by Scrambled and Disgust (difference of means ± s.e.m = 0.26 ± 0.11, Bonferroni corrected $p = 0.04$; Fig. 2(**D**)) was revealed but not between Scrambled and Neutral (difference of means ± s.e.m = 0.06 ± 0.09, Bonferroni corrected $p = 1.00$). As the gradient modulation by Neutral was comparable to Scrambled (emotion-null cue), it suggests that Neutral emotion was inconsequential in influencing visuospatial attention in the participants. By contrast, Disgust emotion modulated visuospatial attention distinctly and differentially from Scrambled as evidenced above. While it was not a question of our *a priori* interest, the difference between Neutral and Disgust was also non-significant (difference of means ± s.e.m = 0.19 ± 0.13, Bonferroni corrected $p = 0.44$). The difference between the Neutral and Disgust emotion signals might be revealed with a larger sample size, which we could not discover in our present sample. A closer look at the distribution of the Disgust-modulated data indicated two subsets of participants split by the median within the same sample with mutually opposite directional modulation of gradients by the Disgust emotion (Fig. 2(**D**); see middle boxplot with overlaid data). Whether this trend was related to the underlying anxiety of the participants was examined next.

Modulation of emotion-induced effects on visuospatial attention gradient by anxiety

The sample of participants had mean trait - anxiety of 49.11 ± 5.34 (mean ± *SD*; range = 40–59) and mean state - anxiety of 48.07 ± 2.40 (mean ± *SD*; range = 44–54). First, it was tested whether individual trait - anxieties influenced the effect of emotions on the visuospatial attention gradient. Thus, the individual self-reported trait-anxiety scores of participants were correlated with their respective gradients modulated by all three emotion signals. This revealed a significant correlation with Disgust emotion (*rho* = −0.55, *CI* = [−0.76, −0.19], two-tailed Bonferroni corrected $p = 0.006$; Fig. 3(**B,E**)), such that Disgust-signalled attention gradient reduced with increasing trait - anxiety levels of participants. Since the gradient value reflects attentional efficiency near the emotion signal relative to far (Near-Far; see *Data analysis*), the above correlation suggests that with increasing trait - anxiety, visual attention closer to the Disgust signal waned relative to the farthest spatial locus. By contrast, no influences of trait anxiety on the effects of either Neutral (*rho* = −0.26, *CI* = [−0.58, 0.13], two-tailed $p = 0.18$; Fig. 3 (**A,D**)) or Scrambled emotions (*rho* = −0.24, *CI* = [−0.61, 0.20], two-tailed $p = 0.22$; Fig. 3(**C,F**)) respectively, were observed. These results point at spatial re-distribution of attention only by Disgust emotion, which is influenced by individual trait - anxiety severities.

Next, on testing whether individual state - anxieties influenced the effect of emotions on the gradient, none of the emotion types were found statistically significant (all *ps* $\geq$ 0.29; see details in Fig. 4).

DISCUSSION

In this study, we examined how facial emotion signals influenced the spatial distribution of visual attention in a sample of healthy individuals which consisted of a predominantly larger percentage of males (~68%). As a result, we found that Disgust emotion cues modulated the gradient of spatial attention in a way such that it was markedly different from the emotion-null Scrambled cue, but the same was not true for Neutral emotion cues. Importantly, self-reported individual trait - anxiety severities were found to specifically condition the Disgust-signalled modulation of attention gradient. Altogether, the findings reveal the effects task-irrelevant, unexpected visual affective signals (especially of negative valence and high arousal) together with individual trait - anxiety severities may have on the spatial deployment of attention. Therefore, this study integrates the two fields of work about the influences of both emotions and anxiety on the spatial distribution of visual attention, instead of dealing with them in isolation.

Our results showed no difference between the Neutral and emotionless, Scrambled-signalled attention gradients, suggesting that the Neutral emotion signal did not have a noticeable effect. This finding generally agrees with evidence that other emotional valences conveyed by faces have pronounced effects compared to Neutral in visual processing (Phelps et al., 2006; Zeelenberg et al., 2006) in healthy individuals. On the other hand, we found that the Disgust-signalled trials had an overall diminished attention gradient close to zero, which was significantly less than the Scrambled-signalled trials. This could mean that either the magnitude of Disgust-signalled gradients was negligible or the direction of the gradients in the sample was in mutually opposite directions resulting in a diminished net gradient (see Data analysis for details). Further analysis of the data confirmed the latter and revealed that there indeed were two distinct subsets of individuals in the sample with relatively higher and lower anxiety, split exactly in half (14 participants in each subset) by the median trait - anxiety score. This when followed up with correlation analysis, demonstrated a monotonic relationship between the trait - anxiety scores and the attention gradients, such that the direction of the attention gradient changed from positive to negative as individual trait - anxiety severity increased. The evident trend implies relatively greater efficiency of visual attention at a spatially closer location to the Disgust signal versus the farther location in the individuals weakened as individual trait - anxiety increased, thereby spatially re-distributing their attentional resources. Our findings generally agree with the previous literature in that negative emotion signals have been shown to influence attention in different ways. For example, negative (sad) as compared to positive (happy) emotional faces tend to shift the allocation of attention more towards the left hemispace (Armaghani et al., 2014); attentional focus onto an emotional target face is lesser when the target expresses negative versus neutral/positive emotions (Fenske and Eastwood, 2003); emotions conveyed by negative faces outside the attentional focus shift focal attention to the visual-spatial loci of the target more than positive faces (Eastwood et al., 2001); negative/aversive stimuli associated with neutral distractors produce momentary lapses in deployment of attention/at-

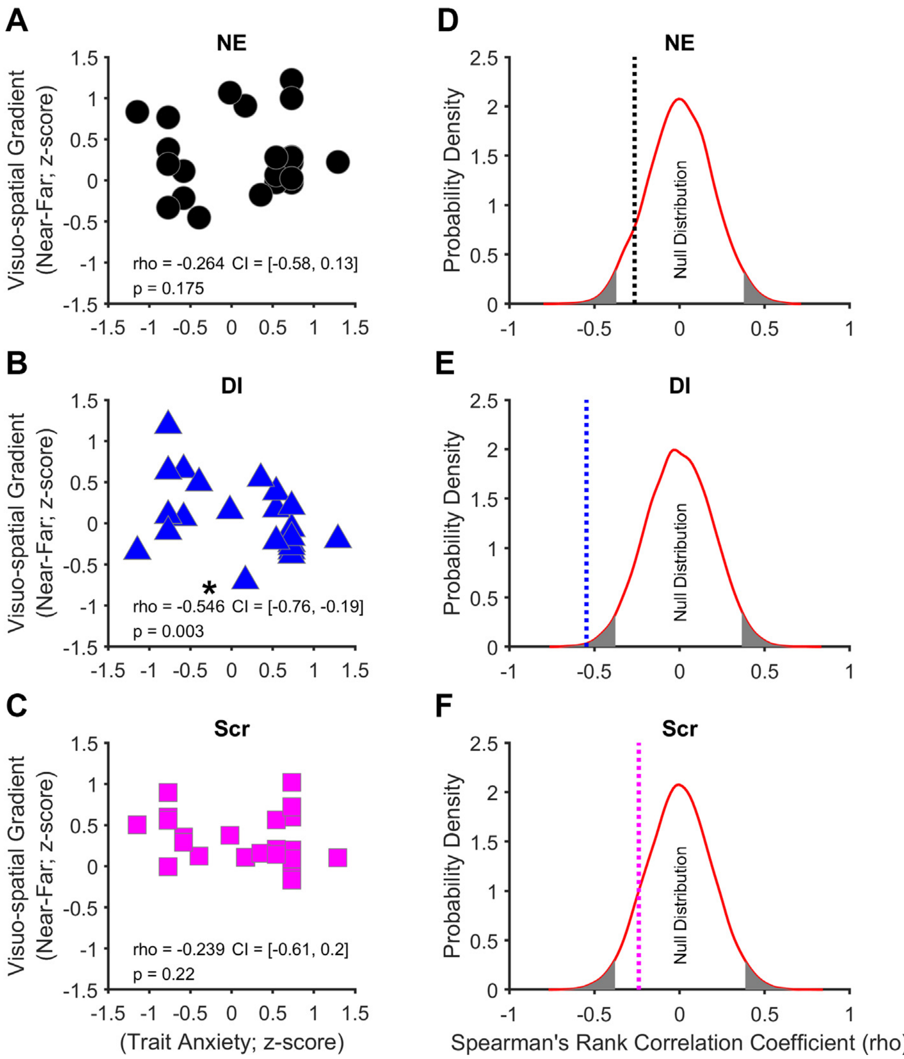

Fig. 3. Modulation of emotion-induced effects on attention gradient by trait - anxiety (A-C) Scatter plots showing Spearman's Rank correlations between participants' trait-anxiety scores and attention gradient influenced by Neutral (NE; black filled circles), Disgust (DI; blue filled triangles), and Scrambled (Scr; magenta filled squares) image primes respectively. **(D-F)** Probability density (smoothing window kernel width = 20) curves created from Spearman's rank correlation coefficients (rho) obtained by 10,000 random permutations (see Data analysis) to estimate the distribution of the null hypothesis that rho is not different from zero. Grey-shaded ends of the distribution show regions rejecting the null hypothesis. Overlaid broken vertical lines indicate the empirical rho values in Neutral (black), Disgust (blue), and Scrambled (magenta) image primes respectively. rho = Spearman's correlation coefficient; CI = 95% confidence interval; $^{*}p < 0.05$.

tentional blink (Smith et al., 2006); attention is allocated automatically towards negative and threatening stimuli (Anderson and Britton, 2020); attentional capture is increased by combat-related negative emotion primes in post-traumatic stress disorder (Olatunji et al., 2013) as well as attentional engagement is increased and disengagement decreased from negative, highly threatening pictures while performing on an exogenous cueing task in high trait - anxiety (Koster et al., 2006). Thus, our result suggesting emotion signals tune the spatial scope of visual attention supplements the above evidence.

Anxiety is an anticipatory apprehension of future threat premised upon no clear object and trait - anxiety indexes a stable disposition of an individual to judge a range of otherwise innocuous events as potentially threatening (Spielberger et al., 1983; Wiedemann, 2015). Studies have shown that the trait - anxiety construct biases the cross-talk between emotions and visual attention in various ways, e.g. facilitation in low-level visual tasks (Phelps et al., 2006; Ferneyhough et al., 2013); inability to maintain attentional focus in emotional Stroop task (Fox, 1993); reactive recruitment of attentional resources under conflict (Osinsky et al., 2012); compromised efficiency of selective search in the presence of distractors (Mathews et al., 1990) and significant differences in engagement and disengagement of attention for faces of negative valence (Mao et al., 2020; Veerapa et al., 2020). In agreement with these earlier studies, we here provide additional evidence that anxiety also biases the cross-talk between emotion and attention such that it extends to the dynamic adjustments in the distribution of visuospatial attention. While to our knowledge, this is not directly reported in the extant literature but our results parallel an earlier report of dynamic adjustments of attentional control while conflict processing in a modified Stroop task (Osinsky et al., 2012). Interpreting our findings within the framework of trait - anxiety and attentional control (Eysenck et al., 2007; Berggren and Derakshan, 2013), it is plausible that the attentional processing efficiency in the space close to the source of the emotional signal as compared to distant was impaired, evidenced by the flipping of the direction of attention gradient with increments in individual trait - anxiety. This implies that the efficiency of visual attention to the space relative to the source of the emotion signal was adjusted over trials as a function of the emotion signal type, which further scaled with the inter-individual differences in trait - anxiety. Our data, therefore, suggest that inter-individual differences of anxiety significantly govern how stray emotions tune the spatial scope of visual attention, which is of relevance given the fact that asymmetric distribution of attentional resources across the visual field may manifest as general impairments in visually guided behaviour by anxious individuals (Najmi et al., 2012). Furthermore, the present findings provide evidence that the above emotion × anxiety cross-talk precipitating visuospatial

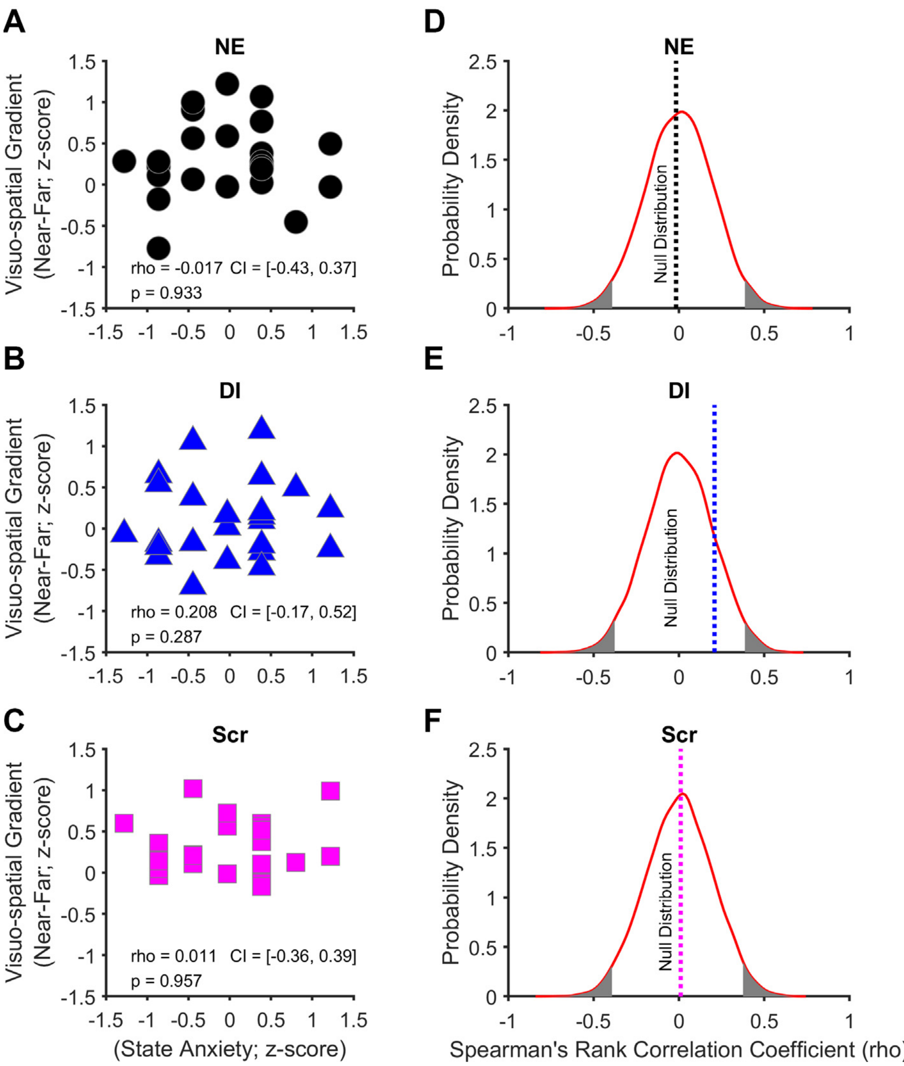

Fig. 4. Modulation of emotion-induced effects on attention gradient by state - anxiety (A-C) Scatter plots showing Spearman's Rank correlations between participants' state-anxiety scores and attention gradient influenced by Neutral (NE; black filled circles), Disgust (DI; blue filled triangles), and Scrambled (Scr; magenta filled squares) image primes respectively. **(D-F)** Probability density (smoothing window kernel width = 20) curves created from Spearman's rank correlation coefficients (rho) obtained by 10,000 random permutations (see *Data analysis*) to estimate the distribution of the null hypothesis that rho is not different from zero. Grey-shaded ends of the distribution show regions rejecting the null hypothesis. Overlaid broken vertical lines indicate the empirical rho values in Neutral (black), Disgust (blue), and Scrambled (magenta) image primes respectively. rho = Spearman's correlation coefficient; CI = 95% confidence interval.

attentional bias is manifest even in otherwise healthy and subclinical individuals with high trait - anxiety. In sum, our study lends credence to the notion that a dimension of personality representing a general sensitivity to threat may be associated with how environmental affect is processed by individuals in tuning higher-order cognitive functions, e.g., visuospatial attention, with the individuals towards the higher end of the dimension being more vulnerable to such biases. Here, it is relevant to note that we did not find any association between state - anxiety and the distribution of visual spatial attention. State anxiety subscale of the STAI assesses current, transient, emotional and physiological state of participants which has been found to associate with cognitive functions such as response-conflict requiring executive control (Choi et al., 2012) and overt visual attention to negative, threat-related visual stimuli (Bishop et al., 2004; Bishop, 2007; Quigley et al., 2012) in non-clinical, healthy individuals. By contrast our non-significant findings could be due to the following. One, these studies (Bishop et al., 2004; Choi et al., 2012; Quigley et al., 2012) have used experimental manipulation of durations ≥500 ms to a few seconds to elevate the state of anxiety for evaluating the role of state - anxiety in cognitive functions, which was absent in our study and thus, we possibly did not truly capture the effect of heightened state of anxiety on emotion-cued visual attention. Two, a sustained high amygdala response to negative, threat-related stimuli has been shown in high state - anxious individuals regardless of their overt visual attention to the stimuli and threat-related stimuli had no particular effect on attentional modulation (Bishop et al., 2004). In line, the negative (Disgust) emotion stimuli in our sample with a relatively high state - anxiety (STAI state score range = 44–54) may have modulated the measured scope of visual spatial attention negligibly. Taken together, it would be of merit to further investigate whether our reported effects in trait - anxiety also extend to state - anxiety of individuals.

A central brain region that processes social-emotional information and shows variable activity based on contextual as well as individual differences, is the amygdala (Fitzgerald et al., 2006; Adolphs, 2010). As the amygdala is densely interconnected with brain regions involved in arousal, sensory processing, and attention (LeDoux, 2007), it could be reasoned that the relative activity patterns of the amygdala together with reciprocally connected region-insula were differentially driven by socially salient facial Disgust information (Sambataro et al., 2006; Gogolla, 2017) by varying severities of trait - anxiety, that led to the effect on the attention gradients influenced by anxiety in our results. Indeed, earlier neuroimaging evidence shows that negative emotional stimuli were processed by the right amygdala and left insula (affective regions of the brain: limbic / para-limbic regions) regardless of task relevance (Pedale et al., 2019). This work further suggests that functional connectivity between the affective regions and the prefrontal cortex enables the optimal spatial distribution of attentional resources to meet task demands in the face of negative emotional stimuli. Thus, it is plausible that the fronto-limbic/para-limbic connectivity weakened with increasing trait - anxiety severities in our experiment, retarding the disengagement of attention from negative stimuli, thereby worsening the attentional task performance spatially closer to the source of the emotional signal relative to far away as manifest in the results. The above speculation, however, needs to be directly validated by separate studies probing brain functions with our experimental design.

We finally, identify a few limitations of our study which may be addressed in the future. First, our responses were taken on a computer keyboard which is known for inaccurate timings in measuring reaction times and thus, usage of a millisecond accuracy keypad is warranted. Second, we presented the targets at full visual target contrast (100%). While we held this contrast equal across all participants, our effects may still be verified by presenting stimuli at an acceptable individual visual contrast threshold of participants. Third, the trait - anxiety subscale of STAI has been reported to have overlapped with measures of depression (Caci et al., 2003; Knowles and Olatunji, 2020), which we cannot rule out in our present results. Thus, our results may apply generally to the trait of negative affectivity rather than specifically to trait - anxiety, which may be clarified in future studies. Fourth, we did not explore whether emotional cues had any effect on the laterality (left/right) of visual-spatial attentional distribution, which could be relevant for future exploration given an earlier report (Price et al., 2015). Fifth, our sample had a greater percentage of males (~68%) and also the trait - anxiety levels of the sample were high (relatively narrow range of 40–59) which could have impacted our results and subsequent conclusions. Similar investigation in a more gender balanced sample with wider distribution of trait - anxiety scores would thus, be of merit. Finally, our sample size was relatively modest and replication of our findings in a larger sample is also warranted.

Despite the above limitations, our findings provide a clear demonstration that temporally unpredictable, negatively valenced, and behaviourally irrelevant social-affective information influence the spatial organization of visual attention relative to the source of the social-affective signal, which in turn is biased by the individual severities of trait-anxiety (serving as a proxy for general negative affectivity). The findings add to the growing body of literature evidencing the role of internal states in the cross-talk of affective information and visual processes. These findings may help further the understanding of visual distortions underlying affective states and disorders.

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COMPETING INTERESTS

The authors declare no competing interests.

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DATA ACCESSIBILITY

All data that led to the reported results can be accessed from the corresponding author upon a reasonable request.

ETHICS STATEMENT

The study and its procedures were approved by the Institutional Review Board of the Indraprastha Institute of Information Technology Delhi, India.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Gursimran Kaur: Methodology, Investigation, Data curation, Software, Writing – original draft. **Rakshita Anand:** Methodology, Investigation, Data curation, Writing – review & editing. **Mrinmoy Chakrabarty:** Funding acquisition, Conceptualization, Methodology, Investigation, Software, Formal analysis, Writing – original draft, Supervision, Project administration.

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APPENDIX A. SUPPLEMENTARY MATERIAL

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neuroscience.2022.11.034.

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Supplementary Information

Title: Trait anxiety influences negative affect-modulated distribution of visuospatial attention

Authors: Gursimran Kaur[1*], Rakshita Anand[2], Mrinmoy Chakrabarty[1*]

[1]Dept. of Social Sciences and Humanities, Indraprastha Institute of Information Technology Delhi, New Delhi 110020, INDIA.

[2]Dept. of Human-Centered Design, Indraprastha Institute of Information Technology Delhi, New Delhi 110020, INDIA.

Correspondence:
Mrinmoy Chakrabarty, Ph.D.
Dept. of Social Sciences and Humanities, Indraprastha Institute of Information Technology Delhi (IIITD), New Delhi 110020, INDIA. TEL: +91-011-26907-363; E-mail: mrinmoy@iiitd.ac.in

***These authors contributed equally to this research.**

Effects of emotions on Reaction Time

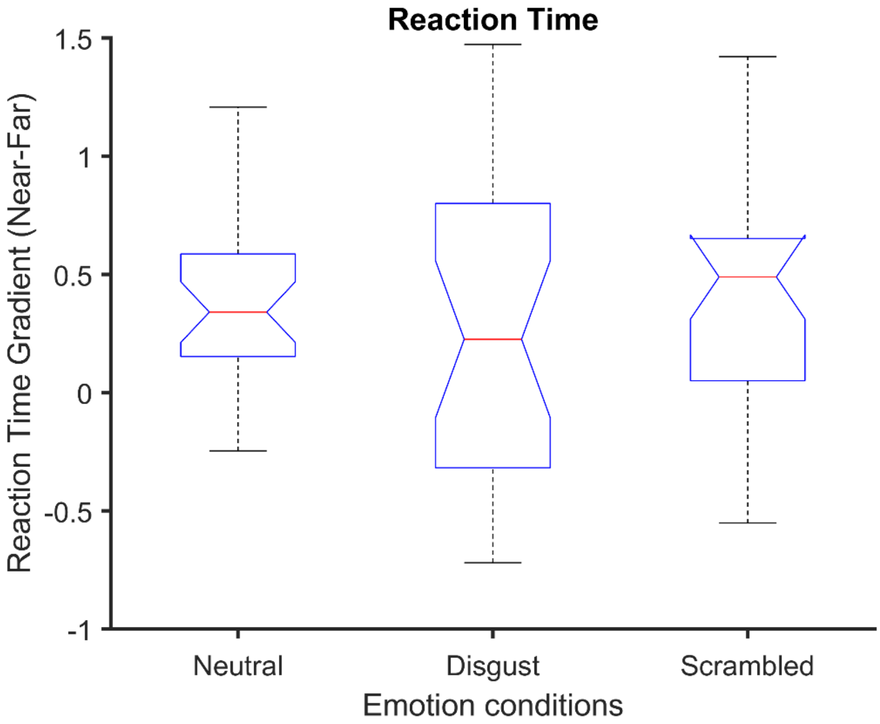

Fig. S1. Boxplots showing the distribution of participants' z-scored reaction time (RT) gradients calculated in the emotion-cued, exogenous visuo-spatial attention task.

- ❖ One way Repeated Measures ANOVA to test for differences of RT gradients across the three emotion conditions

  Mauchly's W for homogeneity = 0.609, p = 0.002; Greenhouse Geisser Corrected F (1.44, 38.82) = 1.046, p = 0.340, partial eta square = 0.037

- ❖ Spearman's Rank Correlation between trait anxiety and RT gradients in three different emotion conditions.

  Neutral: Spearman's Rho = -0.323, p = 0.094 (uncorrected)

  Disgust: Spearman's Rho = -0.349, p = 0.069 (uncorrected)

  Scrambled: Spearman's Rho = -0.094, p = 0.633 (uncorrected)

- ❖ Spearman's Rank Correlation between state anxiety and RT gradients in three different emotion conditions.

  Neutral: Spearman's Rho = 0.049, p = 0.804 (uncorrected)

  Disgust: Spearman's Rho = -0.054, p = 0.784 (uncorrected)

  Scrambled: Spearman's Rho = -0.044, p = 0.825 (uncorrected)

Effects of emotions on Accuracy

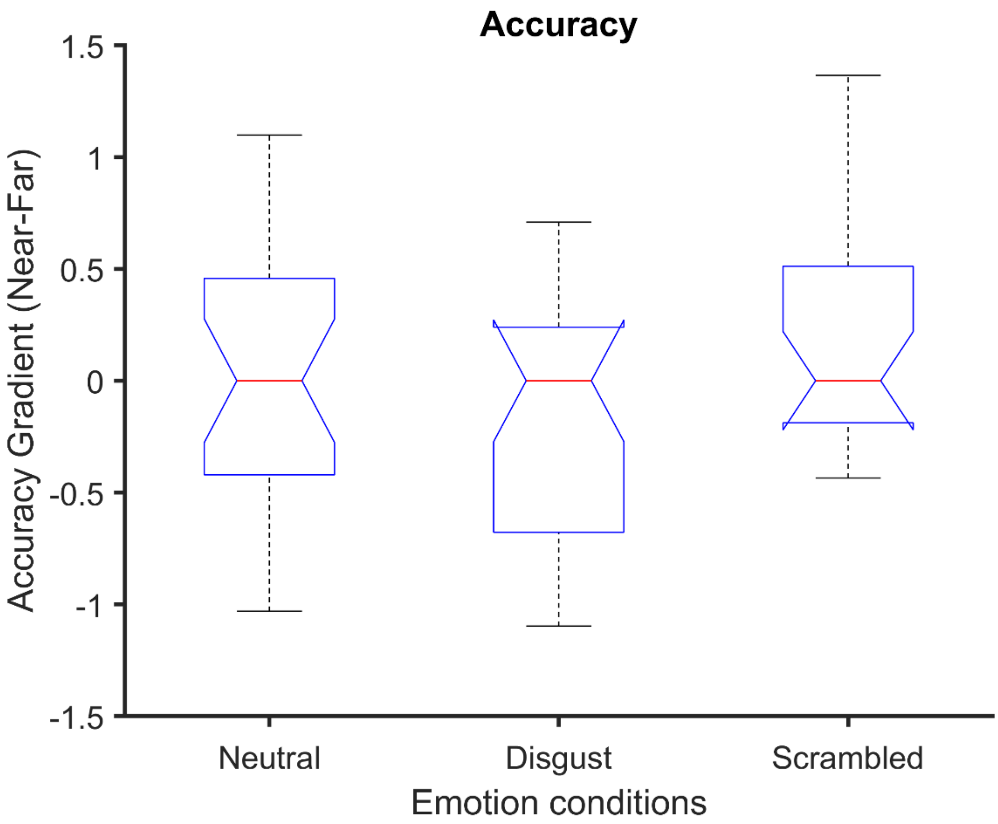

Fig. S2. Boxplots showing the distribution of participants' z-scored accuracy gradients calculated in the emotion-cued, exogenous visuo-spatial attention task.

- One way Repeated Measures ANOVA to test for differences of accuracy gradients across the three emotion conditions

  Mauchly's W for homogeneity = 0.923, *p* = 0.353; F (2, 54) = 2.83, *p* = 0.068, partial eta square = 0.095; Bonferroni corrected posthoc comparison between Disgust and Scrambled (difference of means = -0.320; p = 0.075).

- Spearman's Rank Correlation between trait anxiety and accuracy gradients in three different emotion conditions.

  Neutral: Spearman's Rho = -0.095, *p* = 0.630 (uncorrected)
  Disgust: Spearman's Rho = - 0.258, *p* = 0.185 (uncorrected)
  Scrambled: Spearman's Rho = 0.074, *p* = 0.709 (uncorrected)

- Spearman's Rank Correlation between state anxiety and accuracy gradients in three different emotion conditions.

  Neutral: Spearman's Rho = -0.173, *p* = 0.377 (uncorrected)
  Disgust: Spearman's Rho = 0.567, *p* = 0.002 (uncorrected)
  Scrambled: Spearman's Rho = 0.049, *p* = 0.804 (uncorrected)