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Neurophysiological correlates of attentional bias for emotional faces in socially anxious individuals – Evidence from a visual search task and N2pc

Matthias J. Wieser[a,b,*], Anna Hambach[b], Mathias Weymar[c]

[a] Erasmus University Rotterdam, Institute of Psychology, Rotterdam, Netherlands
[b] University of Würzburg, Department of Psychology, Würzburg, Germany
[c] University of Potsdam, Department of Psychology, Potsdam, Germany

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ABSTRACT

Visual search paradigms have provided evidence for the enhanced capture of attention by threatening faces. Especially in social anxiety, hypervigilance for threatening faces has been found repeatedly across behavioral paradigms, whose reliability however have been questioned recently. In this EEG study, we sought to determine whether the detection of threat (angry faces) is specifically enhanced in individuals with high (HSA) compared to low social anxiety (LSA). In a visual search paradigm, the N2pc component of the event-related brain potential was measured as an electrophysiological indicator of attentional selection. Twenty-one HSA and twenty-one LSA participants were investigated while searching for threatening or friendly targets within an array of neutral faces, or neutral targets within threatening or friendly distractors. Whereas no differences were found in reaction times, HSA showed significant higher detection rates for angry faces, whereas LSA showed a clear 'happiness bias'. HSA also showed enhanced N2pc amplitudes in response to emotional facial expressions (angry and happy), indicating a general attentional bias for emotional faces. Overall, the results show that social anxiety may be characterized not only by a spatial attentional bias for threatening faces, but for emotional faces in general. In addition, the results further demonstrate the utility of the N2pc component in capturing subtle attentional biases.

1. Introduction

Cognitive models of social anxiety disorder (SAD) propose that biases in the processing of social information constitute important factors in the etiology and maintenance of this disorder (Beck, Emery, & Greenberg, 1985; Bögels & Mansell, 2004; Cisler & Koster, 2010; Clark & Wells, 1995; Schultz & Heimberg, 2008; Wong, Gordon, & Heimberg, 2014). Particularly, an early attentional bias to threatening information has been proposed as a major factor which contributes to the etiology, maintenance, or exacerbation of anxiety in general (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007; Okon-Singer, Hendler, Pessoa, & Shackman, 2015) and social anxiety in particular (e.g., Miskovic & Schmidt, 2012).

In social anxiety, an attentional bias is mostly observed for social threat cues such as faces expressing disgust or anger, both on a behavioral and on neurophysiological level (e.g., Gilboa-Schechtman & Shachar-Lavie, 2013; Mogg, Philippot, & Bradley, 2004; Peschard and Philippot, 2016; Wieser, McTeague, & Keil, 2011, 2012; Wieser, Pauli, Weyers, Alpers, & Mühlberger, 2009). Summarizing the empirical evidence from the most frequently used paradigm – the emotional dot-probe task – it has recently been concluded that socially anxious individuals preferentially allocate their attention towards threat faces compared to non-anxious controls, but this bias seems to depend on several critical experimental parameters such as the type of reference stimulus, the stimulus duration, and severity of social anxiety (Bantin, Stevens, Gerlach, & Hermann, 2016).

Besides the aforementioned dot-probe task, one paradigm commonly used to investigate the attentional bias to threat is the visual search task, in which participants are asked to find a (potentially threatening) target (e.g., angry face) amongst neutral distracters and vice versa (Frischen, Eastwood, & Smilek, 2008; Hansen & Hansen, 1988). Using faces as stimuli, an "anger superiority effect" i.e. the faster detection of angry compared to friendly facial expressions in a crowd of distractor faces has been demonstrated using either schematic faces (Calvo, Avero, & Lundqvist, 2006; Fox et al., 2000; Juth, Lundqvist, Karlsson, & Öhman, 2005; Öhman et al., 2001; Tipples, Atkinson, & Young, 2002; Weymar, Löw, Öhman, & Hamm, 2011) or real faces (Fox & Damjanovic, 2006; Gilboa Schechtman, Foa, & Amir, 1999;

* Corresponding author at: Erasmus University Rotterdam, Erasmus School of Social and Behavioural Sciences Mandeville Building, room T13-60, Postbus 1738, 3000 DR Rotterdam, Netherlands.
E-mail address: wieser@fsw.eur.nl (M.J. Wieser).

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Horstmann & Bauland, 2006; Pinkham, Griffin, Baron, Sasson, & Gur, 2010). Within the context of social anxiety, Juth et al. (2005) found in a series of experiments that both high and low socially anxious individuals were faster to detect happy faces in neutral crowds than angry or fearful faces in neutral crowds (see also Rinck, Becker, Kellermann, & Roth, 2003). In contrast, several studies report that participants suffering from clinical social phobia detected angry faces faster than happy faces when presented in neutral crowds, suggesting an attentional bias toward angry faces (Eastwood and Smilek, 2005; Gilboa Schechtman et al., 1999). Gilboa Schechtman et al. (1999) also report that SAD patients were more distracted by angry crowds compared to neutral crowds if the target was absent, suggesting that these individuals have difficulties disengaging attention away from threat. Similar effects were found in two other studies (Banos, Quero, & Botella, 2008).

Event-related brain potentials (ERPs) are particularly suited for examining attentional biases, as they can provide a temporally precise, direct measure of covert attention and may detect biases not evident in behavioral data (Kappenman, Farrens, Luck, & Proudfit, 2014; Reutter, Hewig, Wieser, & Osinsky, 2017). A good electrophysiological index of enhanced engagement of attention towards threat is the N2pc component as an electrophysiological marker of spatial selective attention (Hickey, Di Lollo, & McDonald, 2009; Kiss, Van Velzen, & Eimer, 2008; Luck and Hillyard, 1994). The N2pc is a negative component emerging around 200 ms after stimulus onset, which is enhanced at electrode sites contralateral to an attended location (e.g., Hickey, McDonald, & Theeuwes, 2006; Kappenman et al., 2014; Kiss et al., 2008; Luck & Hillyard, 1994; Woodman and Luck, 2003). It is named for its polarity (negative), latency (approximately 200 ms poststimulus), and topography (posterior/contralateral), and is defined as the difference between the brain wave elicited at target-ipsilateral sites and target-contralateral sites. It has been proposed that the N2pc reflects the deployment of attention to minimize the interference from (or "filter out") task-irrelevant stimuli presented concurrently with task-relevant targets (for a review, see Luck, 2012).

Recent ERP studies demonstrated that highly salient threat cues (such as facial expressions) modulate the N2pc: For instance, larger N2pc amplitudes were found in response to fearful or angry faces, relative to neutral or happy faces in the dot-probe task (Grimshaw, Foster, & Corballis, 2014; Holmes, Bradley, Nielsen, & Mogg, 2009; Holmes, Mogg, de Fockert, Nielsen, & Bradley, 2014; Osinsky, Wilisz, Kim, Karl, & Hewig, 2014) and other tasks tapping into visual attention allocation such as visual search tasks (Eimer & Kiss, 2007; Feldmann-Wustefeld, Schmidt-Daffy, & Schubo, 2011; Ikeda, Sugiura, & Hasegawa, 2013; Weymar et al., 2011). Together with findings showing that the N2pc is also modulated when salient faces are task-irrelevant (e.g., Eimer and Kiss, 2007), current electrophysiological data suggest rapid prioritized spatial attention to facial threat.

Several experiments also showed that anxiety modulates the N2pc for threat stimuli. For example, trait anxious individuals showed a greater N2pc for angry faces compared to healthy individuals in a modified visual-probe task (Fox, Derakshan, & Shoker, 2008), which again suggests that anxious individuals have increased engagement with threat. The N2pc is also modulated by specific fear, as phobic individuals (such as individuals with blood phobia or spider phobia) have a greater N2pc for stimuli related to their phobia than for other threatening stimuli (Buodo, Sarlo, & Munafò, 2010; Weymar, Gerdes, Löw, Alpers, & Hamm, 2013). Compared to non-fearful participants, spider fearful individuals showed a more enhanced posterior N2pc to spider (vs. butterfly) targets in an array of flowers. Furthermore, spider fearful participants showed enhanced hypervigilance for all presented stimuli compared to controls as reflected by enhanced C1 (40–60 ms; Weymar, Keil, & Hamm, 2014) and N1 amplitudes (160–200 ms; Weymar et al., 2013). These findings provide neural evidence not only for a general hypervigilance in potentially dangerous contexts in phobic individuals but also for selective (spatial) attention (e.g., N2pc) to fear-relevant stimuli.

In the present study, we used aforementioned visual search paradigm to investigate spatial attention to fear-relevant and fear-irrelevant stimuli (facial expressions) in socially anxious participants and non-anxious controls. In addition to behavioral measures, we included electrophysiological measures of attention selection. Moreover, to improve ecological validity we used pictures of "real" faces instead of schematic ones (Weymar et al., 2011) in the visual search arrays. In line with previous behavioral studies (Öhman et al., 2001; Soares, Esteves, Lundqvist, & Öhman, 2009b), we expected increased spatial attention towards fear-specific targets (threatening faces) in high socially anxious compared to low socially anxious individuals. Furthermore, in line with our recent electrophysiological studies (Weymar et al., 2013; Weymar et al., 2011) we also expected larger N2pc amplitudes in response to threat-relevant faces in HSA compared to LSA individuals. Potentially, attention to the task-relevant items is distracted in displays with threat-relevant distractors, which would result in slower response times in HSA participants (Gerdes, Alpers, & Pauli, 2008) due to delayed disengagement (Fox, Russo, Bowles, & Dutton, 2001). Thus, we expected the N2pc to be reduced or even absent due to enhanced attention capture by the fear-relevant background objects. As some evidence exists for a left visual field/right brain hemisphere advantage both in sustained attention (e.g., Verleger et al., 2009), face (e.g., Kanwisher, McDermott, & Chun, 1997) and emotion processing (e.g., Borod et al., 1998; Kanwisher et al., 1997), we also looked for differences between targets being present in the left versus in the right visual hemifield.

2. Methods

2.1. Participants

All participants were female undergraduate students at the University of Würzburg without any past or present psychiatric diagnosis (self-report), who were paid or received course credit for participation. More than 1000 students filled in a pre-screening questionnaire consisting of five items (Ahrens, Mühlberger, Pauli, & Wieser, 2014) based on the DSM-IV criteria for social phobia (American Psychiatric Association, 2013), on a 5-point Likert scale (0 = "Strongly disagree" to 4 = "Strongly agree"). Participants scoring from 1 to 4 points were classified as low (LSA) and participants scoring from > 9 points as high socially anxious (HSA). Overall, 45 subjects took part in the study. Two participants had to be excluded due to a self-reported present diagnosed depressive episode and treatment with anti-depressants (BDI scores 37 and 29), and one participant due to excessive artifacts in the EEG (more than 50% trials), such that 42 subjects (HSA: n = 21; LSA: n = 21) were included in the final sample.

Groups did not differ in terms of age (HSA: $M = 21.86$ years, $SD = 1.56$; LSA: $M = 21.38$, $SD = 1.69$, $t(40) = .95$, $p = .348$). To ensure that the screening was successful, subjects again completed the pre-screening, the German version of the Social Phobia and Anxiety Inventory (SPAI; Fydrich, 2002; Turner, Beidel, Dancu, & Stanley, 1989) and the Social Phobia Inventory (SPIN; Connor et al., 2000). As expected, significant group differences were found in the total scores of the pre-screening, $t(40) = 6.79$, $p < .001$, SPIN, $t(40) = 4.80$, $p < .001$, and SPAI, $t(40) = 3.91$, $p < .001$ (see Table 1a). Before the experimental task, subjects also completed the State-Trait Anxiety Inventory (Laux, Glanzmann, Schaffner, & Spielberger, 1981; Spielberger, Gorsuch, & Lushene, 1970) and the Beck Depression Inventory (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). HSA participants showed significantly higher scores in state anxiety, $t(40) = 2.53$, $p = .015$, trait anxiety, $t(40) = 3.91$, $p < .001$, and depression scores, $t(40) = 3.06$, $p < .001$. (see Table 1a). A correlational analysis showed that measures of anxiety and depression were highly correlated (see Table 1b).

All participants gave written informed consent prior to participation. None of them had a family history of epilepsy and all reported normal or corrected-to-normal vision. The study was approved by the ethics committee of the medical department of the University of

Table 1a
Mean age and questionnaire scores by group.

	LSA		HSA			
	M	*SD*	*M*	*SD*	*t*	*p*
age	21.38	1.68	21.86	1.56	0.95	.348
Pre-Screening	3.29	2.26	9.62	3.62	6.79	< .001
SPAI	53.47	18.71	81.45	24.90	4.11	< .001
SPIN	10.19	5.31	20.29	8.06	4.80	< .001
STAI trait	35.24	8.09	45.62	9.11	3.91	< .001
STAI state	32.52	5.56	38.29	8.82	2.53	.015
BDI	5.43	5.09	11.00	6.63	3.06	.004

Note: The German SPAI scores were transformed into the original scores. Pre-Screening = Sum Score of DSM V based 5-item questionnaire about social anxiety disorder symptoms (range 0–20); SPAI = Social Phobia and Anxiety Inventory; SPIN = Social Phobia Inventory; STAI = State-Trait Anxiety Inventory; BDI = Beck Depression Inventory. See methods section for further details about questionnaires.

Table 1b
Correlations of anxiety and depression questionnaires.

	SPAI	SPIN	BDI III	STAI Trait	STAI State
SPAI		.862**	.687**	.799**	.537**
SPIN			.762**	.778**	.438**
BDI III				.816**	.535**
STAI Trait					.568**

Note: ** p < .001.

Würzburg.

2.2. Stimulus material and procedure

The paradigm was adapted from Weymar et al. (2011, 2013). In short, faces from five male actors (happy, angry, neutral) were taken from the KDEF database (Lundqvist, Flykt, & Öhman, 1998), and converted to greyscale in order to minimize physical differences between categories. Visual search arrays (see Fig. 1) were created containing 6 faces with angry targets amongst neutral distractors, happy targets amongst neutral distractors, neutral targets amongst angry distractors, neutral targets amongst happy distractors, and 3 displays with no targets (7 conditions). The stimuli displayed arrays of six faces arranged in a circle around the fixation cross (0.37°width × 0.38° height). The distance from the fixation cross at the center of the display to the center (nose) of each of the six faces was 4.69°. The individual faces were 1.99° width × 2.65° height. Overall, 90 trials were presented per condition, resulting in a total of 630 trials. The targets occurred 15 times at one of the six positions in the matrix per condition. Targets positions were randomized over trials. Examples of the stimulus arrays are shown in Fig. 1. The matrices were presented on a 19” computer monitor (1024 × 768, 60 Hz) located 1 m in front of the viewer.

Participants were seated in a dimly-lit, sound-attenuated, cabin. After electrode attachment, participants were instructed to attentively watch the displays on the screen, and to detect as quickly and accurately as possible a discrepant face in the presented search arrays of six faces. Participants had to press different keys (“yes” or “no” button) depending on whether a discrepant target was present in the array. Before the task, all participants practiced the visual search task in a series consisting of 6 trials with displays containing a target or not. A trial was started with a fixation-cross presented for 500 ms, preceding each onset of the search array. The arrays were presented in random order for each participant with the constraint that no array with a target (either angry or happy) was presented on more than four consecutive trials. A trial was terminated by the participants' response. A variable inter-trial interval (ITI) of 1500, 2000, or 2500 ms (blank screen) was presented between trials. Before starting the task, subjects were instructed to avoid eye blinks and excessive body movements during ERP measurement.

After the visual search task, participants were asked to rate each face in terms of affective valence and arousal using the self-assessment manikin (SAM; Bradley & Lang, 1994). Each face appeared centrally on the screen for 500 ms, afterwards the SAM scales were presented.

2.3. Apparatus and data analysis

The EEG was continuously recorded from 129 electrodes using an Electrical Geodesics System (EGI, Eugene, OR, USA), referenced to Cz, digitized at a rate of 250 Hz, and on-line band-pass filtered from 0.1 to 100 Hz with a notch filter of 50 Hz. Scalp impedance for each sensor was kept below 50 kΩ, as recommended for the Electrical Geodesics high-impedance amplifiers. All channels were bandpass filtered online from 0.1 to 100 Hz. Off-line analyses were performed using EMEGS (Peyk, De Cesarei, & Junghofer, 2011) including low-pass filtering at 30 Hz, an artefact rejection, eye movement correction, sensor interpolation, baseline correction, and conversion to an average reference (Junghöfer, Elbert, Tucker, & Rockstroh, 2000). First, extracted epochs were corrected for eye movements and blink artifacts using the MATLAB-based toolbox BioSig (Vidaurre, Sander, & Schlogl, 2011). This fully automated correction method is based on linear regression to remove electrooculogram (EOG) activity from the EEG (Schlögl et al., 2007). EOG activity (horizontal and vertical EOG) was measured from frontal electrodes (8, 9, 10, 14, 15, 16, 17, 18, 21, 22, 25, 125, 126, 127, 128). Then, trials with artifacts were identified based on the distribution of statistical parameters of the EEG epochs extracted (absolute value, standard deviation, maximum of the differences) across time points, for each channel, and – in a subsequent step – across channels. Sensors contaminated with artifacts were replaced by statistically weighted, spherical spline interpolated values. The maximum number of approximated channels in a given trial was set to 20. Such strict rejection criteria also decrease the probability of residual artifacts stemming from vertical and horizontal eye movements (even after blink and eye movement correction). Stimulus-synchronized epochs were extracted from 100 ms before to 800 ms after picture onset and baseline corrected (100 ms prior to stimulus onset).

The lateralized N2pc component was calculated by averaging the electrocortical activity ipsi- or contralateral relative to a target event. The ipsilateral waveform was computed as the average of the left-sided

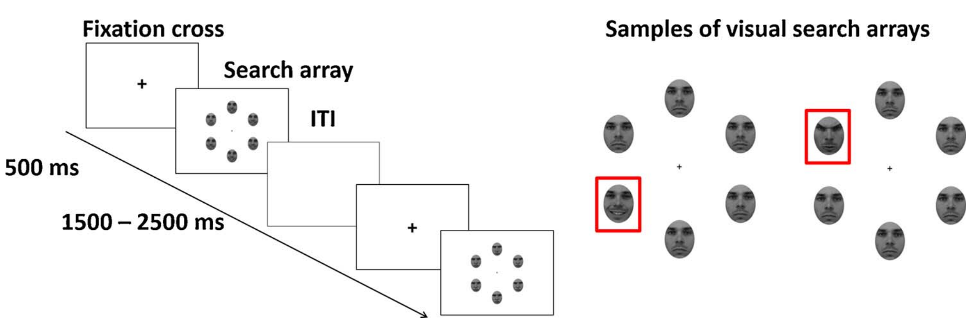

Fig. 1. Experimental trial and samples of visual search arrays. Red rectangles mark targets and were not present during stimulus presentation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

electrode cluster when the target was presented to the left, and the right-sided electrode cluster when the target was presented to the right. The contralateral waveform was defined as the average of the left-sided electrode cluster to the right-sided target and the right-sided electrode cluster to the left-sided target. Averaged ERPs were based on correctly responded trials only. Overall, approximately 22.8% of the trials had to be rejected because of artifacts and outliers in reaction times. These rejected trials were equally distributed across all target categories ($p > .213$), and did not differ between groups (HSA: 21.69%; LSA: 23.66% rejected trials $p > .384$). Finally, separate averages were computed for each condition including target facial expression (threatening vs. friendly), contralaterality (contralateral vs. ipsilateral hemisphere relative to the target position), and group (LSA vs. HSA). As in our previous studies (Weymar et al., 2011, 2013), upper and lower left objects (faces) were merged to one single left location condition (n = 30 for each facial expression), whereas the upper right and lower right objects (faces) were averaged for the right location condition (n = 30 for each facial expression). Face targets presented at the top or bottom positions did not enter the analyses. Corresponding sensory cluster and time window representative for the N2pc component were determined based on visual inspection of individual subject waveforms and in line with prior research (Eimer & Kiss, 2007; Weymar et al., 2011, 2013). Analyses focused on lateral occipital electrodes in the time between 160 and 280 ms, where the N2pc component was maximal, and was quantified as mean amplitude at the EGI sensors 58 59 64 65 68 69 (left), and 89 90 91 94 95 96 (right). In the first step, mean ERP amplitudes were entered into a repeated-measures ANOVA including the within-subjects factors target facial expression (threatening vs. friendly), contralaterality (contralateral vs. ipsilateral hemisphere relative to the target faces position), and the between-subjects factor group (LSA vs. HSA). Because the N2pc is a lateralized component, the presence of the N2pc will be indicated by a significant effect of contralaterality.

In a second step, the N2pc in response to neutral targets was analyzed by a repeated-measures ANOVA including the factors facial expression of the distractor faces (threatening vs. friendly), contralaterality (contralateral vs. ipsilateral hemisphere relative to the target faces position), and the between-subjects factor group (LSA vs. HSA).

In a third step, the aforementioned analysis was run on the average ERPs for each condition including target facial expression (threatening vs. friendly), target location (left vs. right relative to fixation) and electrode cluster (left vs. right cluster), thus making it possible to qualify any hemifield asymmetries. Here, the occurrence of a reliable N2pc is indicated by a significant interaction between target location and electrode cluster: i.e., an N2pc is present when in response to a left-sided target the mean ERP amplitude across the contra-lateral right electrode cluster is more negative than across the ipsilateral left cluster, and vice versa for targets presented on the right side.

In order to investigate general ERP responses to face arrays, the P1, and N1, of the ERPs in response to no target arrays were investigated. The P1 and N1 amplitudes were scored based on visual inspection of the grand averages over electrodes were peaks were maximal. The P1 was scored as mean activity between 104 and 136 ms across a left (sensors 65, 66, 70) and right cluster (83, 84, 90). The N1 again was scored as mean activity between 160 and 180 ms across the EGI sensors 58, 59, 64, 65, 68, 69 (left), and 89, 90, 91, 94, 95, 96 (right). P1 and N1 amplitudes were analyzed employing repeated-measures ANOVAs including the factors facial expression (neutral vs. threatening vs. friendly), and electrode cluster (left vs. right cluster), and the between-subjects factor group (LSA vs. HSA).

For behavioral data, reaction times (RT) and accuracy rates (AR) were analyzed. Accuracy was calculated as the percentage of targets correctly detected for each facial expression and each side of array (chance level = 1/6 = 16.67% per condition). Mean reaction times were calculated using correct trials only, for each condition and each participant. Behavioral data were submitted to repeated measures ANOVAs using the factors facial expression (threatening vs. friendly), target location (left vs. right), and group (LSA vs. HSA). Finally, a correlation analysis was performed to determine possible relations between the behavioral and N2pc data.

Affective ratings (valence, arousal) were analyzed with repeated-measures ANOVAs containing the within-subject factor facial expression (angry, happy, neutral) and the between-subject factor group (LSA vs. HSA).

For all statistical tests, Greenhouse-Geisser correction of degrees of freedom (GG-ε) was applied if necessary. A significance level of 0.05 (two-tailed) was used for all analyses. Throughout this manuscript, the uncorrected degrees of freedom, the corrected p values, the Greenhouse-Geisser (GG) ε, and the partial η^2 (η_p^2) are reported (Keil et al., 2014; Picton et al., 2000).

3. Results

3.1. Event-related brain potentials

3.1.1. N2pc in response to emotional targets (angry and happy faces amongst neutral distractors)

No general N2pc was observed, $F(1,40) = 2.35$, $p = .133$, $\eta_p^2 = 0.06$. However, a reliable N2pc was present in the HSA group, as indicated by a significant interaction of contralaterality x group, $F(1,40) = 4.21$, $p = .047$, $\eta_p^2 = 0.10$. Separate analyses per group confirmed that a N2pc to face targets (both happy and threatening) was only detectable in HSA, $F(1,20) = 4.47$, $p = .047$, $\eta_p^2 = 0.18$, whereas LSA showed no reliable N2pc, $F(1,20) = 0.24$, $p = .630$, $\eta_p^2 = 0.01$ (see Table 2 and Fig. 2). No interaction effects with target facial expression were observed. Overall, the ERP amplitudes were more negative in LSA compared to HSA, $F(1,40) = 6.32$, $p = .016$, $\eta_p^2 = 0.14$.[1]

The exploratory analysis of hemispheric asymmetries or visual field advantages revealed a main effect of electrode cluster, $F(1,40) = 5.13$, $p = .029$, $\eta_p^2 = 0.11$. Moreover, the significant interaction of group, target location, and electrode cluster revealed, as in the previous analysis, that the presence of the N2pc was differentially expressed in the two groups, $F(1,40) = 4.21$, $p = .047$, $\eta_p^2 = 0.10$, (Fig. 3). No interaction effects with target facial expression were observed.

A separate analysis for each experimental group revealed that only in the HSA group, both happy and angry targets elicited larger N2pc amplitudes but only when the targets were presented in the left visual hemifield, as the paired *t*-test for targets in the left visual hemifield over left ($M = -1.97\,\mu V$, $SD = 1.88$) compared to the right electrode cluster ($M = -2.79\,\mu V$, $SD = 2.59$) revealed, $t(20) = 4.41$, $p < .001$ (Fig. 4). The topography of the difference map between targets in the left visual field and targets in the right visual field are given in Fig. 5.

Together, these findings indicate that HSA show enhanced attentional engagement to both happy and angry facial expressions, but especially when they appear in the left visual hemifield. This shows that HSA compared to low socially anxious show earlier attentional engagement (attentional bias) to emotional facial expressions. Moreover, this also indicates a LVF bias for facial expressions in general in high socially anxious individuals.

3.1.2. N2pc in response to neutral targets (neutral target faces amongst angry or happy distractors)

Neither the main effect of contralaterality nor the interaction of

[1] In order to test the influence of trait and state anxiety and depression, we ran the main analysis also as separate ANCOVAs including these questionnaire measures as co-variates of interest. This changes the critical interaction group x contralaterality from $p = .048$ to $p = .065$ with trait anxiety (STAI-T) as co-variate, from $p = .048$ to $p = .045$ with depression (BDI) as co-variate, and from $p = .048$ to $p = .031$ with state anxiety (STAI-S) as co-variate. This points at a subtle influence of the general level of trait anxiety on the observed attentional bias for emotional expressions.

Table 2
Mean ERP amplitudes and N2pc amplitudes (contra- minus ipsilateral) in response to angry and happy face targets, collapsed across hemifields. Mean amplitudes (160–280 ms) are given in μV for the clusters of six electrodes each contra- and ipsilateral to target onset, and the respective N2pc amplitudes.

	ERP amplitudes								N2pc amplitudes			
	angry ipsilateral		angry contralateral		happy ipsilateral		happy contralateral		N2pc angry		N2pc happy	
group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
HSA	−1.74	1.42	−1.88	1.33	−1.45	1.29	−1.83	1.18	−0.14	0.44	−0.38	0.99
LSA	−2.84	1.73	−2.70	1.73	−2.85	1.61	−2.90	1.47	0.13	0.62	−0.06	0.53

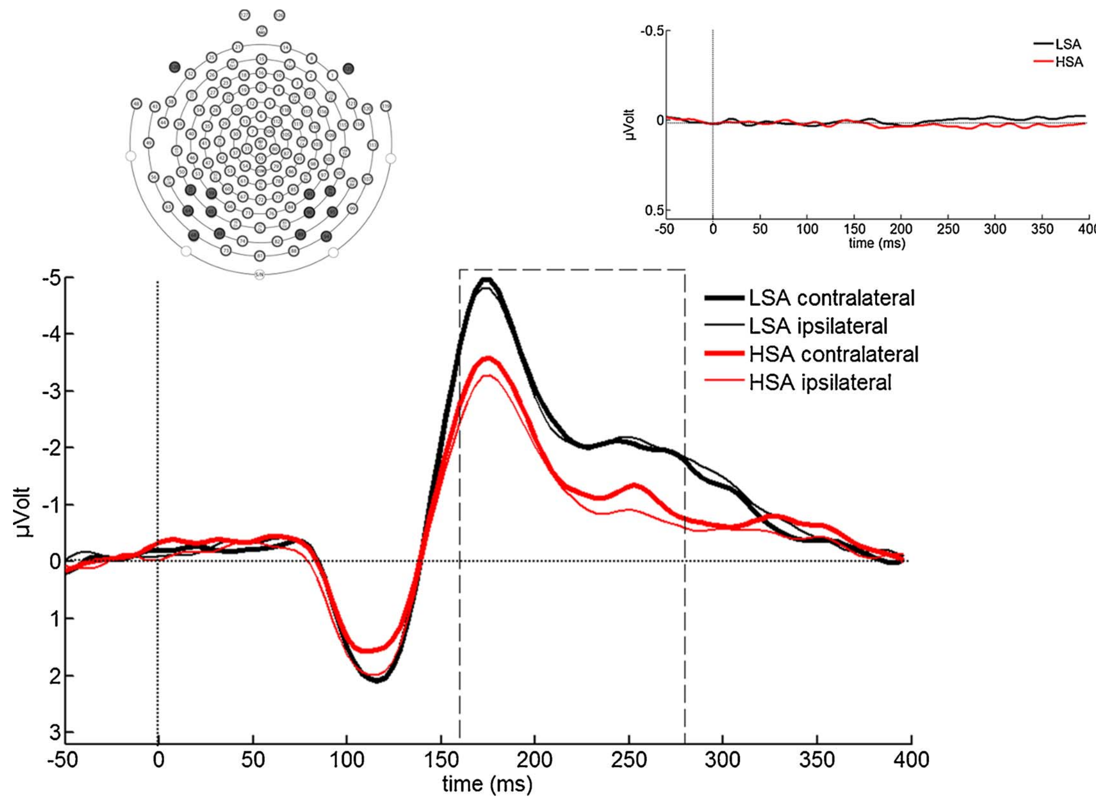

Fig. 2. Grand averaged ERPs elicited in the 400-ms interval after target onset in response to emotional face targets contralateral (thick lines) and ipsilateral (thin lines) to the visual field where the stimulus was presented for both groups (LSA, black lines; HSA, red lines). The hatched box indicates the time interval used to score the N2pc. ERPs are averaged across electrodes within posterior clusters used in the analyses (see left inlay). In the upper right corner, difference waveforms of contralateral and ipsilateral ERPs in response to face targets are displayed for HSA (red line) and LSA (black line) participants at two representative frontal sensors (#128 and #125, see geodesic sensor net) indicating that no residual eye moments were present after artifact correction and rejection. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

contralaterality were found to be significant. This indicates that no reliable N2pc was observed in response to neutral targets. Again, the main effect of group was significant, $F(1,40) = 4.49$, $p = .040$, $\eta_p^2 = 0.10$, reflected by lower ERP amplitudes in HSA compared to LSA.

The exploratory analysis of hemispheric asymmetries or visual field advantages revealed a main effect of electrode cluster, $F(1,40) = 6.13$, $p = .018$, $\eta_p^2 = 0.13$, and experimental group, $F(1,40) = 4.48$, $p = .040$, $\eta_p^2 = 0.10$, indicating more negative ERP amplitudes across the right electrode cluster, and overall reduced ERP amplitudes in HSA. Furthermore, a significant interaction Group x Cluster was found, $F(1,40) = 5.66$, $p = .022$, $\eta_p^2 = 0.12$, indicating larger ERP amplitudes for HSA but only on right compared to left electrodes. Critically, the interaction of target location and cluster failed to reach significance, $F(1,40) = 2.44$, $p = .18$, $\eta_p^2 = 0.13$. In accordance with the previous analysis, this indicates that no reliable N2pc was observed in response to neutral targets.

3.1.3. ERPs in response to arrays without targets

To measure electrocortical responses to different facial expression arrays when there were no competing distracters present, we compared the P1 and the N1/N170 elicited by angry, happy and neutral facial arrays between groups. For the P1, no effect emerged involving the factors group and facial expressions. Higher amplitudes were observed over the left compared to the right electrode cluster, $F(1,40) = 5.69$, $p = .022$, $\eta_p^2 = 0.13$. The analysis of the N1 also revealed a significant main effect of electrode cluster, $F(1,40) = 14.10$, $p = .001$, $\eta_p^2 = 0.26$, with more negative amplitudes observed across the right hemispheric cluster. Overall, the N1/N170 was less negative in HSA compared to LSA, $F(1,40) = 4.53$, $p = .040$, $\eta_p^2 = 0.11$. More important, a significant three-way interaction between facial expression x electrode cluster and group was detected, $F(2,80) = 4.13$, $p = .020$, $\eta_p^2 = 0.09$. Between-group *t*-tests revealed that LSA compared to HSA showed more negative amplitudes in response to all facial expressions over left electrodes (all t's > 2.58, all p's $< .014$), whereas no differences between groups were observed for electrodes over the right hemisphere (all t's < 1.44, all p's $> .158$). Separate analysis per group revealed in

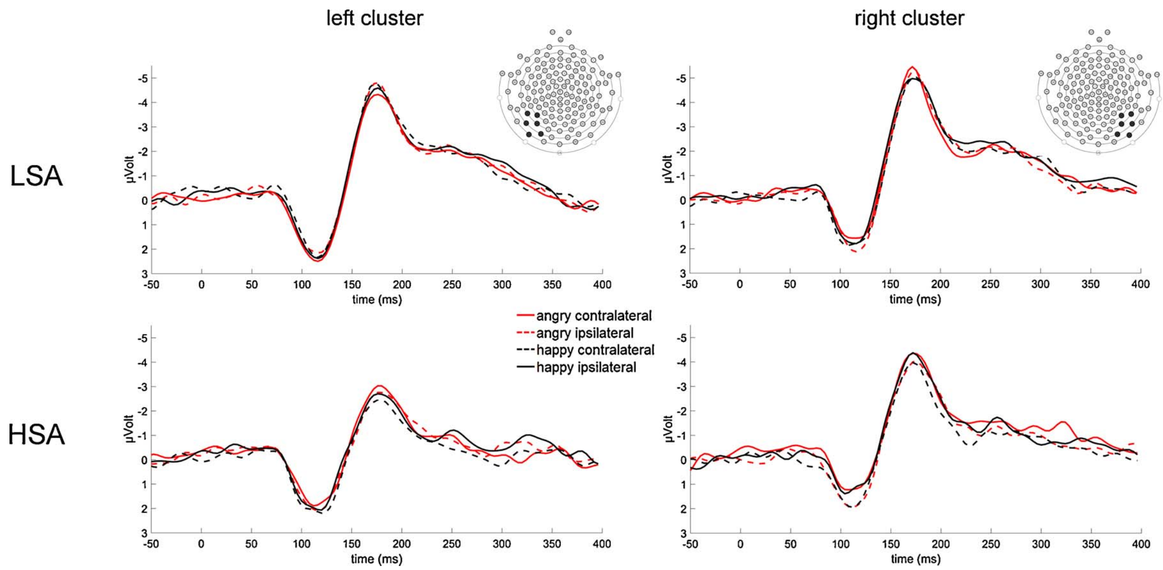

Fig. 3. Grand mean evoked potentials spatially averaged across a left and right clusters of six electrodes (see inlays), evoked by angry and happy face targets for high socially anxious (HSA) and low socially anxious (LSA) participants.

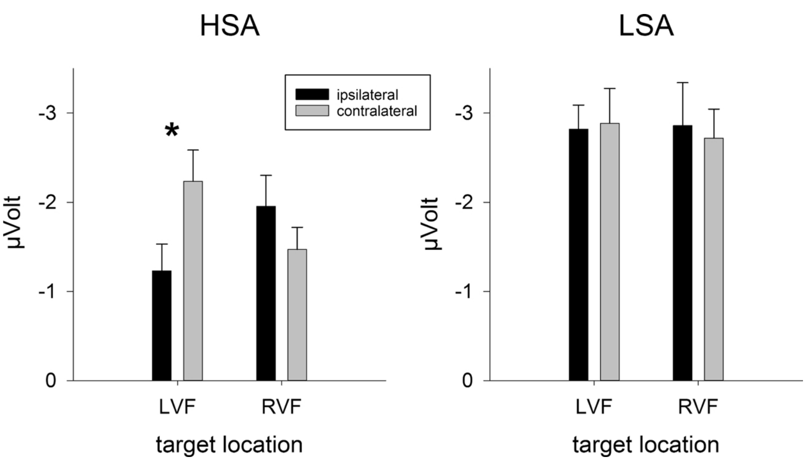

Fig. 4. Mean ERP amplitudes (negative up) and SEM evoked by targets in the left (LVF) and right (RVF) visual field. Only in HSA, a clear N2pc is observed in response to LVF targets.

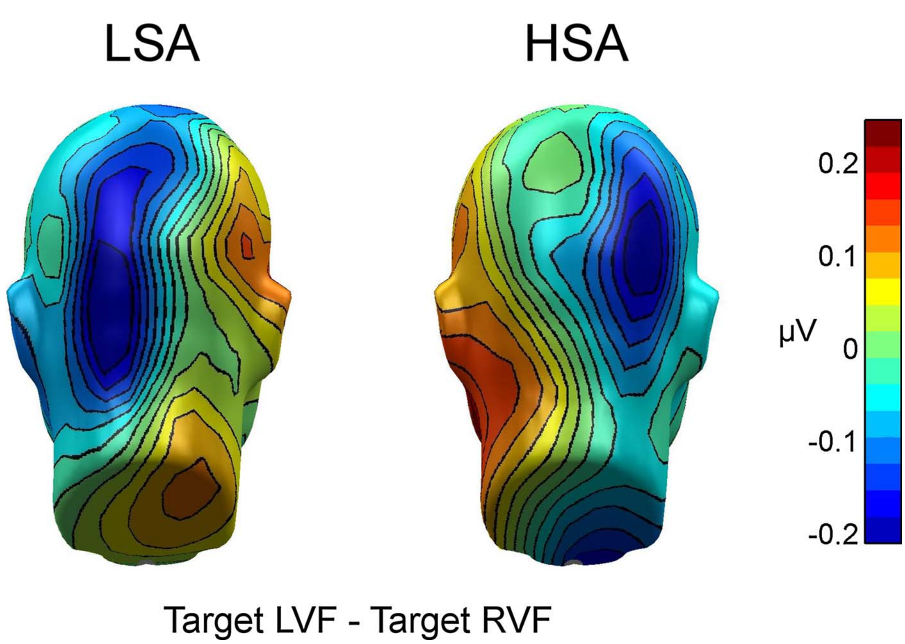

Fig. 5. Grand mean topographical distribution of the difference wave (target LVF –target RVF) for LSA and HSA. Only in HSA, a clear N2pc in response to emotional target faces is observed with a pronounced negativity over contralateral electrodes (right).

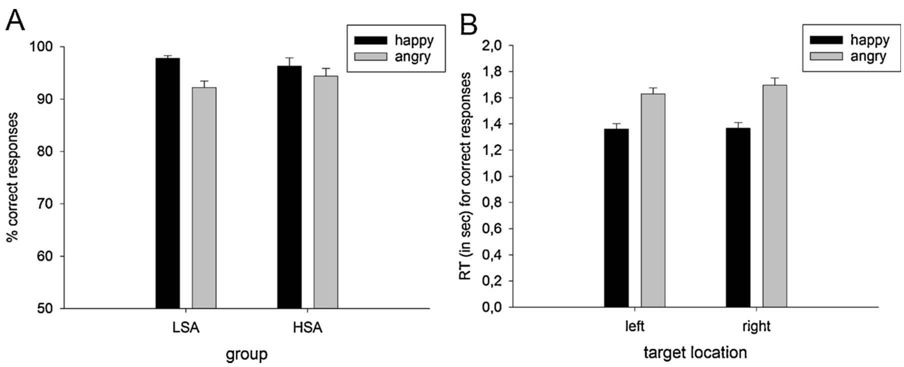

Fig. 6. Performance in the visual search task. A) Mean hits (+SE) for emotional targets faces in both groups. B) Mean RTs (+SEM) for emotional target faces presented in the left (LVF) or right visual field (RVF).

HSA that neutral faces elicited larger N1 amplitudes compared to angry faces over right electrodes, $t(20) = 2.89$, $p = .009$. A small effect was observed in LSA, where happy faces elicited enhanced N1 amplitudes compared to angry faces over left electrodes, $t(20) = 2.20$, $p = .038$.

3.2. Task performance

3.2.1. Emotional targets (angry and happy faces amongst neutral distractors)

Overall, HSA showed a higher detection rate of threatening faces compared to LSA, $F(1,40) = 10.45$, $p = .002$, $\eta_p^2 = 0.12$, which was confirmed by post-hoc between-groups *t*-tests, $t(40) = 3.02$, $p = .018$ for threatening faces, and $t(40) = 0.24$, $p = .809$ for happy faces. In general however, happy face targets were detected more often than angry face targets, $F(1,40) = 44.62$, $p > .001$, $\eta_p^2 = 0.53$ (see Fig. 6A).

The analysis including visual hemifield also showed that happy targets were detected with higher accuracy than angry targets, $F(1,40) = 35.77$, $p < .001$, $\eta_p^2 = 0.47$. This effect was differentially expressed in both groups, $F(1,40) = 8.57$, $p = .006$, $\eta_p^2 = 0.19$. Whereas LSA showed a clear happiness bias, i.e. they detected happy faces more often than angry faces *(*$M = 97.78\%$, $SD = 2.43$ vs. $M = 92.22\%$, $SD = 5.59$; $t(20) = 5.76$, $p < .001$), this difference was much lower in HSA, ($M = 96.27\%$, $SD = 7.45$ vs. $M = 94.36\%$, $SD = 6.80$; $t(20) = 2.41$, $p = .026$). Target detection was also differentially expressed depending on the side of the visual field in which the target was presented, $F(1,40) = 35.77$, $p < .001$, $\eta_p^2 = 0.47$. Whereas angry faces were more often correctly detected on the left compared to the right side, $M = 94.29\%$, $SD = 7.45$ vs. $M = 92.30\%$, $SD = 6.26$, $t(20) = 2.22$, $p = .032$, happy faces were more often detected on the right compared to the left side, $M = 98.02\%$, $SD = 5.36$ vs. $M = 96.03\%$, $SD = 6.30$, $t(20) = 3.36$, $p = .002$.

Interestingly and in contrast to our expectations, happy targets were detected faster than threatening targets as revealed by a main effect of facial expression for mean reaction times, $F(1,40) = 188.39$, $p < .001$, $\eta_p^2 = 0.83$. The analysis including the factor hemifield showed that this effect was dependent on the side where the target was presented, $F(1,40) = 4.15$, $p = .048$, $\eta_p^2 = 0.09$. Whereas no differences were found for the detection of happy faces, angry faces were detected slightly faster when appearing left rather than right, $t(41) = 1.98$, $p = .051$. No interaction with group was found (see Fig. 6B).

3.2.2. Neutral targets (neutral target faces amongst angry or happy distractors)

Overall, neutral targets were detected with higher accuracy amongst happy distractors, $F(1,40) = 25.49$, $p < .001$, $\eta_p^2 = 0.39$. Again, this effect was differentially expressed in HSA compared to LSA, $F(1,40) = 5.63$, $p = .023$, $\eta_p^2 = 0.13$. This interaction was due to higher detection rates of angry targets within neutral distractors in HSA (93.8%, $SD = 4.45$) compared to LSA (90.16%, $SD = 6.81$), $t(40) = 2.06$, $p = .046$, whereas no differences were found for the detection rate of happy faces amongst neutral distractors between groups (HSA: 95.92%, $SD = 2.75$, LSA: 96.03%, $SD = 3.73$), $t(40) = 0.11$, $p = .917$.

Taking the visual hemifield into account, this was differentially expressed depending on the side where the target appeared, as the significant 3-way interaction Distracter Emotion x Side of target X Group indicates, $F(1,40) = 3.39$, $p = .027$, $\eta_p^2 = 0.12$. HSA detected neutral targets presented on the right side amongst angry distractor faces ($M = 91.90\%$, $SD = 7.12$) compared to happy distractor faces ($M = 95.40\%$, $SD = 7.33$) with significant lower accuracy, $t(20) = 3.44$, $p = .003$, whereas LSA showed this effect of better neutral face detection amongst happy distractor faces ($M = 93.65\%$, $SD = 5.47$) compared to angry distractor faces ($M = 86.67\%$, $SD = 9.77$) for targets presented on the left side, $t(20) = 3.82$, $p = .001$.

Analysis of the RT revealed that neutral targets were detected faster amongst happy ($M = 1.50$ s, $SD = 0.29$) compared to amongst angry distractors ($M = 1.71$ s, $SD = 0.32$), $F(1,40) = 136.20$, $p < .001$, $\eta_p^2 = 0.77$. This effect was slightly modulated by the side of the target, $F(1,40) = 4.04$, $p = .051$, $\eta_p^2 = 0.09$. Whereas neutral target faces were detected slower amongst angry faces when presented right compared to left, $t(41) = 2.01$, $p = .051$ (left: $M = 1.69$ s, $SD = 0.32$; right: $M = 1.74$ s, SD = 0.34), no differences appeared between sides in RT to neutral targets amongst happy distractors, $t(41) = 0.21$, p = .837. No significant differences were observed involving the factor group.

3.3. Affective ratings

Valence ratings of facial expressions showed the expected effect of Emotion, $F(2,80) = 167.32$, $p < .001$, $\eta_p^2 = 0.81$, with angry faces rated as more unpleasant ($M = 3.37$, $SD = 1.09$) than happy ($M = 6.86$, $SD = 0.75$) as well as neutral faces ($M = 4.73$, $SD = 0.47$), $t(40) = 13.67$, $p < .001$, and $t(40) = 8.57$, $p < .001$, respectively (Table 3). No other effects were found to be significant. The same picture emerged for arousal ratings with a significant main effect of Emotion, $F(2,80) = 22.55$, $p < .001$, $\eta_p^2 = 0.36$ (Table 2). Angry faces were rated as more arousing ($M = 5.71$, $SD = 1.51$) than happy ($M = 4.73$, $SD = 1.29$) as well as neutral faces ($M = 4.04$, $SD = 0.94$), $t(40) = 3.52$, $p = .001$, and $t(40) = 6.61$, $p < .001$, respectively. Also similar to valence ratings, happy facial expressions were rated as more

Table 3
Mean affective ratings of faces (+SEM) for both groups.

	LSA				HSA			
	Valence		Arousal		Valence		Arousal	
face	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
angry	3.14	1.19	5.70	1.59	3.59	0.96	5.71	1.47
happy	7.04	0.64	4.53	1.19	6.68	0.82	4.93	1.38
neutral	4.62	0.42	3.99	0.92	4.86	0.49	4.10	0.99

arousing than neutral faces, $t(40) = 3.33$, $p = .002$. Again, no differences between groups or an interaction of facial expressions and group.

3.4. Correlations between behavioral measures and N2pc amplitude

The reaction times were not correlated neither with the amplitude of the N1 nor the N2pc for both emotional facial expressions across and within groups.

4. Discussion

Using a visual search paradigm, we investigated if and how individuals with high social anxiety show enhanced attentional capture by threatening faces. In behavior, HSA indeed showed more accurate but not faster responses to angry faces targets. In the N2pc component of the visual ERP elicited by face targets, we found further evidence for an enhanced attention allocation and engagement in HSA for emotional target faces per se: HSA exhibited enhanced spatial attention to emotional (angry and happy) faces as indexed by larger N2pc amplitudes. Together, these findings provide further evidence that social anxiety is associated with an early attentional bias for emotional faces per se but not for threat in particular.

Interestingly, HSA also showed better detection of neutral targets amongst angry distractors. This points towards enhanced performance in the presence of threat rather than enhanced distraction. These results somewhat mimic studies where shorter RTs were observed for trials containing arrays with threat targets and backgrounds (Soares, Esteves, & Flykt, 2009a; Weymar et al., 2013). Possibly, this can be explained in light of recent findings showing that perceptual load interferes with emotional attention such that high perceptual load reduces the effect of even highly salient distractors (Lavie, 2005, 2010). As the current search display with overall six items can be seen as relatively high perceptual load, HSA seem to perform better when threatening information is present. Of course, this would need further support by studies directly manipulating perceptual load during visual search. In any case, these findings suggest that HSA show a better discrimination between angry and neutral faces (see further discussion below). Another explanation for this effect may also be that HSA see neutral faces as potentially more threatening than NSA, which has been described on behavioral and neural levels (e.g., Cooney, Atlas, Joormann, Eugène, & Gotlib, 2006; Peschard & Philippot, 2017; Yoon & Zinbarg, 2007). This may be due to a heightened intolerance of ambiguity in social anxiety disorder (Kuckertz, Strege, & Amir, 2017).

Overall, the shorter response times for happy targets support the notion of an advantage for happy rather than angry faces. In recent years, considerable efforts were made to investigate why sometimes an anger-superiority and sometimes a happy-superiority effect is observed in these visual search tasks (for a review of these inconsistent results, see e.g., Becker, Anderson, Mortensen, Neufeld, & Neel, 2011; Horstmann & Bauland, 2006). Low level features such as raised eyebrows, wide-open eyes or open mouths (Frischen et al., 2008) or the stimulus set (Savage, Becker, & Lipp, 2016) have been identified to play a critical role in visual search performance. A recent meta-analysis revealed that a happy face detection advantage seems to be restricted to photographic faces, whereas a clear angry face advantage was mainly found for schematic and "smiley" faces (Nummenmaa & Calvo, 2015). Recently, it was also discussed that arousal rather than valence of the facial expressions may be the critical player at work here (Lundqvist, Bruce, & Ohman, 2015; Lundqvist, Juth, & Ohman, 2014). The latter seems an unlikely confound in our study, since the subjective ratings clearly show that angry faces were rated the most arousing stimuli, which would suggest to find an anger-superiority effect. However, it seems likely that open-mouth low-level feature may be partly responsible for the observed happy-superiority effect since 4 out of 5 happy faces in our study were open-mouth with teeth and only 2 out of 5 angry faces were open-mouth with teeth. It has been argued that a smiling mouth would be the critical factor driving attention to the happy faces (Becker et al., 2011; Calvo & Nummenmaa, 2008). As we also found better and faster responses for neutral targets amongst happy distractors, we assume that the non-emotional perceptual differences between the happy and neutral faces in our study were larger than for angry and neutral faces, which made it overall easier to distinguish between both types of faces. It has to be noted, however, that a happiness superiority in visual search may not be entirely due to teeth displays, but could also be due to stimulus set specific characteristics which may bias the emotional advantage in favor of either happiness or anger superiority (Savage et al., 2016). Nevertheless, the HSA still showed selectively enhanced detection rates between neutral and angry targets, which point at the notion of selective attention towards angry faces in social anxiety even when due to factors mentioned above the visual search is prone to detect happy faces easier and faster.

At first glance, our results with enhanced N2pc amplitudes in response to both threatening *and* friendly faces in HSA is in contrast to previous research which has shown that anxiety acts as a strong modulator of the N2pc for threat stimuli. For example, anxious individuals show a greater N2pc for angry and disgust faces compared to healthy individuals (Fox et al., 2008; Judah, Grant, & Carlisle, 2016), and the N2pc is also modulated by specific fear such that phobic individuals have a greater N2pc for stimuli related to their phobia than for other threatening stimuli (Buodo et al., 2010; Weymar et al., 2013). However, we assume that due to the factors mentioned above, in our paradigm the "default response" was enhanced attention to friendly faces. Thus, we would argue that in addition to this HSA show an enhanced bias for angry faces, which is both observed on behavioral (accuracy) and electrophysiological levels. This is also in line with a recent finding of positive correlations of social anxiety and N2pc amplitudes to angry faces in a visual dot-probe design (Reutter et al., 2017).

The observed dissociation between reaction times and electrophysiology seems to point at different stages of stimulus processing and further questions the reliability of behavioral indices for detecting attentional bias. It has been argued for example that although individuals show early engagement with threat, they may have sufficient attentional control to easily disengage their attention from threat when it is not relevant to the task, and as a result, do not show a measurable behavioral bias (Koster, Leyman, Raedt, & Crombez, 2006). Moreover, at least for the widely used dot-probe task, it has been shown that the behavioral bias measured is not sensitive enough and is therefore unreliable (Kappenman et al., 2014; Reutter et al., 2017). Thus, the N2pc may be a more direct measure of biased attentional engagement with threat than behavioral measures.

Interestingly, no reliable N2pc was observed in the group of non-anxious LSA participants. This is partly in line with a study in spider-anxious participants and controls, where a reliable N2pc in response to spider targets was also only found in anxious but not in non-anxious individuals (Weymar et al., 2013). One possible explanation for a lacking N2pc in our LSA group may be the fact that the task is much more difficult than a normal visual search tasks (which is reflected by the long RT latencies). This may blur the emotional target effects in persons who are not very sensitive to social threats (either positive or negative). Indeed in several studies, it has been demonstrated that low socially anxious individuals (trait or state) do not show an enhanced processing of angry compared to neutral facial expressions (e.g., McTeague, Shumen, Wieser, Lang, & Keil, 2011; Wieser et al., 2011, 2012; Wieser, Pauli, Reicherts, & Mühlberger, 2010). Interestingly, it was recently demonstrated that the N2pc in response to angry faces in a dot-probe paradigm with two faces was correlated with social anxiety. This means that indeed with lower levels of anxiety, reduced or even a lack of N2pc effects may be found (Reutter et al., 2017).

The exploratory analysis including visual hemifield as a factor revealed that the attentional bias for emotional faces in high socially anxious students may be especially pronounced when the faces appear in the left visual hemifield and the right hemisphere is processing the target face. This is in accordance with several findings from basic attention, face and emotion processing research. Interestingly, both in sustained attention paradigms and face/emotion tasks, hemispheric asymmetries are commonly observed. Attention research has shown a right hemisphere visual processing superiority during conditions of sustained alertness. For example, the target-evoked N2pc component has been found to be stronger (earlier) over right hemisphere in response to left visual field targets (Verleger et al., 2009). Other studies also point at a left visual field information bias in the visuospatial attention tasks (Corbetta, Shulman, Miezin, & Petersen, 1995; Siman-Tov et al., 2007). Especially for faces, this right hemisphere left visual hemifield advantage has been shown (Kanwisher et al., 1997). In addition, several studies point also at a right hemisphere advantage for processing emotion (Borod et al., 1998; Dimberg & Petterson, 2000; Moscovitch & Olds, 1982; Nicholls, Mattingley, Berberovic, Smith, & Bradshaw, 2004), sometimes especially for negative emotions (Killgore, Yurgelun-Todd, & Id Killgore, 2007; Najt, Bayer, & Hausmann, 2013).

Several limitations of the present study should not forego uncommented. First, the study was done with pre-selected students who scored not as high as expected on the SPIN and SPAI. Naturally, the missing selective effect on threatening facial expressions could be due to this fact. Clearly further research with more socially anxious students or even better – patients suffering from clinical social phobia is needed. Second, as the analysis including depression and trait anxiety measures as covariates shows, the effects may not be solely explained by the group differences in social anxiety, but rather a combination of trait anxiety, state and social anxiety, and depression. Third, as mentioned above low-level perceptual features may account for some of the effects observed here (happiness bias). Nevertheless, these effects would work in favor of an enhanced happiness bias, so the detected bias for angry faces in HSA may be even stronger if these confounds were better controlled. Another limitation is that we only investigated female participants due to the over-representation of women in psychology students. This of course hampers the generalizability of our results. The same is true for only using male faces. Finally yet importantly, it should be noted that the task using natural rather than schematic faces (Weymar et al., 2011) seems to be much more demanding as can be seen in the relatively long RTs (> 1000 ms). Further research should clarify if differences in task difficulty may interfere with observed attentional bias for threatening or emotional stimuli in social anxiety.

Altogether, the present results point at enhanced attention for emotional faces in social anxiety. Taking behavioral and electrocortical measures together, it seems that despite an overall happiness bias, high socially anxious individuals exhibit biased attention for threatening faces, which is prominent at relatively early levels of attention deployment. Given the above-mentioned limitations, further research in clinical social anxiety employing visual search tasks including both happy and angry natural faces seems warranted.

Author notes

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