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Research Paper

Impact of visual eccentricity on emotional reactivity: implications for anxious and depressive symptomatology

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A R T I C L E I N F O

Keywords:
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A B S T R A C T

Background: Behavioural and autonomic dysregulation of emotion is reported in anxiety and depression. However, most experiments have focused on emotional stimuli presented in central vision (CV), although affective saliency has been observed in peripheral vision (PV).

Methods: Unpleasant (U), pleasant (P) and neutral (N) pictures from the International Affective Picture System were presented to 40 participants at three eccentricities (CV: 0°; PV: -12 and 12°). Anxious and depressive symptomatology was evaluated with STAI and BDI scores respectively. Participants had to categorise pictures on their emotional content while skin conductance (SC), heart rate (HR), and pupillary responses (PR) were recorded.

Results: Emotional pictures were better categorised than neutral ones in both CV and PV. Unpleasant pictures were better categorised than pleasant ones in CV but not in PV. An opposite pattern of autonomic arousal (SC, HR, PR) was observed between CV and PV. In CV, a response bias was associated with higher SC to unpleasant pictures, whereas this association was the opposite in PV. Finally, depression scores were associated with better categorisation of emotional pictures in CV, whereas trait-anxiety was associated with a response bias to unpleasant pictures in PV.

Limitations: The choice of subclinical populations limits the scope of our results to moderate levels of depression and anxiety.

Conclusions: Results suggest that the capacity of visual eccentricity to induce emotion reactivity is modulated by anxious and depressive symptomatology. These findings strengthen the usefulness of a central-peripheral visual model of behavioural stimulation to differentiate emotional reactivity dysfunctions in both affective disorders.

1. Introduction

The perceptual and attentional selection of emotional information allows individuals to ensure their preservation and well-being (Vuilleumier, 2015). This selectivity has been observed in central vision (CV) and in peripheral vision (PV), despite its low acuity (D'Hondt et al., 2016). At behavioural level, a better categorisation performance of emotional relative to neutral pictures was observed with presentations in PV (Calvo and Lang, 2005; Fernández-Martín and Calvo, 2016; Nummenmaa et al., 2006), as well as a different decision criterion between emotional and neutral pictures during a recognition test (Calvo and Lang, 2005). Greater attentional selection has been reported in the literature for both pleasant relative to unpleasant (Calvo et al., 2015, 2014) and for unpleasant relative to pleasant (Simola et al., 2013). In addition, emotional stimuli occurring in PV interfere with the processing of information appearing in CV (Calvo and Nummenmaa, 2007; Calvo and Avero, 2008; D'Hondt et al., 2014, 2013). Hence, PV appears to be an alert system able to detect relevant information and summon sufficient attentional resources to challenge the priority of a CV task.

This privileged processing of emotional information also translates into a set of physiological responses, especially those depending on the autonomic nervous system (ANS). Autonomic changes are known to be related to the two main emotional dimensions, i.e. arousal, reflecting physiological and psychological levels of activation, and valence, reflecting the appetitive and aversive value of stimuli (Lang et al., 1993). Among autonomic expressions, electrodermal activity (EDA), often analysed as skin conductance responses (SCRs; Critchley, 2002; Sequeira et al., 2009), and pupil dilation (Bradley et al., 2008) have proved to be robust indices for revealing the arousal dimension of an emotional stimulus. Heart rate (HR) variations are indicative of the

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valence and arousal dimensions of the same stimulus: HR slows down in response to unpleasant cues while it increases with emotional arousal and pleasant stimuli (Bradley, 2009; Bradley et al., 2001; Lang et al., 1993). However, to our knowledge, autonomic responsiveness to emotional cues presented in PV has received little attention, in spite of the fact that emotional faces induce higher cortical activation than neutral ones when presented to up to 30° eccentricity (Rigoulot et al., 2012, 2011). In view of the above, the modulation of autonomic activities by the detection of emotional information in PV remains to be determined, and the link with the ability to categorise emotional from neutral information needs to be clarified.

Difficulties in the processing of emotional stimuli have repercussions on behaviour and autonomic activities, particularly in people with anxiety and depression. Anxious individuals tend to have a greater initial orientation towards threat followed by avoidance (Pflugshaupt et al., 2005; Rohner, 2002) or a difficulty in disengaging their attention from what they perceive as threatening information (Fox et al., 2001; Yiend and Mathews, 2001). In addition, the threat detection threshold seems to be lower in people with anxiety, leading to misinterpretation of ambiguous situations and exaggeration of minor threats (Beck et al., 2005; Coussement and Heeren, 2015). At the autonomic level, the reactivity of individuals with trait-anxiety is associated with significantly high SCRs to emotional pictures (Najström and Jansson, 2006), indicating a sustained sympathetic mobilisation when they are exposed to emotional stimuli. In depression, an attentional bias towards unpleasant stimuli has also been well documented (e.g., Gotlib and Cane, 1987; Gotlib and McCann, 1984; Mathews et al., 1996; Rinck and Becker, 2005). Indeed, depression is associated with an increased perception of unpleasant stimuli (Wenzler et al., 2017) and with the attribution of unpleasant affects to neutral (Gollan et al., 2008) and pleasant stimuli (Falkenberg et al., 2012). Despite this behavioural consistency, the impact of depressive states on autonomic responses to emotion remains to be clarified. Depression has been associated with either a decreased autonomic reactivity to unpleasant stimuli (Bylsma et al., 2008) or an increased autonomic reactivity to emotional narratives (Schneider et al., 2012), sad films (Panaite et al., 2016) and unpleasant pictures (Wenzler et al., 2017). Importantly, depressive and anxiety disorders share the highest frequency of comorbidities (Zbozinek et al., 2012). The association between anxiety and depression has also been established in subclinical populations, particularly when it is assessed through self-reported scales (Haaga et al., 1993; Karagozoglu et al., 2005). This link between anxiety and depression makes it difficult to disentangle their mutual influence on emotional processing and autonomic reactivity.

Anxiety is characterised by a state of alertness and increased vigilance (Chua and Dolan, 2000). It is associated with an excessive propensity to control external stimuli (Pruneti et al., 2016) and manifests itself as greater monitoring of the visual environment (Bar-Haim et al., 2007). These expressions of hypervigilance may result in increased attentional resources, which could be extended to PV in order to detect potentially relevant stimuli (MacLeod and Mathews, 2012). On the contrary, depression is characterised by psychomotor retardation disturbing visual exploration leading to increased reaction times, especially in prosaccade and anti-saccade tasks (Carvalho et al., 2015; Mahlberg et al., 2001). In addition, in free-view tasks, patients with a depressive disorder show fewer saccades and longer fixation than controls (Li et al., 2016). Lastly, depressed individuals show deficits in visual orienting and in sustained and executive attention (Paelecke-Habermann et al., 2005). Overall, contrary to what is observed in anxiety, a decrease in attentional resources dedicated to PV with less visual exploration can be hypothesised in depression. However, the impact of emotional pictures projected in CV and PV remains elusive and no data is available about anxiety and depression. In this context, the use of a design based on central vs. peripheral emotional stimulation could contribute to a better differentiation of anxious and depressive individuals, thanks to behavioural and autonomic expressions.

The aim of this study was thus twofold: 1/ to estimate the association between behavioural and autonomic responses to emotional pictures presented in CV and PV; and 2/ to assess the link between these responses and anxious and depressive symptomatology. We hypothesised that: 1/ emotional pictures are better categorised than neutral ones, even in PV; 2/ this better categorisation is associated with autonomic activation; 3/ anxiety is associated with greater reactivity, especially in PV, while depression is associated with lower performance and reactivity in the same peripheral eccentricities. We thus compared the categorisation performance of emotional pictures and the autonomic reactivity to these pictures presented in CV and in PV, and we assessed the association of these emotional effects on behaviour and autonomic activity with anxious and depressive symptomatology.

2. Material and methods

2.1. Participants

Forty healthy unmedicated participants (mean age 21.18 ± 2.23; 20 females) were recruited through an online questionnaire. They were all French speakers, right-handed (Edinburgh Handedness Inventory, EHI; Oldfield, 1971) and had a normal or corrected to normal vision (Snellen, 1862). Individuals with a history of neurological disorders or drug consumption were not included.

To obtain a homogeneous distribution of anxiety and depressive symptoms across our sample, participants were recruited according to their scores at the Trait Anxiety Inventory (STAI-B; Spielberger et al., 1983) and Beck Depression Inventory (BDI-II Beck et al., 1996), respectively. Considering low (STAI-B $\leq$ 46) and high anxiety (STAI-B $>$ 46) and low (BDI-II $<$11) and high depression (BDI-II $\geq$ 11), we included 5 women and 5 men presenting low anxiety and low depression, high anxiety and high depression, low anxiety and high depression and high anxiety and low depression.

Each participant provided an informed consent statement and received a 20-€ compensation for his/her participation. This study was approved by the Ethics Committee of the Université de Lille [Reference: 2018-1-S54] and conducted in accordance with the Declaration of Helsinki at Faculté de Médecine, Université de Lille, France.

2.2. Apparatus and Stimuli

Participants were seated at a fixed viewing distance of 60 cm from the projection screen (30 inches, 2560 × 1600 resolution, DELL 3007WFP HC), which was connected to a computer (DELL Optiplex 9020, Windows 7 Professional) that controlled the presentation of pictures and recorded behavioural responses thanks to a homemade program (*MATLAB* software). The pictures were displayed on a black background and each picture was presented pseudo-randomly based on a Latin square design, either in central vision (0°), in the left (-12°) or in the right peripheral (+12°) visual positions.

The stimuli corresponded to three sets of 16 pictures, either unpleasant (U), neutral (N) or pleasant (P), selected from the International Affective Picture System (IAPS; Lang et al., 2008), which provides *a priori* standardised values for each picture on valence and activation dimensions. Given the recognised differences in emotional evaluation according to gender (Bradley et al., 2001; Collignon et al., 2010), we selected three sets of pictures for each gender resulting in equivalent *a priori* valence and activation values. Both selections included 37 gender-specific and 11 common images.

The three sets of selected pictures significantly differed on valence (*women*: U = 2.53, N = 4.82, P = 7.10, $F_{1,15}$= 457.30; $p < 0.001$; *men*: U = 2.71, N = 4.84, P =7.06, $F_{1,15}$ = 445.00; $p < 0.001$). In terms of arousal, the unpleasant and pleasant sets did not differ but they were higher than the neutral sets (*women*: U = 5.73, N = 3.18, P = 5.52, $F_{1,15}$ = 182.81; $p < 0.001$; *men*: U = 5.56, N = 2.90, P = 5.51, $F_{1,15}$ = 210.24; $p < 0.001$). For each picture, the angular size (12°x8°), the spatial frequencies (Delplanque et al., 2007) and main physical properties were extracted (*ImageJ v1.50 software*), among which luminance and contrast for the greyscale version and the RGB (red, green and blue) layers. Besides, the complexity of digitised pictures was estimated in terms of the number of bytes of the compressed image file size in JPEG format (Calvo and Lang, 2005). All these picture properties were homogenised: no significant difference was observed between the three sets of pictures for both genders (Table S1). Therefore, the selected pictures differed only in terms of emotional dimensions.

2.3. Recordings

Skin conductance (SC) and electrocardiogram (ECG) were recorded during a baseline period, the task and a recovery period, using a BIOPAC MP35 system connected to a second computer with an ad hoc software *(BIOPAC Student Pro 3.7)*, for an acquisition at 200 Hz. SC was recorded through bipolar Ag/AgCl surface electrodes (BIOPAC EL507), pre-gelled with an isotonic electrolyte (0.05 molar NaCl) and attached to the palmar side of the middle phalanges of the index and middle fingers of the participant's non-dominant hand. SC was measured with a 5 μS/V gain, low-pass filtered at 10 Hz. The ECG was recorded using a DI modified bypass, placing the Ag/AgCl pre-gelled (BIOPAC EL503, 7% NaCl) surface electrodes on the participant's left and right wrists and with a band-pass filter set between 0.5 and 66.5 Hz.

Eye movements and pupil diameter were recorded using an eye tracker (SMI RED-m Eye Tracking System) connected to the projection computer with *SMI iView RED-m 2.11* software, for an acquisition at 120 Hz.

At the end of the experiment, the participant was asked to rate the valence and arousal values of all the pictures using the two nine-point SAM scales (Self-Assessment Manikin; Bradley and Lang, 1994), ranging from 1 (very unpleasant) to 9 (very pleasant), and from 1 (very calm) to 9 (very arousing), respectively. Ratings were recorded with *OpenSesame* (Mathôt et al., 2012).

2.4. Procedure

The experimental procedure was divided into three steps. *The first step* was devoted to the installation of electrodes, the acclimatisation of the participant to the experimental environment and the assessment of participants' anxiety state (State-Trait Anxiety Inventory, STAI-A; Spielberger et al., 1993). The task was then explained orally to the participants.

The second step started with autonomic recordings during a task-free 2-minute baseline period. This period was followed by recordings of behavioural and autonomic responses during the presentation of the 48 pictures, one at a time, in a pseudo-random order at the three eccentricities. Pictures were shown in 144 trials divided into 4 blocks of 36 trials, between which participants were given the opportunity to rest. Each trial corresponded to the following sequence: a fixation cross projected at the centre of the screen for a random duration between 1 to 2 seconds, then the picture projection for 300 ms, followed by a black screen for a random duration between 9 to 13 s. The inter-stimulus interval (ISI) therefore varied from 10 to 15 s, which is an ideal interval to avoid the habituation phenomenon often observed with autonomic signals, particularly in electrodermal activity. Participants had to categorise the image as unpleasant, neutral or pleasant thanks to a response box. They were instructed to keep their gaze on the central cross throughout the course of the experiment, a required behaviour to trigger the stimulation. Trials containing saccades were automatically reprojected once at the end during a fifth presentation block. After the task, the autonomic activity was still recorded during a 2-min recovery period.

Finally, to validate our selection of pictures, participants were asked to evaluate the valence and arousal dimensions using the two nine-point SAM scales. These subjective ratings reflect the *a posteriori* values of pictures.

2.5. Data analyses

All trials containing saccades were rejected. Across all participants and conditions, 15% of the trials were rejected. The percentage of remaining trials did not differ between conditions (X^2 Yates = 2.8, df = 8, $p = 0.945$). All conditions were therefore represented by an equivalent number of trials.

2.5.1. Behavioural data

Firstly, *a posteriori* values of valence and activation were given by each participant for each image. Secondly, signal detection theory (Stanislaw and Todorov, 1999) was applied to the accuracy of categorisation, considering either the set of unpleasant, neutral or pleasant images as the signal and the images of the other two sets as the noise. Based on the proportion of correct detections and false alarms, a sensitivity index (d') was calculated, greater d' value indicating a better ability to distinguish signal from noise. The response bias index (β) was calculated, a $\beta < 0$ indicating a bias towards the signal, reflecting a more liberal decision criterion with more false alarms, minimising omissions. Conversely, a $\beta > 0$ corresponds to a response bias towards noise, corresponding to a more conservative decision criterion resulting in a minimisation of false alarms and an increase in omissions. Thirdly, speed and accuracy in categorising pictures, respectively measured by reaction time (RT) and sensitivity (d'), were used to compute a Speed-Accuracy Composite Score (SACS, Collignon et al., 2010). The SACS is a general index of performance that rules out a possible speed/accuracy trade-off effect and measures the efficiency of the categorisation. In order to attribute the same weight to RT and d' across participants, the SACS is calculated by subtracting the normalised RT from the normalised d' [SACS = z(d') – z(RT)]. When the RT decreases and/or the d' increases, the efficiency increases.

2.5.2. Autonomic data

The SC, ECG and pupil variations, were down sampled at 10 Hz using *LabChart7*. For the SC variations to pictures, the phasic waveforms were derived from the tonic signals with an offline 0.05 Hz high-pass filter using *AcqKnowledge 4.1* software. For the ECG, the instantaneous heart rate (HR) was calculated in beats per minute (BPM) from the R waves intervals and smoothed with the triangular Bartlett window with a 1-s width, using *LabChart7*. For the pupil responses (PR), eye blinks, which expressed themselves in the signal as sudden drops in pupil diameter, were eliminated and the missing data was linearly extrapolated. Pupil and HR variations in response to stimulation were obtained by subtracting the average over a 3-s pre-stimulus period to the 10-s post-stimulus period data. After baseline correction (-3 to 0 s), epochs were averaged (0 to 10 s) and time-locked to the stimulus onset for each condition and each participant.

Skin conductance responses were calculated by computing the integrals of SC amplitude over each averaged post-stimulation period for each condition and participant. HR deceleration and acceleration were calculated by integrating decreases and increases in HR over the post-stimulation period, respectively. Finally, reflex pupillary constriction was estimated by the maximum post-stimulation decrease in pupil diameter. Pupil dilation was estimated by the maximum post-stimulation increase in pupil diameter.

2.6. Statistical analysis

Regarding the subjective evaluation of pictures, the Pearson coefficient was calculated between *a priori* and *a posteriori* ratings. A repeated measure analysis of variance (ANOVA) was applied to *a posteriori* ratings with emotion as within-subject factor and gender as between-subject factor. Regarding emotion and according to its dimensional theory (Lang et al., 1993), we expected two emotional effects: 1) a valence effect (Unpleasant vs. Pleasant), being modelled by a first-degree polynomial contrast (Unpleasant – Pleasant); and 2) an arousal effect (Emotion vs. Neutral) being modelled by a second-degree polynomial contrast ([Unpleasant + Pleasant]/2 – Neutral). The use of contrasts allows for the totality of the variability caused by emotional factors to be considered. Regarding position, the effects of laterality were not considered here so the analyses focused on the effects of eccentricity (Centre vs. Periphery), being modelled by a second-degree polynomial contrast ([Left + Right]/2 – Centre).

These contrasts were assessed with a repeated measure ANOVA, applied to the behavioural and autonomic measures. A sensitivity analysis, performed by *G*Power 3.1.9.4* (Faul et al., 2007), indicated that for an analysis of variance applied to such contrasts, given a sample size N = 40, $\alpha = 0.05$ and $\beta = 0.20$, we could detect an effect of minimum size of f = 0.227 (i.e. $\eta^2 = 0.049$).

Finally, we calculated the correlation coefficients between the psychometric, behavioural and autonomic measures (Pearson's r). The significance threshold was set at $p < 0.05$ (bilateral).

3. Results

3.1. Subjective assessment of stimuli

A posteriori and *a priori* ratings were correlated for both genders on valence (*women*: $r_{47} = 0.95$, $p < 0.001$, Fig. 1A; *men*: $r_{47} = 0.95$, $p < 0.001$, Fig. 1B) and arousal (*women*: $r_{47} = 0.87$, $p < 0.001$, Fig. 1C: *men*:

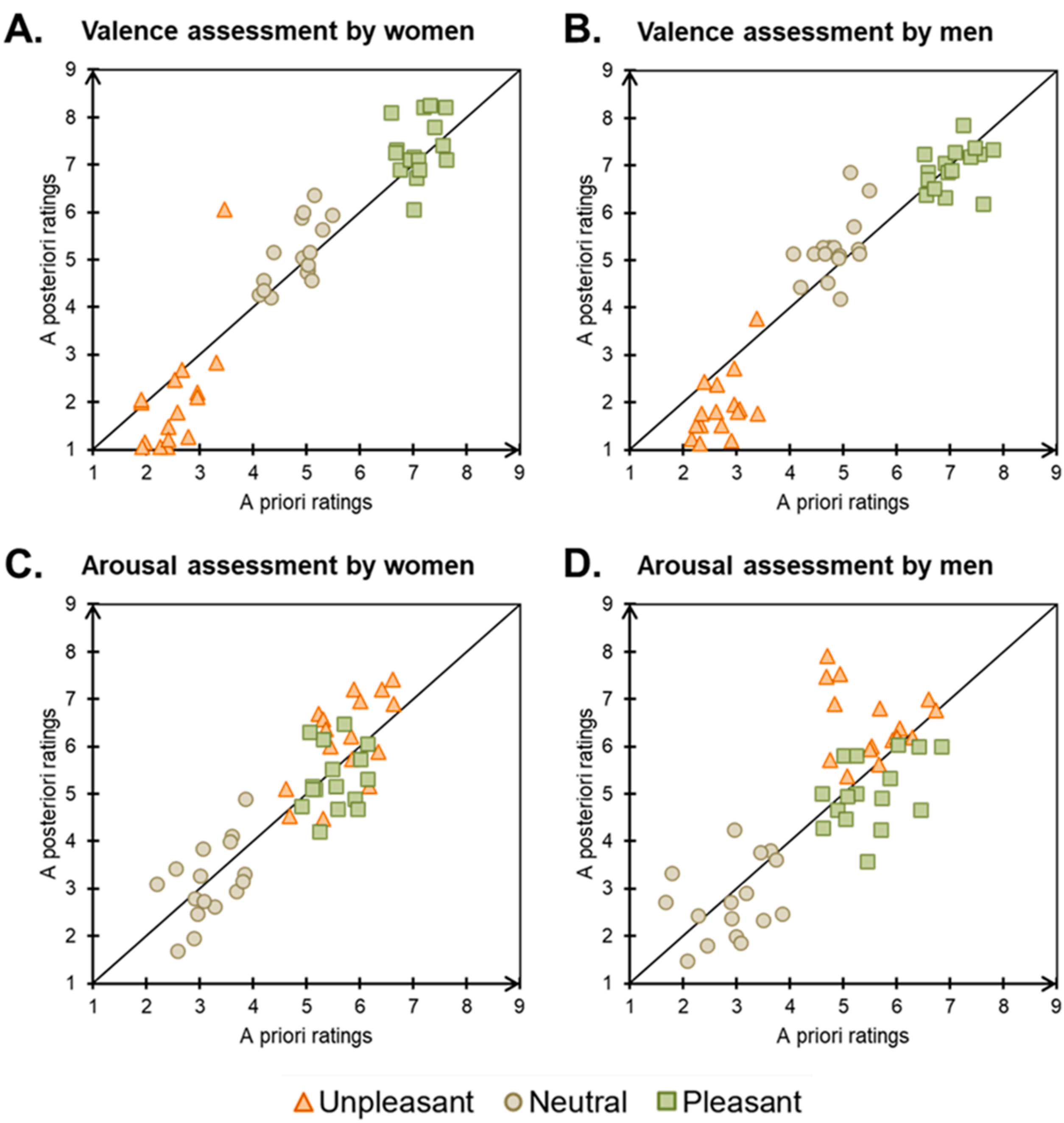

Fig. 1. Validation of picture selection using correlations between standardised (*a priori*) ratings by International Affective Picture System (IAPS) and mean subjective (*a posteriori*) ratings of unpleasant and neutral pictures. Ratings for unpleasant, neutral and pleasant. (A) Valence ratings for women; (B) valence ratings for men; (C) arousal ratings for women; (D) arousal ratings for men.

$r_{47} = 0.78$, $p < 0.001$, Fig. 1D). As expected, the participants' valence assessment differed according to the emotional category (U = 1.96, N = 5.18, P = 7.15; $F_{1,36} = 771.21$; $p < 0.001$; $\eta^2 = 0.955$). Participants thus rated unpleasant pictures with a lower valence than pleasant ones, although the valence gap with neutral pictures was greater for unpleasant pictures ($F_{1,36} = 49.14$; $p < 0.001$; $\eta^2 = 0.577$). The participants' arousal assessment also differed according to the emotional category (U = 6.33, N = 2.93, P = 5.18; $F_{1,36} = 233.49$; $p < 0.001$; $\eta^2 = 0.866$). While unpleasant and pleasant pictures were evaluated as more arousing than neutral ones, the participants evaluated unpleasant pictures as more arousing than pleasant ones ($F_{1,36} = 52.69$; $p < 0.001$; $\eta^2 = 0.594$).

3.2. Behavioural data

Interactions between eccentricity and arousal ($F_{1,36} = 30.36$, $p < 0.001$, $\eta^2 = 0.457$, Fig. 2A) and between eccentricity and valence ($F_{1,36} = 13.76$, $p = 0.001$, $\eta^2 = 0.277$, Fig. 2B) were observed on the SACS. Participants showed greater performance in categorising emotional pictures than neutral ones, and in categorising unpleasant pictures than pleasant ones. The effect of arousal was greater in CV but still observed in PV (12°; $p = 0.004$). The effect of valence was observed in CV (0°; $p = 0.002$) but not in PV (12°; $p = 0.681$).

The interaction between eccentricity and valence also reached significance for the response bias ($F_{1,36} = 6.67$, $p = 0.016$, $\eta^2 = 0.211$, Fig. 2C), as it was greater for unpleasant than for pleasant stimuli in CV (0°: $F_{1,36} = 7.94$, $p = 0.008$) but not in PV (12°: $F_{1,36} = 0.002$, $p = 0.965$). This corresponds to a more conservative decision criterion for unpleasant cues, with fewer false alarms in CV. The interaction between eccentricity and arousal did not reach significance ($F_{1,36} = 1.31$, $p = 0.263$, $\eta^2 = 0.050$).

3.3. Physiological data

Regarding the effects of eccentricity on autonomic responses, a trend towards greater (by 38%) SCRs for CV than for PV presentation was observed ($F_{1,36} = 3.89$, $p = 0.060$, $\eta^2 = 0.135$, Fig. 3A). Compared to PV presentation, stimulation in CV induced lower (by 13%) HR acceleration ($F_{1,36} = 5.39$, $p = 0.029$, $\eta^2 = 0.177$, Fig. 3B), higher (by 14%) pupil constriction ($F_{1,36} = 102.64$, $p < 0.001$, $\eta^2 = 0.804$, Fig. 3C) and lower (by 8%) pupil dilation ($F_{1,36} = 12.72$, $p = 0.001$, $\eta^2 = 0.337$, Fig. 3D).

Concerning effects of emotional content, a main effect of valence was observed on pupil reflex constriction ($F_{1,25} = 12.89$, $p = 0.001$, $\eta^2 = 0.340$), with greater pupil constriction (by 2%) to unpleasant pictures than to pleasant ones. Furthermore, a main effect of arousal was observed at autonomic level with higher SCRs (by 23%) to emotional pictures than to neutral ones ($F_{1,25} = 5.65$, $p = 0.025$, $\eta^2 = 0.184$, Fig. 4A) and higher HR acceleration (by 13%) to neutral pictures than to emotional ones ($F_{1,25} = 8.86$, $p = 0.006$, $\eta^2 = 0.262$, Fig. 4B). The contrast analysis revealed a trend towards an interaction between eccentricity and arousal on SCRs ($F_{1,25} = 3.85$, $p = 0.061$, $\eta^2 = 0.133$), with higher SCRs in CV than in PV for emotional but not for neutral pictures.

3.4. Behavioural, autonomic and psychometric correlates

For CV stimulation, the valence effect observed on the response bias parameter was correlated with the valence effect on the SCRs ($r_{38} = 0.330$, $p = 0.037$, Fig. 5A). The participants exhibiting a bias in favour of unpleasant pictures also showed greater SCRs to these unpleasant pictures, while the participants exhibiting a bias in favour of pleasant pictures showed greater SCRs to these pleasant pictures.

For PV stimulation, an opposite association was observed: the participants exhibiting a bias in favour of unpleasant pictures showed lower SCRs to these unpleasant pictures, while the participants exhibiting a bias in favour of pleasant pictures showed lower SCRs to these pleasant

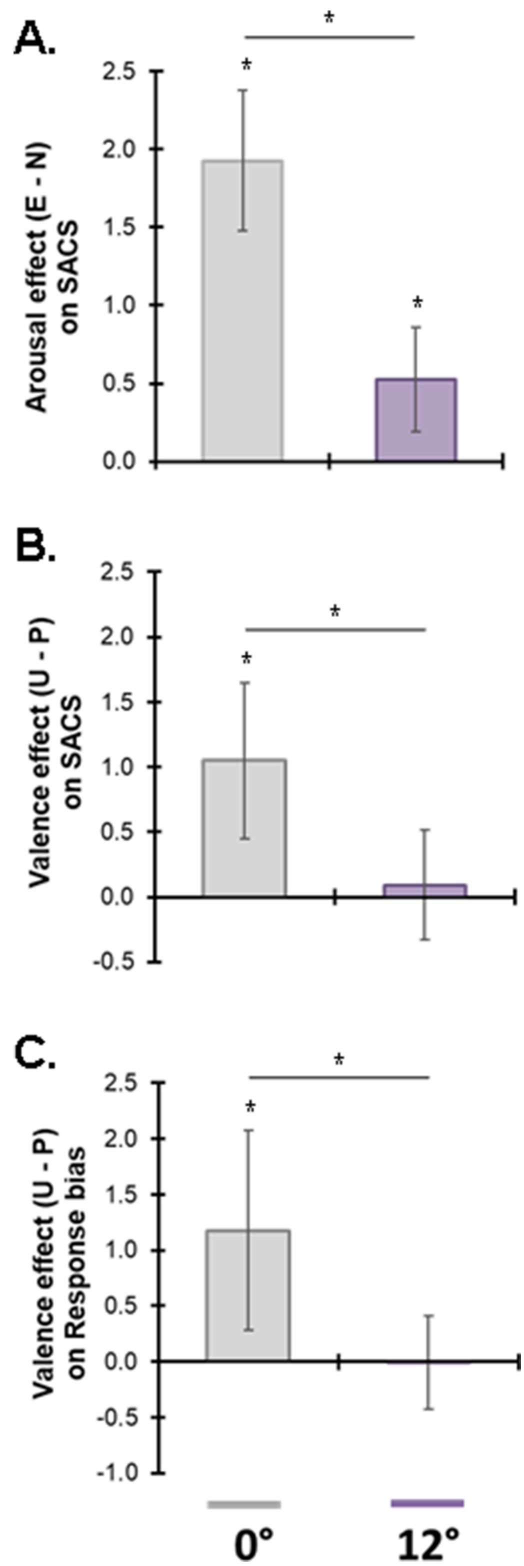

Fig. 2. Effect of arousal and valence on the speed-accuracy composite scores and the response bias according to eccentricity of pictures. Effects of arousal (Emotion – Neutral) (A) and valence (Unpleasant – Pleasant) (B) on speed-accuracy composite scores (SACS), and effects of valence (Unpleasant – Pleasant) on response bias parameter from signal detection theory (C) for stimulation presented in central (0°) and peripheral (12°) vision. Positive values indicate greater performance in categorising emotional than neutral pictures and greater performance with unpleasant than with pleasant pictures (* $p < 0.05$). Error bars represent 95% confidence interval.

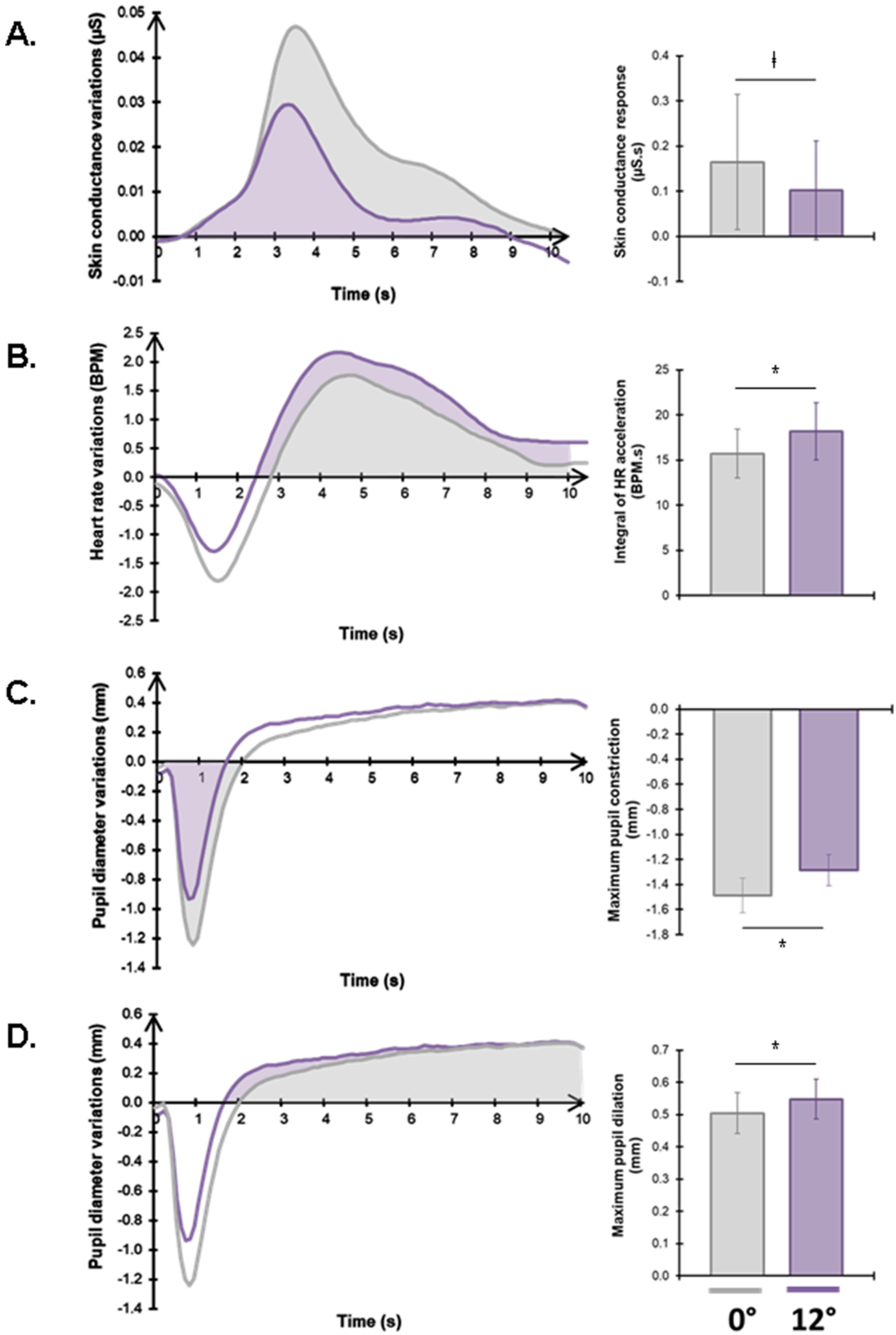

Fig. 3. Effect of eccentricity of pictures on autonomic responses. Left panel presents skin conductance (μS) (A), heart rate (BPM) (B) and pupil diameter (mm) (C & D) variations as a function of time for central (0°, grey) and peripheral (12°, purple) stimulation. Right panel presents skin conductance responses (μS.s) (A), heart rate acceleration (BPM.s) (B), pupil constriction (mm) (C) and pupil dilation (mm) (D) for central (grey) and peripheral (purple) presentation (* $p < 0.05$; ƚ $p > 0.10$). Error bars represent 95% confidence interval.

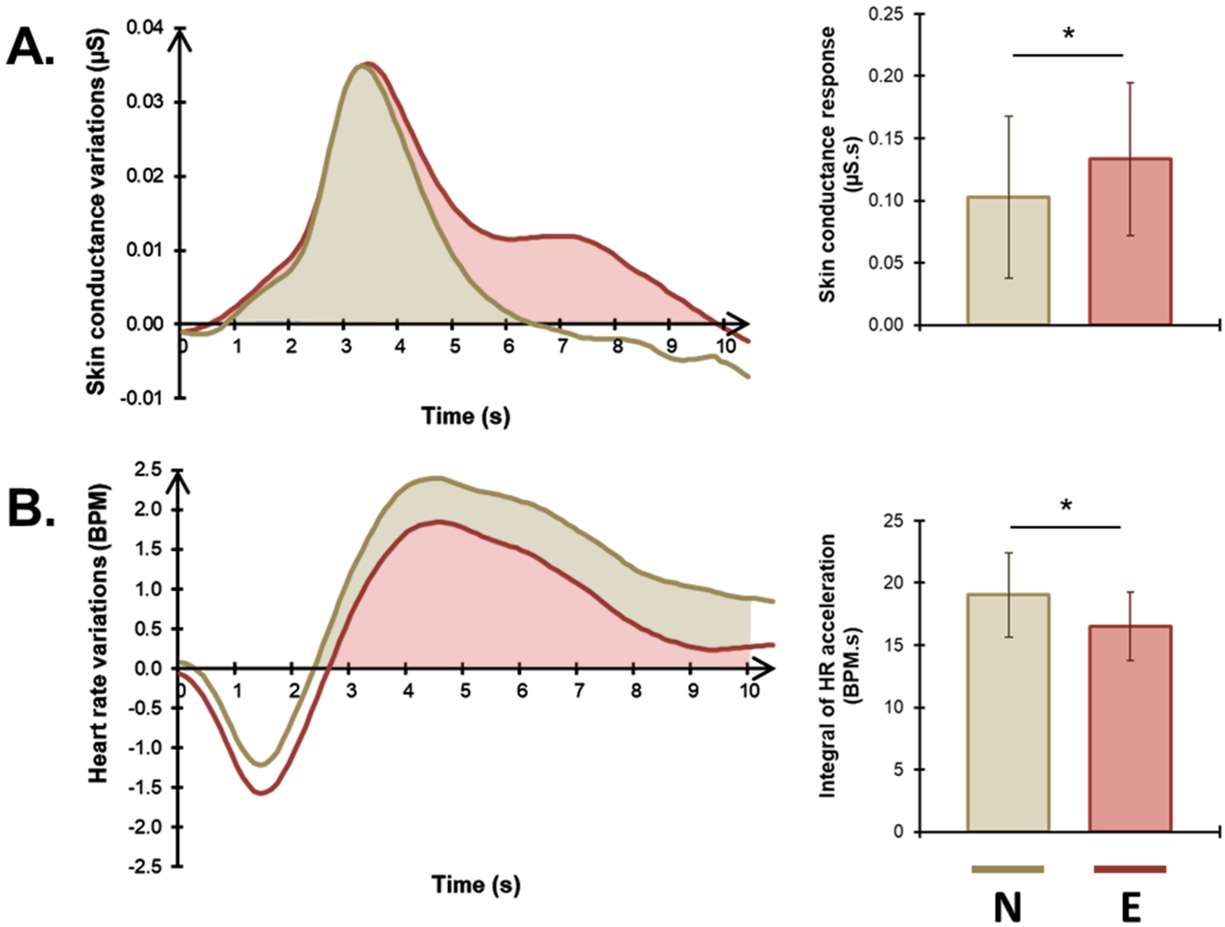

Fig. 4. Effect of emotional arousal on autonomic responses. Left panel presents skin conductance (µS) (A) and heart rate (BPM) (B) variations as a function of time for emotional (red) and neutral (grey) stimulation. Right panel presents skin conductance responses (µS.s) (A) and heart rate acceleration (BPM.s) (B) for emotional (red) and neutral (grey) pictures. Error bars represent 95% confidence interval (* $p < 0.05$).

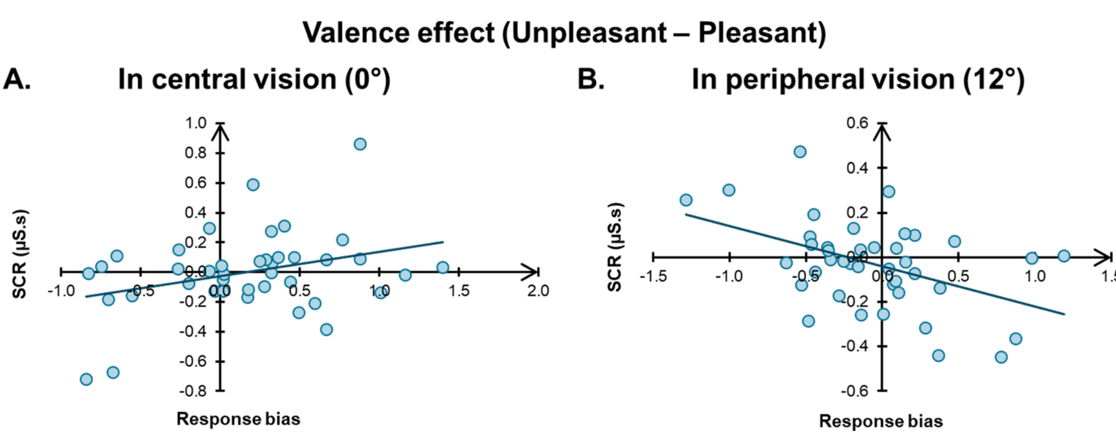

Fig. 5. Autonomic responses according to response bias for valence effect according to eccentricity. Valence effect (Unpleasant – Pleasant) on skin conductance responses (µS.s) according to valence effect observed on response bias for presentation in central vision (0°) (A), and for presentation in peripheral vision (12°) (B). Positive values indicate greater autonomic responses on Y axis and greater response bias on X axis for unpleasant than for pleasant pictures. Negative values indicate greater autonomic responses on Y axis and greater response bias on X axis for pleasant than for unpleasant pictures.

pictures (r_{38} = -0.461, p = 0.003, Fig. 5B).

Trait anxiety scores correlated with greater response bias to unpleasant pictures presented in PV (r_{38} = 0.323, p = 0.042; Fig. 6A). The greater the trait anxiety, the greater the response bias towards unpleasant pictures presented in PV. High state anxiety was associated with lower performance in categorising pleasant pictures (r_{38} = -0.366, p = 0.020; Fig. 6B). The greater the state anxiety, the lower the performance in categorising pleasant pictures.

For CV stimulation, the more the participants were depressed, the better was their performance in categorising emotional pictures relative to neutral ones (r_{38} = 0.313, p = 0.050; Fig. 6C).

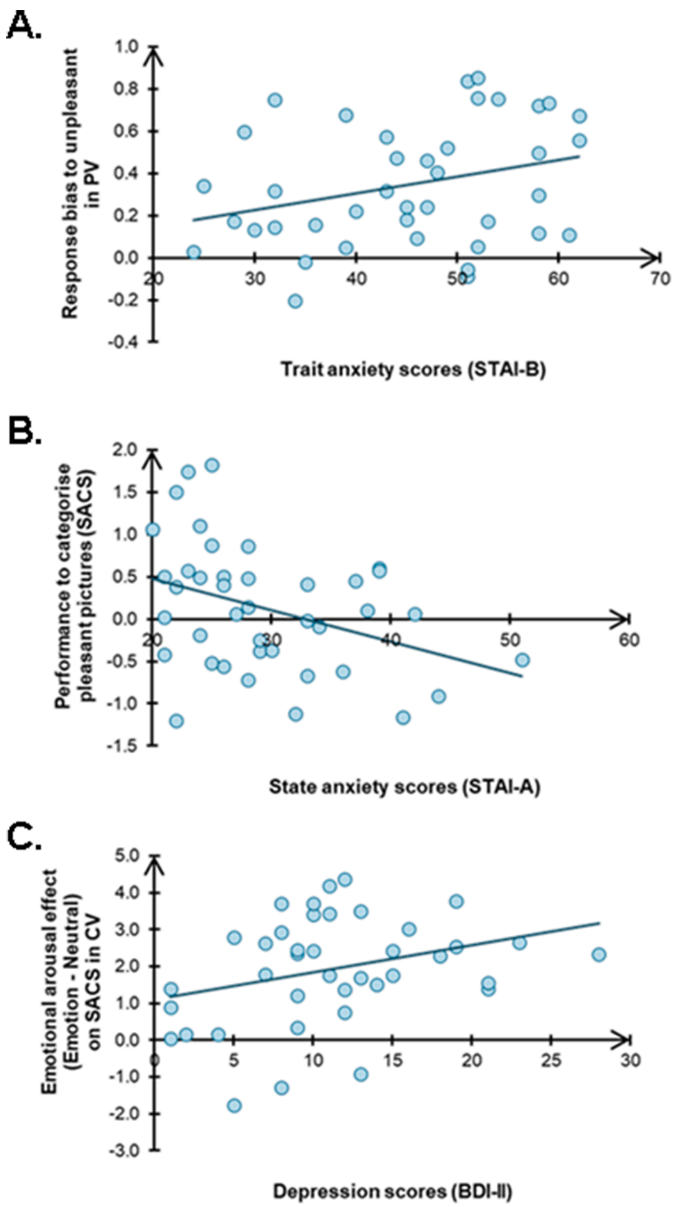

Fig. 6. Behavioural response and response bias according to anxiety and depression. Response bias to unpleasant pictures in peripheral vision (PV, 12°) according to STAI-B scores (A), performance in categorising pleasant pictures indexed by speed-accuracy composite score (SACS) according to STAI-A scores (B) and arousal effect (Emotion – Neutral) observed in central vision (CV, 0°) on categorisation performance index by speed-accuracy composite scores (SACS) according to depression scores (BDI-II) (C).

4. Discussion

The present study aimed at establishing the association between behavioural and autonomic responses to emotional pictures presented in CV and PV, and between those responses and the anxiety and depression symptomatology. In support of our hypotheses, we found: 1/ in CV and in PV, a better categorisation of emotional pictures when compared to neutral ones and an association of such categorisation with autonomic responses; 2/ in CV, participants exhibited greater performance in categorising unpleasant pictures while there was no difference between unpleasant and pleasant pictures in PV; 3/ in CV, a response bias to unpleasant pictures was associated with higher autonomic arousal to the same pictures, whereas this association was the opposite in PV; 4/ trait anxiety was associated with a response bias towards unpleasant pictures presented in PV, while state anxiety was associated with lower performance in categorising pleasant pictures; 5/ in CV, depression was associated with better performance in categorising emotional pictures.

4.1. Emotional impact persists in peripheral vision

At behavioural level in CV, participants exhibited lower performance in categorising neutral pictures than emotional ones, especially when unpleasant. Moreover, this arousal effect was significantly greater for pictures presented in CV than for those presented in PV, in which there were no differences between unpleasant and pleasant ones. These results confirm the preferential processing of emotion when it comes to categorising natural scenes. (Vuilleumier, 2015). According to the literature (Calvo and Lang, 2005; D'Hondt et al., 2016; Fernández-Martín and Calvo, 2016; Nummenmaa et al., 2006), this privileged processing of emotion also concerns the information projected in PV. However, better performance in categorising unpleasant pictures over pleasant ones was observed only in CV. In addition, participants adopted a more conservative decision criterion for unpleasant than for pleasant cues presented in CV, minimising false detections of the unpleasant ones. However, for PV, no difference was observed on the response bias between unpleasant and pleasant pictures. Therefore, participants did not seem to present different strategies for categorising unpleasant and pleasant images when presented in PV. Overall, this suggests that the privileged processing of emotional scenes presented in PV depends on their arousal dimension.

At the physiological level, CV stimulation induced a trend towards greater SCRs than PV stimulation, regardless of emotional content. SCRs are a robust indicator of physiological arousal (Critchley, 2002; Sequeira et al., 2009) and have been related to perceptual processing subsequent to initial attention capture. Furthermore, the amplitude of SCRs constitutes a reliable expression of reticular activation (Sequeira and Roy, 1993). Greater SCRs to CV than to PV presentation may therefore indicate a greater reticular activation, owing to greater resources allocated to the high acuity process of central visual information. However, the fact that this eccentricity effect was not significant but observed in trends may indicate that such reticular activation persists despite the poor acuity of PV. Higher SCRs were also induced by emotional pictures without differences between unpleasant and pleasant ones, in accordance with previous findings (Bradley et al., 2001; Lang et al., 1993).

Interestingly, the response bias and associated SCRs were characterised by an opposite pattern between central and peripheral vision. When pictures were presented in CV, the greater the autonomic responses were, the fewer were the false alarms in categorising these pictures. As participants exhibited greater performance in categorising unpleasant pictures with fewer false alarms, it is possible that greater autonomic activation helped the participants categorise emotional pictures as such when processed in detail. However, when pictures were presented in PV, the greater the autonomic responses were, the more false alarms occurred in categorising these pictures. With PV serving as an alert system, greater autonomic responses could lead to the attribution of emotional value to pictures that do not necessarily have any, and therefore to more false alarms. Considering the poor acuity of PV, it would be in the organism's interest to demonstrate hyperactivity to unclearly identified stimuli. This would give a behavioural advantage to the individual to prepare for action.

PV presentation induced higher pupil dilation and HR acceleration. Pupil dilation lets more light reach the retina (Purves et al., 2012) and is considered a classic indicator of sympathetic reactivity to stimuli (Bradley et al., 2017). HR acceleration is considered as a response to the preparation for action, indicating a typical arousal of somato-cardiovascular integration (Sequeira et al., 2000). In the present study, participants showed higher autonomic arousal when categorising pictures, regardless of emotional content. The emotional categorisation of such information comes with a greater engagement of autonomic resources, possibly induced by the uncertainty caused by the limited PV processing of this information.

To summarise, despite its low visual acuity, PV appears to be able to detect emotional cues based on arousal. Moreover, autonomic activation is associated with differential behavioural strategies in CV and PV to categorise pictures. Higher sympathetic mobilisation could therefore optimise behavioural reactivity in low visual acuity conditions.

4.2. Effect of anxiety and depressive symptomatology

In PV, the greater the trait-anxiety was, the greater was the response bias to unpleasant pictures. This result partly confirms our hypothesis according to which anxiety is associated with greater reactivity, especially in PV. It is also consistent with the excessive propensity of anxious individuals to control external stimuli (Pruneti et al., 2016) and reinforces the hypervigilance hypothesis in anxiety (MacLeod and Mathews, 2012). In this context, it seems that unpleasant information prevails in people with anxiety. Indeed, it has been shown that the threshold for activating the threat assessment system in anxious individuals is quite low, resulting in higher attentional resources allocated to stimuli considered as threatening (Coussement and Heeren, 2015). The results of the present study show such a negativity bias in anxiety towards natural scenes presented in PV, despite the complexity of the stimuli and the low acuity of PV. In this context, hypervigilance puts the cognitive system on alert mode and ready to detect potentially threatening signals (Beck and Clark, 1997; Dolan and Vuilleumier, 2003). Such dominance of peripheral vision might be an evolutionary adaptation to optimise stimulus detection under specific conditions of anxiety conditions. Shapiro & Lim (1989) suggested that it would be in the organism's interest to employ its peripheral detection mechanisms to locate and be prepared to react to a source of relevant information. This suggestion was supported by Beck & Emery (1985), who argued that anxiety leads an individual to reach a state of hypervigilance thanks to which he/she mobilises specific attentional resources to constantly scan the environment in the search for signs of danger.

Otherwise, state-anxiety is associated with lower performance in categorising pleasant pictures. Indeed, anxiety has been reported to lead to difficulty in the processing of pleasant information (Carl et al., 2013; Eisner et al., 2009). The preferential orientation of the attention of anxious individuals on negative cues (Liu et al., 2019) and their increased responsiveness to ambiguous ones, considered rather negative, (Olatunji et al., 2011), may lead to difficulty in directing attention toward pleasant information. In this context, attentional training to encourage the processing of pleasant information seems to be beneficial to increase attention towards pleasant information and thus reduce anxious symptomatology (Sass et al., 2016; Waters et al., 2013).

Another original result is that depressive symptomatology was associated with better categorisation of emotional pictures in CV. This result partly confirmed our hypothesis according to which depression may be associated with greater reactivity in CV but not in PV. This observation is consistent with that of De Zorzi et al. (2020) in patients with major depressive disorders, who showed a negativity bias and enhanced autonomic responses in CV but not in PV. A greater autonomic reactivity to unpleasant pictures presented in CV was also observed with high BDI scores (De Zorzi et al., 2021). Depressive symptomatology thus leads to increased processing of emotional information associated with a CV focus, consistent with the fewer saccades and longer fixation observed in depressed patients (Li et al., 2016), which in turn suggests that depressed individuals undertake less visual exploration.

To summarise, trait-anxiety is associated with a higher response bias to unpleasant stimuli in PV, possibly reflecting the allocation of greater resources to react to negative information in extended portions of the visual field. State-anxiety is associated with lower performance in categorising pleasant stimuli, which is consistent with the difficulty in dealing with pleasant information. Finally, higher depressive scores led to better performance in categorising emotional stimuli in CV but not in PV.

4.3. Strengths, limitations and conclusions

This study has several methodological strengths. First, considering that physical saliency influences visual search and attention (Lucas and Vuilleumier, 2008) and gender differences in emotional assessment and reactivity (Bradley et al., 2001), we carried out a rigorous selection of stimuli. Second, considering the predominant view that the autonomic nervous system is not a unitary system (Berntson et al., 1998), the recording of both autonomic branches provided a reliable and comprehensive overview of autonomic functioning. Third, in an innovative protocol, we considered both central and peripheral visual fields to present emotional information. This is particularly relevant because data from the literature and our own results show a differential behavioural and autonomic reactivity to emotional information according to the visual eccentricity it was presented in. Nevertheless, the study also has some limitations. In particular, the choice of subclinical populations limits the scope of our results to moderate levels of depression and anxiety. Nonetheless, salient effects were observed, thus justifying the exploration of similar research approaches in clinical syndromes. Finally, as the current study is based on the dimensional theory of emotion, conclusions must be drawn in terms of valence and arousal.

In conclusion, the present findings provide new evidence suggesting that visual eccentricity serves as a privileged dimension in combination with behavioural and autonomic reactivities to explore affective disorders. First, given that differences in behavioural and autonomic responses according to central or peripheral presentation were observed, it appears relevant to consider the spatial position of visual information during emotional tasks in order to optimise the characterisation of individual reactivity. Second, anxiety and depression appear to modulate behavioural reactivity to emotional information according to its presentation in more or less eccentric positions. Consequently, central and peripheral vision could serve as a paradigmatic model to distinguish anxiety and depression, which are strong mutually comorbid pathologies. Finally, the differential impact of emotional information over the visual field indicates the value of using new stimulation strategies to attenuate anxiety and depression, such as attentional training which helps to modify the deployment of attentional resources towards emotional information over the visual field.

Contributors

LDZ, JH and HS conceptualized the research question. LDZ, SR, JH and HS contributed to the methodology. Data curation, formal analysis and investigation were performed by LDZ, SR and CR. LDZ and SR wrote the original draft of the manuscript and LDZ, SR and HS reviewed and edited the manuscript. All authors approved the final version of the manuscript for submission.

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Declaration of Competing Interest

None.

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Supplementary materials

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