Available online at www.sciencedirect.com

SciVerse ScienceDirect

www.elsevier.com/locate/brainres

BRAIN RESEARCH

Research Report

Electrophysiological correlates of enhanced perceptual processes and attentional capture by emotional faces in social anxiety

Mandy Rossignol[a,*], *Pierre Philippot*[a], *Cécile Bissot*[a], *Simon Rigoulot*[b], *Salvatore Campanella*[c]

[a]*Institut de Recherche en Psychologie, Université Catholique de Louvain, Louvain-La-Neuve, Belgium*
[b]*Neurosciences Fonctionnelles & Pathologies, CNRS, UMR 8160, Service EFV, CHRU-Université de Lille II, 59037 Lille, France*
[c]*Psychological Medecine, Université Libre de Bruxelles, Brussels, Belgium*

ARTICLE INFO

Article history:
Accepted 18 April 2012
Available online 26 April 2012

Keywords:
Attention
Emotional perception
Face processing
Social anxiety
Event-related potential

ABSTRACT

Behavioural studies have used spatial cueing designs extensively to investigate emotional biases in individuals exhibiting clinical and sub-clinical anxiety. However, the neural processes underlying the generation of these biases remain largely unknown. In this study, people who scored unusually high or low on scales of social anxiety performed a spatial cueing task. They were asked to discriminate the orientation of arrows appearing at the location previously occupied by a lateralised cue (consisting of a face displaying an emotional or a neutral expression) or at the empty location. The results showed that the perceptual encoding of faces, indexed by P1, and mobilisation of attentional resources, reflected in P2 on occipital locations, were modulated by social anxiety. These modulations were directly linked to the social anxiety level but not to trait anxiety. By contrast, later cognitive stages and behavioural performances were not modulated by social anxiety, supporting the theory of dissociation between efficiency and effectiveness in anxiety.

1. Introduction

Attention biases towards threatening emotional facial expressions (EFE) have been widely described in clinical and sub-clinical anxious states (for a review, see Bar-Haim et al., 2007; Cisler and Koster, 2010). In particular, social anxiety has been characterised by abnormal processing of social information (Hirsch and Clark, 2004).

Amongst the different experimental designs used to demonstrate such biases, the dot-probe paradigm has been developed by MacLeod et al. (1986) to assess selective attention processes: participants are asked to stare at a fixation cross located at the centre of the screen. Two stimuli, one neutral and one emotional, are presented on either side of the screen for a short interval (most commonly 500 ms). After that, a target is presented in the location of one of the two cues and participants have to indicate the position or the shape of the target as fast as possible (see for instance Salemink et al., 2007). While the original studies of spatial attention demonstrated that people respond faster to a probe stimulus presented in a region to which they have been paying attention (Posner et al., 1980), the emotional dot-probe has allowed the increased allocation of visual attention towards threat-related cues to be demonstrated. This is evidenced by decreased reaction times in response to

* *Corresponding author at:* Institut de Psychologie, Université Catholique de Louvain, Place du Cardinal Mercier 10, 1348 Louvain-La-Neuve, Belgium. Fax: +32 10473774.
E-mail address: mandy.rossignol@uclouvain.be (M. Rossignol).

0006-8993/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.brainres.2012.04.034

targets following a threatening stimulus, compared to those following neutral cues (Fox et al., 2002; MacLeod et al., 1986; Telzer et al., 2008).

Event-related potential (ERP) studies have detected this orienting effect as soon as 100 ms after the presentation of a validly-cued target, through an amplification of the occipito-parietal P1 component. This component is generated by extra-striate cortices and reflects basic visual processing (Allison et al., 1999), which can be facilitated for stimuli appearing in an expected location (Hillyard and Anllo-Vento, 1998; Luck et al., 1996). Using modified versions of a cue-target design, several studies have found enlarged P1 amplitudes when cues showing fearful (Pourtois et al., 2004) or angry (Fox et al., 2008; Santesso et al., 2008) faces are replaced by neutral targets. These enhancements imply that visual processes are guided by spatial attention, and that vigilance for threatening cues persists in time (Holmes et al., 2003).

In addition, a wealth of behavioural studies using dot-probe and spatial cueing designs support the hypothesis of hyper-vigilance towards threat in social-anxiety disorders (Mogg and Bradley, 1999, 2002; Mogg et al., 2004; Pishyar et al., 2008). Recently, electrophysiological studies have provided temporal markers of this enhanced vigilance towards faces in social anxiety (Kolassa et al., 2009; Kolassa et al., 2007). Subclinical social anxiety has been associated with an enhancement of P1 during a task involving passive viewing of artificial and natural faces (Muhlberger et al., 2009), with a more marked enhancement for emotional (angry, fearful or happy) as compared to neutral faces (McTeague et al., 2011). These results support the hypothesis of an amplification of early sensory attention (Hillyard et al., 1998), but the absence of a specific enhancement to threat also sustains the idea of a general hyper-vigilance in phobic patients (Eysenck, 1997).

Importantly, the P1 enhancement seems to be specifically correlated with social anxiety and not with trait-anxiety scores (Kolassa et al., 2009; Kolassa and Miltner, 2006), as suggested by Mogg and Bradley (2002) who argued that vigilance for faces is primarily a function of social anxiety, rather than trait anxiety. Accordingly, high trait-anxious individuals did not show enhanced P1 in response to face stimuli (Eldar et al., 2010; Holmes et al., 2009; Rossignol et al., 2008; Rossignol et al., 2005). However, they produced enhanced N2pc in response to angry faces (Fox et al., 2008) and increased P1 responses for targets replacing threatening pictures (Li et al., 2005). These results suggest that exogenous attention is captured by threat location in trait anxiety and indicate the necessity to distinguish the impact of trait and social anxiety on emotional processing.

The early attentional bias for threat in social phobia has also been evidenced by increased P2 amplitudes for angry faces as compared to neutral or happy expression (van Peer et al., 2010). The P2 has been functionally associated not only with sustained perceptual processing (Schupp et al., 2003; Schupp et al., 2004), but also with the evaluation of the emotional relevance of a visual stimulus (Carretié et al., 2001; Dennis and Chen, 2007). The P2 may also be enhanced by emotional categorisation, as shown by Kolassa et al. (2009) who reported an increase in the P2 amplitude when schematic faces were classified as neutral, as compared to happy, sad or angry. It can be argued that the classification was more difficult for ambiguous drawings, the P2 amplitude reflecting the complexity of this emotional appraisal. Hence, the enhancement of this component, also evidenced in high trait anxiety (Bar-Haim et al., 2005; Eldar et al., 2010), could mirror a greater mobilisation of attentional resources on motivationally significant stimuli (i.e. angry faces) in social phobic participants. However, social anxiety influence was not consistently observed on the P2 (Kolassa et al., 2009; Kolassa and Miltner, 2006) and may depend on several parameters, including the task and the stimuli.

Among later components indicating more strategic processes, the P3 is sensitive to task-relevance, arousal level, motivational significance, and the influence of these factors on cognitive resource allocation (MacNamara et al., 2009 ; Olofsson et al., 2008). Hence, if socially anxious individuals pay particular attention to threatening EFE, the P3 component should be enhanced in response to these stimuli. However, the current literature does not offer convincing evidence of P3 modulation by social anxiety (Staugaard, 2010). Some studies reported greater P3 for threatening faces (Moser et al., 2008) and positive correlations between social anxiety and peak voltage of P3 for angry but not for happy faces (Sewell et al., 2008). But several other studies did not report modulation of late positive ERP during the processing of EFE by individuals suffering from social anxiety (Rossignol et al., 2007; van Peer et al., 2010).

Finally, unsolved issues relate to the time course of the bias (see for instance Cisler and Koster, 2010; Mogg et al., 2008). One hypothesis suggests that socially anxious individuals may have difficulties disengaging their attention from threat-related material (Amir et al., 2003; Buckner et al., 2010; Moriya and Tanno, 2011). Indeed, the disengagement process has been defined by Posner and Petersen (1990) as a complementary process to that of orienting toward stimuli. Indeed, when a target is presented at a different location to the preceding cue, participants have to disengage from the cue location, move to the target location, and engage this new location. Previous studies have shown that highly anxious individuals may take longer to respond to a target when the cue stimulus is threatening than when it is neutral or positive (Fox, 2002; Fox et al., 2001; Georgiou et al., 2005; Salemink et al., 2007; Yiend and Mathews, 2001). Moreover, the facilitated responses to valid targets following threatening cues may arise not only from increased vigilance towards a threat, but also from difficulty in disengaging from the threat location, or from a combination of both (Koster et al., 2004).

Disentangling these complementary processes and their modulation by anxiety is an important challenge and different procedures have been suggested. On the one hand, Koster et al. (2004) have recommended comparing responses following neutral and threatening cues: faster responses to the targets replacing the threat stimuli would reveal faster orientation towards threat, while slower responses to targets appearing in an invalid location would reflect difficulties in disengaging from a threat. On the other hand, Fox et al. (2001) have suggested using a single cue to observe disengaging abilities. When two faces are presented simultaneously, the participants have the opportunity to direct their attention successively to one or the other, and the role of a facilitated engagement is intertwined with the effect of a complicated disengagement (Fox, 2004; Fox et al., 2001).

Alternatively, the early initial vigilance may be followed by a subsequent strategic avoidance of threat-related stimuli (Amir

et al., 1998; Horley et al., 2003; Mansell et al., 1999; Vassilipoulos, 2005). This idea is supported by the results of Mueller et al. (2008), who investigated the electrophysiological correlates of the behavioural performances of social phobic patients in a dot-probe design. These authors reported enhanced P1 amplitudes to angry–neutral compared to happy–neutral pairs of faces with social phobia, but also decreased P1 amplitude to targets following emotional, as compared to neutral, faces. These results were interpreted within the framework of vigilance/avoidance theory, as the sign of an amplified early vigilance to faces, followed by a reduced visual processing of emotionally salient locations.

The present study was designed to examine the involvement of attentional engagement and disengagement in social anxiety. In order to decide between slower disengagement and faster engagement, we adapted the spatial-cueing design described by Fox et al. (2001) by considering the constrains of an electrophysiological study (Li et al., 2005; Pollack and Toley-Shell, 2003). Behavioural measures were combined with the assessment of ERPs described by Bar-Haim et al. (2005) (i.e. the P1 and P2 for cues, and the P1 and P3 for targets). The assessment of these particular components of early, middle and late latencies allowed not only sensory processes to be explored, but also subsequent attentional deployment during cue and target processing. The participants had to detect an arrow following a single cue presented on the right or the left hemifield. Faces displaying four types of emotion (anger, fear, disgust and happiness) were used as cues, in contrast to neutral faces. As the cue consisted of a single face, we postulated that all the participants would focus their attention on this cue (for a discussion on attentional capture by facial stimuli, see for instance Langton) et al., 2008. Therefore, we hypothesised that it would be easier to detect valid targets (i.e. those where the target appears in the same location as the cue) than invalid ones (when the target appears on the other side of the screen). Behaviourally, these effects would result in shorter reaction times for valid than for invalid targets. In line with previous ERP data, this should be indicated neurophysiologically by an enhanced P1 for valid as compared to invalid targets, and increased neural responses to targets preceded by negative cues (Pourtois et al., 2004; Santesso et al., 2008).

The main aim of the present study was to investigate what happens in participants with high levels of social anxiety. We hypothesised that they would show an enhancement of both P1 (Kolassa et al., 2009; Kolassa et al., 2007; Muhlberger et al., 2009), and P2 components (Bar-Haim et al., 2005; van Peer et al., 2010) for facial cues, as compared to participants displaying low levels of social anxiety. Moreover, the examination of neural response to targets may yield information about engagement and disengagement processes in social anxiety. First, we postulated an increased P1 for valid targets following negative cues, because of facilitated engagement; invalid targets require a rapid disengagement from the cue, so we hypothesised a decreased P1 for negatively-cued invalid trials in the case of disrupted disengagement from negative cues. Finally, we explored the P3 component to decide between the presence (Moser et al., 2008; Sewell et al., 2008) and absence (Rossignol et al., 2007; van Peer et al., 2010) of an influence of social anxiety on this component.

2. Results

2.1. Behavioural data

2.1.1. Correct responses

Analysis yielded a main effect of Validity on the percentage of correct responses ($F(1,26)=82.92$, $p<.001$), with better performance for validly-cued trials. There was also a main effect of Emotion ($F(4,104)=21.15$, $p<.001$) with the best performance for angry-cued targets (M=95%), followed by neutrality (M=93.1%) and disgust (M=91.7%). A significant Validity × Emotion interaction ($F(4,104)=25.21$, $p<.001$) indicated that the emotional effect was not apparent in the Valid condition ($F(4,108)=.65$, $p=.55$) but was clear in the Invalid one ($F(4,108)=36.03$, $p<.001$). Invalid targets following faces displaying anger were more effectively detected (94.9%) than those following disgust (M=87.6%, $p<.001$), neutrality (M=90.2%, $p<.001$), or happiness (M=92.5%, $p=.03$) (see Table 1). Performance was not influenced by Group ($F(1,26)=1.175$, $p=.29$), there being no significant difference between LSA and HSA.

2.1.2. Response latencies

Analysis showed a main effect of Validity on response latencies ($F(1,26)=12.08$, $p=.002$). Participants responded faster to validly-cued targets than to invalidly-cued ones. A main effect of Emotion ($F(4,104)=3.762$, $p=.01$) indicated slower reactions to targets following images of disgust than to those showing fear ($p=.02$) or anger ($p=.01$). There was also a significant interaction between Validity × Emotion ($F(4,104)=5.25$, $p=.001$) indicating that the disgust effect was evident in the invalid condition ($F(4,108)=7.88$, $p<.001$), but not in the valid condition ($F(4,108)=.51$, $p=.67$). The Group effect was not significant ($F(1,26)=.15$, $p=.70$).

2.2. ERP waveforms locked at the start of the facial cues (see Fig. 1 and Table 2).

2.2.1. P1 component

2.2.1.1. Latency. Analysis revealed no significant main effect involving Group ($F(1,26)=2.43$, $p=.131$) or Emotion ($F(4,104)=1.57$, $p=.20$), and no interaction between these variables ($F(4,104)=.72$, $p=.55$).

2.2.1.2. Amplitude. A main effect of Group ($F(1,26)=7$ .23, $p=.01$) was found, meaning that P1 was higher in the HSA group (2.286 μV) than in the LSA (0.789 μV) one (see Fig. 1). Emotion did not significantly modulate the P1 amplitudes ($F(4,104)=.97$, $p=.43$) and did not interact with Group ($F(4,104)=1.35$, $p=.26$).

2.2.2. P2 component

2.2.2.1. Latency. P2 latencies were modulated by Emotion ($F(4,104)=2.726$, $p=.03$): angry faces evoked earlier P2 (mean of 276 ms) than happy (287 ms, $p=.05$) or disgusted ones (292 ms, $p=.008$). The Group effect was not significant ($F(1,26)=.21$, $p=.65$) and did not interact with Emotion ($F(4,104)=1.12$, $p=.35$).

Table 1 – Mean response times (RT, in ms) and percentage accuracy (CR, in %) for target detection in each condition for LSA and HSA (standard deviations are presented between brackets).

		LSA		HSA		Mean	
		Valid trial	Invalid trials	Valid trial	Invalid trials	Valid trial	Invalid trials
Response latencies (ms)	Anger	541 (70.1)	567 (74.2)	558 (64.5)	570 (66.2)	550 (66.8)	569 (69.1)
	Disgust	536 (67.5)	575 (84.6)	555 (62.3)	577 (61.7)	546 (64.6)	576 (72.6)
	Fear	537 (65.8)	565 (80.9)	558 (65.6)	565 (60.5)	548 (65.5)	565 (70.0)
	Happiness	543 (69.0)	559 (77.5)	556 (59.4)	559 (59.6)	550 (63.5)	559 (67.8)
	Neutrality	542 (68.0)	566 (82.3)	555 (56.9)	569 (59.6)	549 (61.9)	568 (70.4)
Correct responses (%)	Anger	95.9 (4.1)	93.8 (5.9)	94.2 (5.7)	94.7 (5.8)	95.0 (5.0)	94.3 (5.7)
	Disgust	94.7 (3.7)	87.0 (5.1)	95.7 (5.7)	86.3 (8.6)	95.2 (4.8)	86.6 (7.1)
	Fear	94.7 (3.7)	93.0 (3.9)	95.7 (5.7)	93.2 (7.0)	95.2 (4.8)	93.1 (5.6)
	Happiness	95.3 (4.6)	92.7 (3.8)	96.2 (3.9)	91.5 (6.5)	95.7 (4.8)	92.1 (5.3)
	Neutrality	95.7 (4.3)	88.7 (3.8)	95.5 (5.2)	90.5 (6.6)	95.6 (4.7)	89.6 (5.4)

2.2.2.2. Amplitude. A main effect of Group ($F(1,26)=4.66$, $p=.04$) was found: a larger P2 wave was evoked in the HSA group (1.657 μV) than in the LSA (0.308 μV). The effect of Emotion was not significant ($F(4,104)=1.03$, $p=.39$) and did not interact with the Group ($F(4,104)=1.60$, $p=.22$).

2.3. *ERP waveforms locked at the onset of the probe arrow (see Fig. 2 and Table 3).*

2.3.1. *P1 component*

2.3.1.1. Latency. A main effect of Validity was found ($F(1,26)=5.31$, $p=.03$) with slightly earlier P1 for valid (153 ms) than for invalid (157 ms) targets. The Validity effects are shown in Fig. 2; see also Table 3. Emotion ($F(4,104)=1.92$, $p=.11$) did not significantly modulate P1 latency and did not interact with Validity ($F(4,104)=.86$, $p=.48$) or Group ($F(4,104)=.37$, $p=.11$). Despite a trend towards delayed P1 in HSA (158 ms vs. 152 ms for LSA), Group effect was not significant ($F(1,26)=3.02$, $p=.09$)

Table 2 – Mean amplitudes in μV (first line) and peak latencies in ms (second line) at the maximal point of temporal windows around the P1 and P2 components produced by HSA and LSA in response to the different categories of facial cues (S.D. between brackets). For each emotion category, the numbers between brackets present the mean and standard deviation of ERP trial numbers entered into grand-average event related potentials across participants.

Type of cue	P1		P2	
	LSA	HSA	LSA	HSA
Anger	1.0 (1.4)	2.67 (1.3)	0.40 (1.7)	1.97 (2.3)
(μ=80.4 ; SD=5.2)	148 (10)	150 (12)	274 (22)	278 (29)
Disgust	0.98 (1.65)	1.98 (1.8)	0.69 (2.3)	1.55 (2.1)
(μ=80.5 ; SD=5.9)	144 (10)	152 (13)	284 (23)	299 (42)
Fear	0.86 (1.8)	2.1 (1.4)	0.80 (1.7)	1.50 (2.9)
(μ=70.6 ; SD=7.2)	149 (8)	156 (15)	283 (37)	295 (42)
Happiness	1.06 (1.65)	2.2 (1.44)	0.42 (2.1)	1.42 (2.5)
(μ=79.8 ; SD=6.6)	146 (11)	153 (12)	287 (31)	237 (39)
Neutrality	0.38 (3.5)	2.39 (1.3)	1.06 (2.7)	1.83 (2.66)
(μ=79.8 ; SD=6.0)	148 (8)	154 (14)	284 (34)	280 (45)

2.3.1.2. Amplitude. There were no main effects of Validity ($F(1,26)=.29$, $p=.60$), Group ($F(1,26)=1.94$, $p=.18$), or Emotion ($F(4,104)=.32$, $p=.86$), and no significant interaction between these variables.

2.3.2. *P3 component*

2.3.2.1. Latency. Analyses did not reveal any significant effect of Validity ($F(1,26)=1.62$, $p=.21$), Emotion ($F(4,104)=.94$, $p=.43$), or Group ($F(1,26)=.77$, $p=.39$) on P3 latency. However, a significant interaction between Validity and Emotion ($F(4,104)=3.98$, $p=.008$) was evident, and could be further decomposed into separate ANOVA on valid and invalid conditions. First, Emotion influenced the P3 latencies in the invalid condition ($F(4,108)=2.73$, $p=.03$): the latencies were less for fearful cues (358 ms) as compared to happy (380 ms, $p=.014$) or disgusted (375 ms, $p=.03$) ones. On the other hand, Emotion had an effect in the valid condition ($F(4,108)=2.55$, $p=.04$), with longer latencies for fearful (381 ms) and angry cues (378 ms) than for happy (364 ms) ones ($p=.007$ and .02, respectively). Moreover, paired-*t*-tests comparing emotion cues in valid and invalid conditions showed significantly faster P3s for targets validly cued by happy faces ($t(27)=2.70$, $p=.01$) and invalidly cued by fearful faces ($t(27)=2.29$, $p=.03$). Other paired comparisons were not significant.

2.3.2.2. Amplitude. Emotion ($F(4,104)=1.16$, $p=.33$), and Group ($F(1,26)=.53$, $p=.47$) did not affect P3 amplitude and did not interact significantly with each other. Despite a tendency towards higher amplitudes for invalid targets (mean amplitude of 2.883 μV for invalid targets and 2.556 μV for valid trials), this effect did not reach the 0.05 significance level ($F(1,26)=3.42$, $p=.08$).

2.4. *Correlations*

P1 and P2 were recorded in response to faces, whereas P1 and P3 related to target processing. To test whether these constitute the successive steps of a continuum in cognitive processing, Pearson's correlations were performed between these components for both amplitude and latency. The results, shown in Table 4, confirm that the latencies and amplitudes of ERPs produced in response to cues and targets were linked: P1 latencies and amplitudes for cues and targets were highly

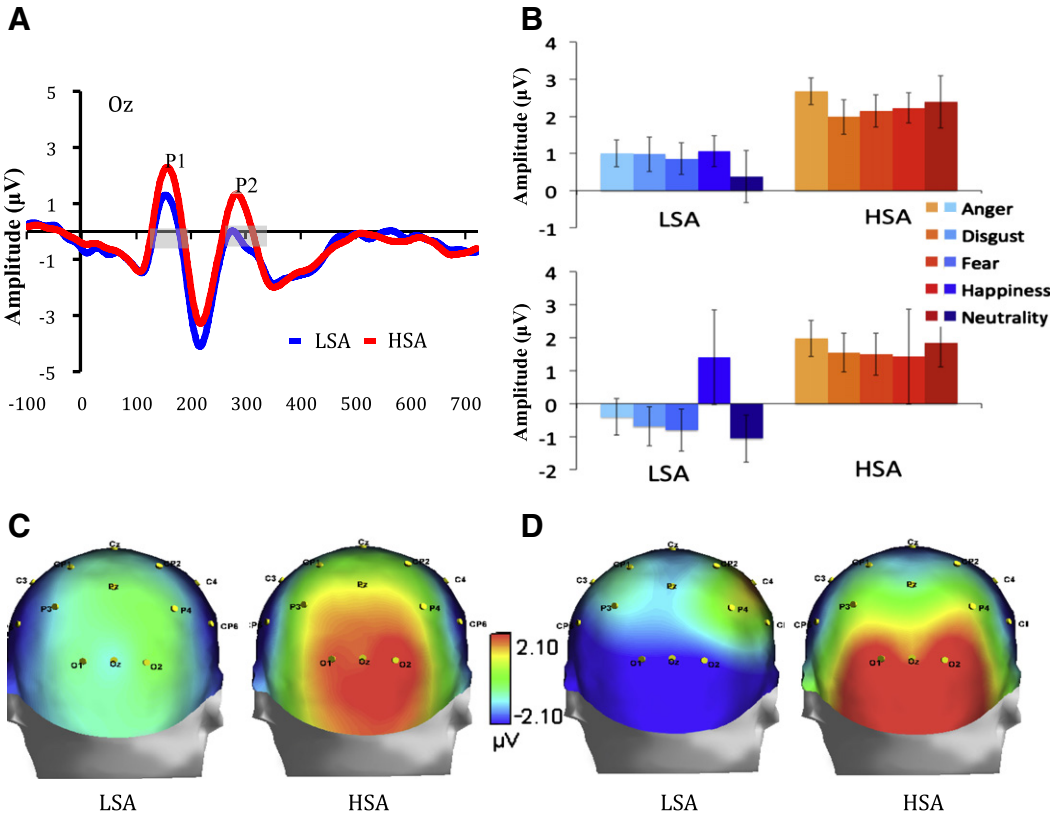

Fig. 1 – A. Grand mean baseline corrected ERP time courses at Oz with time windows of P1 and P2 indicated by grey boxes. B. Mean amplitudes and error bars for P1 (top) and P2 (down) for LSA and HSA. C. Scalp topographies of P1 (on the left) and P2 (on the right), averaged across all conditions.

associated, as were the amplitudes of P1 and P3 in response to targets.

2.5. *Regression analyses*

A stepwise multiple-regression analyses indicated that the P1 amplitude was predicted by FNE alone ($F(1,26)=4.49$, $p=.04$; $r^2=.15$; $\beta=.384$), as was the P2 amplitude ($F(1,26)=10.64$, $p=.003$; $r^2=.29$; $\beta=.539$). On the other hand, STAIT was the only predictor of P3 latencies ($F(1,26)=8.23$, $p=.008$; $r^2=.24$; $\beta=.490$).

3. Discussion

Our results showed the expected effect of Validity: performance was significantly better for valid targets (i.e. those presented in the same place as the cue). This cueing facilitation effect was reflected in shorter reaction times, higher rates of correct responses, and earlier P1 components. When the cue correctly indicated the target position, attention to this position was not modulated by facial expression. Conversely, when the target appeared on the opposite side to the cue, Emotion had an effect on behaviour: 1) the targets following an invalid angry EFE cue were more effectively discriminated, and gave rise to faster response times, 2) targets succeeding an invalid fear cue were also detected more quickly, but 3) targets following an invalid disgust cue were discriminated both more slowly and less efficiently. At a neurophysiological level, this emotional effect appeared on the P2 wave (which emerged earlier for faces expressing anger than for those expressing disgust), and on the P3 component. In invalid conditions, this wave appeared earlier for targets cued by fearful faces and later for those following disgusted faces, while happy cues gave rise to faster P3 responses in valid condition. However, the P1 responses to cues and targets were not modulated by facial expressions.

Our study also suggests that social anxiety modulates cognitive processes during the execution of the task. ERP data point to two major influences of social anxiety: both the P1 and the P2 components were enhanced among socially anxious participants. The occipital P1 component indexes perceptual processing, related to activity in the extrastriate visual cortex (Allison et al., 1999). The P1 amplitude has been reported to be modulated by Emotion (Batty and Taylor, 2003), and increased by threatening stimuli (Holmes et al., 2008; Streit et al., 1999). These data have been interpreted as reflecting a rapid orientation of visual attention towards significant stimuli (Vuilleumier and Pourtois, 2007). If enhanced P1 amplitudes mirrors increased visual attention, the general increase in perceptual processes for facial cues suggests that socially anxious participants pay particular attention to facial stimuli. This is in line with previous observations (Kolassa et al., 2009; Kolassa et al., 2007; Kolassa and Miltner, 2006; McTeague et al., 2011; Muhlberger et al., 2009). Moreover, the absence of an interaction with

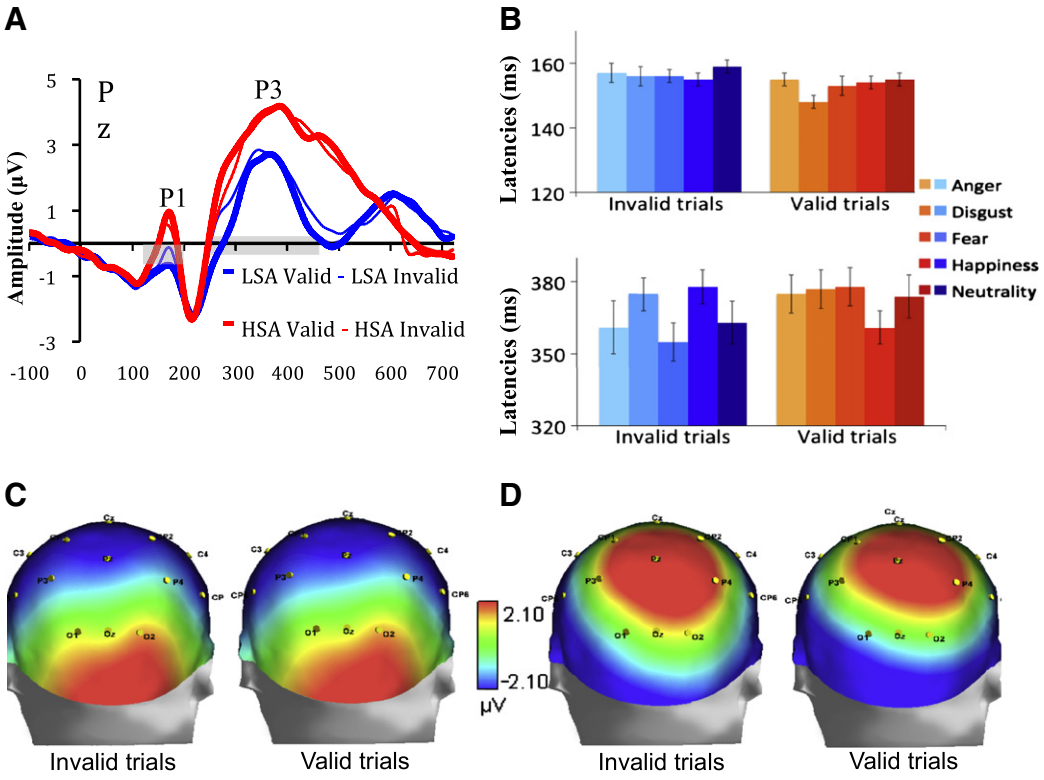

Fig. 2 – A. Grand mean baseline corrected ERP time courses at Pz with time windows of P1 and P3 indicated by grey boxes. B. Mean latencies and error bars for P1 (top) and P3 (down) for LSA and HSA. C. Scalp topographies of P1 (on the left) and P3 (on the right), averaged across all conditions.

Table 3 – Mean amplitudes in μV (first line) and peak latencies in ms (second line) at the maximal point of temporal windows around the P1 and P3 components produced by HSA and LSA in response to the targets cued by the different categories of faces (S.D. between brackets). For each condition, the numbers between brackets present the mean and standard deviation of ERP trial numbers entered into grand-average event related potentials across participants.

	Type of cue	P1		P3	
		LSA	HSA	LSA	HSA
Invalid	Anger	1.28 (1.5)	1.57 (1.47)	2.61 (2.1)	3.14 (2.8)
	(μ=30.9 ; SD=5.0)	153 (15)	162 (13)	360 (54)	362 (57)
	Disgust	1.21 (1.3)	1.97 (1.6)	2.52 (1.7)	2.94 (2.5)
	(μ=28.8 ; SD=5.1)	154 (14)	158 (14)	370 (41)	379 (31)
	Fear	1.17 (1.31)	2.11 (2.2)	2.66 (2.2)	3.46 (2.9)
	(μ=30.5 ; SD=5.3)	156 (10)	156 (15)	359 (43)	356 (46)
	Happiness	1.21 (1.4)	1.86 (2.1)	2.63 (1.65)	3.15 (2.8)
	(μ=30.1 ; SD=4.9)	153 (11)	157 (14)	378 (34)	368 (47)
	Neutrality	1.17 (1.7)	1.91 (1.6)	2.68 (1.8)	3.02 (2.6)
	(μ=29.5 ; SD=4.7)	156 (13)	162 (13)	364 (53)	368 (46)
Valid	Anger	.83 (1.9)	1.93 (1.7)	2.01 (1.5)	2.54 (2.6)
	(μ=41.4 ; SD=6.7)	152 (10)	156 (12)	364 (38)	356 (45)
	Disgust	1.47 (1.3)	1.81 (2.1)	2.22 (1.3)	2.83 (2.9)
	(μ=41.0 ; SD=6.1)	144 (10)	152 (13)	364 (36)	394 (45)
	Fear	.82 (1.7)	2.16 (1.9)	2.09 (1.7)	3.51 (3.4)
	(μ=41.5 ; SD=6.8)	149 (19)	156 (14)	369 (40)	392 (48)
	Happiness	1.34 (2.0)	1.73 (1.9)	2.53 (3.2)	2.66 (2.6)
	(μ=41.4 ; SD=6.3)	151 (10)	156 (12)	363 (36)	363 (41)
	Neutrality	.87 (1.5)	2.04 (2.0)	2.24 (1.4)	2.91 (2.5)
	(μ=41.5 ; SD=6.6)	151 (15)	158 (11)	364 (39)	383 (47)

Emotion sustains the hypothesis that socially anxious participants show a general interest in stimuli carrying important information about social interaction (Yoon and Zinbarg, 2008). Indeed, Moriya and Tanno (2009) recently suggested that high social anxiety may be associated with an enhanced exogenous attentional system and that socially anxious individuals are attracted to salient stimuli, regardless of their emotionality. Our data support that model, but it should be noted that the enhancement of perceptual processes has also been reported in other types of phobic syndromes, and such a state of hypervigilance towards incoming stimuli might be a feature of the cognitive functioning of phobic individuals (Kolassa et al., 2009; Kolassa et al., 2006). Future studies are warranted to determine whether this enhanced sensitivity to faces characterises social anxiety and is limited to facial stimulation (or to other stimuli with a social value), or whether it is generalised to all categories of visual stimuli.

The observation of a strongly increased P2 in response to face presentation among HSA individuals upholds the hypothesis that they show a particular interest in facial cues. The occipital P2 has been functionally associated with early attentional capture and mobilisation of resources (Bar-Haim et al., 2005; Mercado et al., 2006) and with the evaluation of the emotional relevance of a visual stimulus (Carretié et al., 2001; Dennis and Chen, 2007; Schutter et al., 2004). Increased P2 amplitudes were reported in healthy participants for fearful (Ashley et al., 2004) and angry face perception (Schutter et al., 2004), in high trait-anxious individuals (Bar-Haim et al., 2005; Eldar et al., 2010) and in individuals with high threat sensitivity processing irrelevant facial cues (Dennis and Chen, 2007). Conversely, Kolassa et al. (2009) reported a modulation by emotional classification but no effect of social anxiety on the P2. However, schematic faces were used in that study, which can carry a more limited emotional load than the one displayed by real expressive faces or emotional scene. Here, the P2 appeared slightly later than reported in previous studies, but the use of lateralised stimuli may explain this latency delay (Rigoulot et al., 2008). Nonetheless, the generalised enhancement of P2 might mirror a global capture of attention by face cues, and suggests that all face categories constitute salient stimuli in social anxiety.

The P2 amplitude was furthermore predicted by the FNE scores, higher social anxiety scores being associated with enhanced attentional capture by facial cues. This observation supports the model of a greater attentional orienting (on the P1 wave) followed by an intensified attentional fixation (on the P2 wave) (Fox, 2004). Moreover, since previous spatial cueing studies in high-trait anxiety individuals have reported a comparable P2 amplification but no effect on the P1 component (Bar-Haim et al., 2005; Eldar et al., 2010), it can be argued that the enhancement of perceptual processing of social cues is specific to social anxiety, while the subsequent capture of attention is more generic to all anxious states.

To sum up, the ERP waves associated with the processing of face cues argue for increased perceptual and attentional processes in socially anxious participants. A major contribution of our study is the indication that these enhancements in early processing are directly associated with social anxiety scores, as suggested previously (Kolassa et al., 2009; Kolassa and Miltner, 2006; Moriya and Tanno, 2011), but not with trait anxiety scores. We have already shown that elevated trait anxiety (characterised by scores over 56 on the STAI scale), is associated with later modifications of EFE processing (Rossignol et al., 2008; Rossignol et al., 2005) and this study consistently outlines a relationship between trait anxiety and P3 latency. However, we selected our participants according to their level of trait-anxiety, which has to be normal (under 56, Liebowitz, 1987) and avoid to explore the influence of higher level of trait-anxiety. Consequently, the present findings suggest that the effects of social anxiety and of trait anxiety should be considered independently but they have to be confirmed by studies on unselected samples.

Lastly, we investigated whether the intensified attentional fixation on faces has an effect on target-processing in socially anxious participants. The inspection of neural responses to targets allowed us to explore the process of disengagement, compared to attentional engagement. As the present experimental design used a single lateralised cue, we postulated that the first stage for all participants would be to orient their attentional resources towards this cue. Then, they had to disengage their attention from the cued location to process invalid targets, while valid-target processing was facilitated by sustained engagement with the cue location. Consequently, we postulated that a P1 enhancement for targets in the cued location only would suggest an enhanced engagement with the validly cued targets, while a diminished P1 in other locations could be attributed to disengagement disabilities. Here, the lack of a P1 effect suggests that sub-clinically socially-anxious individuals without elevated trait anxiety do not show a persistent effect of the initially enhanced orientation towards faces.

The late stages of cognitive processing showed no further influence of social anxiety, and behavioural performances were not modulated. These results confirm previous observations that social anxiety may be associated with early hypervigilance to social cues without bias in the subsequent processing (Gamble and Rapee, 2010; McTeague et al., 2011). However, further investigations are needed to explore the role of several factors such as the history of anxiety or disorder, and the co-morbidity of symptoms. It is conceivable that early modulations of perceptual processes are a feature of social anxiety in young individuals with a limited co-morbid symptomatology (see also McTeague et al., 2011), while more severe forms of social phobia may affect later cognitive processes and lead to significant

Table 4 – Pearson's correlations and level of significance (*.05; **.01; *.001) between mean amplitudes and peak latencies (italic) of ERP waves produced in response to cues and targets.**

		ERP waves for cues		ERP waves for targets	
		P1	P2	P1	P3
ERP waves for cues	P1		.281	.672**	.478*
			.174	*.878***	*–.060*
	P2	.281		–.011	.206
		.174		.159	.145
ERP waves for targets	P1	.672**	–.011		.577**
		.878	.159		*–.082*
	P3	.478*	.206	.577**	
		–.060	.145	*–.082*	

behavioural expressions (Kessler et al., 1999; Mueller et al., 2008).

In this context, the model of attentional control developed by Eysenck, Derakshan and their collaborators is particularly interesting (Derakshan et al., 2009b; Eysenck et al., 2007). The hypothesis of a lack of attentional control in anxiety has been supported by recent behavioural (Derakshan et al., 2009a; Fox et al., 2005; Ladouceur et al., 2009; Reinholdt-Dunne et al., 2009) and neuroimaging data (Bishop, 2009; Dennis and Chen, 2007; Savostyanov et al., 2009) and seems to apply to social anxiety (Moriya and Tanno, 2008). In addition to predicting impaired performances on a task (implying a high level of cognitive control), this model postulates that anxiety alters processing efficiency (observable through an enhanced effort and an increased use of processing resources) more than performance effectiveness (quality of performance), through the use of compensatory strategies. Our results suggest a similar effect in connection with sub-clinical social anxiety, where behavioural performances are not modified by the presence of an interaction with cognitive processing.

Some issues should be clarified in future studies. The major objective of this study was to identify how faces showing different emotions cued the discrimination of subsequent targets. Classical studies have shown that P1 amplitude is dependent on visual selective attention (Mangun and Hillyard, 1996), as enhanced P1s were recorded for targets appearing in the location where attention was focused (Coull, 1998; Hillyard et al., 1998). In the present study, the amplitudes of P1 in response to the targets were not modulated by the validity (i.e. the location) of the target: arrows occurring in the location cued by a face did not capture any more attentional resources than those appearing in a previously empty location. However, the duration of the interval between the cue and the target might be responsible for that lack of effect. The targets were presented after an interval varying from 200 ms to 400 ms in order to avoid the forward-masking effect (Broomfield and Turpin, 2005; Li et al., 2005) or the appearance of ERP component reflecting the expectation of the stimulus (e.g. CNV, Wright et al., 1995). By using a similar stimulus onset asynchrony (SOA), Li et al. (2005) observed a validity bias for threatening pictures on target-locked components and a differential influence of high and low trait anxiety. However, their cues consisted of emotional pictures, known to hold a higher arousal value than faces (Britton et al., 2006). Given the role of arousal in the allocation of spatial attention (Vogt et al., 2008), it is reasonable to suppose that attentional bias may be evident at a 200–400 SOA for highly arousing material, but that this interval may be too long for the orienting effect of emotional faces to persist.

This hypothesis is sustained by the results of Fox et al. (2008) who found enhanced P1 amplitude in the responses to targets replacing angry facial cues after a short interval (150 ms), but no effect after a longer SOA. These results suggest that threatening stimuli may lead to a brief enhancement of the sensory process with a rapid orientation of spatial attention to the threat location (Pourtois et al., 2004). Similarly, Moriya and Tanno (2011) reported disengagement difficulties when facial cues remained on the screen while targets were being processed, but no effect when there was a temporal gap between the end of the presentation of the cue and the beginning of that of the target.

The duration of the presentation of the stimulus also played an important role. Socially anxious individuals displayed longer response latencies than socially confident participants in response to angry faces presented for 300 ms or more, but no effect for shorter presentation times (i.e. 100 or 200 ms) (Moriya and Tanno, 2011, Experiment 2). Consequently, future studies should consider of several cued-target-onset asynchronies (CTOA) to investigate the temporality of the process of disengagement in anxious and non-anxious participants.

This factor may also be responsible for the absence of an influence of emotion on the target-locked P1 amplitude in our investigation, while previous studies reported enhanced P1 for targets cued by threatening faces (Fox et al., 2008; Pourtois et al., 2004; Santesso et al., 2008). The particular nature of our design can also explain these discrepancies. There are two major differences: first, we used a design with a single lateralised cue, emotional or neutral, while previous studies presented two cues, one neutral and one emotional, simultaneously; secondly, our research design included five different facial expressions, whereas previous studies only considered the difference between negative and positive cues. It is conceivable that the contrast between two emotions, one negative and one positive, is less marked when several negative emotions are considered. To investigate this hypothesis, already formulated by Calvo and Nummenmaa (2008), it would be interesting to replicate this design by contrasting emotions such as happiness and anger or disgust, which seem particularly relevant to social anxiety (Buckner et al., 2010; Rossignol et al., 2007).

In summary, the present research investigated the modulation of cognitive processing by the presentation of emotional faces as cues to detect neutral targets. While behavioural results and the late stages of cognitive processing were not modulated by social anxiety, perceptual process and attentional capture by facial cues were enhanced in socially anxious participants. These early modulations were independent of the emotional charge, suggesting a general salience of faces in social anxiety. Moreover, these results were specifically related to the level of social anxiety, which argues for a refinement of models to distinguish trait and social anxiety.

4. Experimental procedures

4.1. *Participants*

Thirty participants were selected from a group of 250 university students screened using the Fear of Negative Evaluation (FNE) scale (Watson and Friend, 1969). The presence of social anxiety was indicated by a score above 19 on the FNE scale, which corresponds to the threshold for clinical social phobia (see Douilliez and Philippot, 2003; Philippot and Douilliez, 2005). Trait anxiety and depression were also controlled: all the participants had to score under 56 on the Spielberger Trait Anxiety Inventory (STAI-B)[1] (Spielberger et al., 1983) and under 9

[1] State-Trait Anxiety Inventory scores traditionally distinguish the following levels of anxiety: less than 36: very low; 36–45: low; 46–55: normal; 56–65: high; more than 65: very high (Spielberger et al., 1983). Accordingly, we aimed to select participants with normal to low levels of trait anxiety.

on the 13-item Beck Inventory (Beck and Beamesdefer, 1974) to limit the co-morbid symptomatology. Using these criteria, we selected the 15 participants with the lowest scores and the 15 participants with the highest scores on the FNE scale to constitute the low and the high social anxiety groups (LSA and HSA respectively).

At the beginning of the session, participants also completed the Spielberger State Anxiety Inventory (STAI-A) (Spielberger et al., 1983). Two participants were excluded because of artefacts in their ERP recordings, so that twenty-eight participants remained in the study. All the participants were right-handed, between the ages of 18 and 24, with normal/corrected vision, and without any neurological diseases.

The characteristics of the two groups are reported in Table 5. The Groups did not differ in terms of age ($t(26)=2.04$, N.S.), depression ($t(26)=1.58$, N.S.) or trait anxiety ($t(26)=2.00$, N.S.). The HSA group scored higher than the LSA group on measurements of social anxiety ($t(26)=12.09$, $p<.001$) and state anxiety ($t(26)=2.73$, $p=.01$). Significant inter-correlations were observed between state, trait and social anxiety (STAIA-STAIB: $r=.44$, $p=.021$; STAIA-FNE: $r=.40$, $p=.03$; STAIB-FNE: $r=.39$, $p=.04$). Depressive affects were positively correlated with state ($r=.43$, $p=.02$) and trait anxiety ($r=.62$, $p<.001$), but not with social anxiety ($r=.29$, NS).

4.2. *Experimental design*

The stimuli comprised 30 black and white pictures of six different individuals (3 males and 3 females), taken from Beaupre and Hess's (2006) database, and displaying either neutrality, anger, disgust, happiness or fear. After trimming to exclude non-facial contours and hair, each facial stimulus was enclosed in a rectangular frame measuring 4×6 cm, subtending 4.5°×6.8°.

The target probe was a white arrow pointing up or down, with a length of 2 cm (visual angle: 2.86°), presented against a black background either at the location of the emotional face (valid trial), or on the other side (invalid trial). Probe type and location were counterbalanced through the task.

All stimuli were presented on a black background on a 17 in. computer Dell Inspiron with the software Eeprobe. Fig. 3 illustrates the experimental design. Each trial started by showing a 2×2 cm fixation cross in the centre of the screen for 200 ms, followed by a delay (blank screen) of 200 ms, and then by the face-cue. The face was presented either on the centre of the right or the left visual field for 200 ms, with an equal number of appearances on each side during the course of the experiment. Between 200 and 400 ms after the disappearance of the cue, the probe was presented for 200 ms. The probe could either replace the face or appear on the previously empty side of the screen. A black screen was then displayed to indicate an inter-trial interval, lasting for 1000 ms. As a consequence, participants had 1200 ms to provide their response to each trials. Six blocks were created, each containing 70 trials (40 valid trials and 30 invalid trials). The participants were asked to press one of two response buttons to indicate the orientation of the arrow ("up" or "down"), and they were told that speed was important but not at the cost of accuracy.

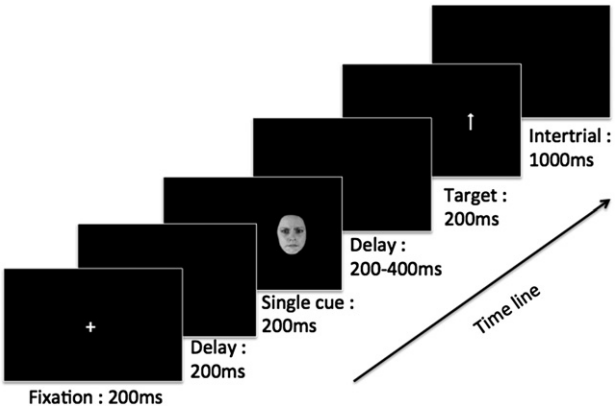

Fig. 3 – Sequence of the events in the spatial cueing task.

Participants sat in a dark room on a chair placed at 30 cm from the screen with their head restrained by a chin rest. Before starting the task, practice trials were used to familiarise the participants with the procedure. Then, they were presented with the 12 blocks (6 blocks repeated twice) of 70 trials (the entire experiment comprised 840 trials, 480 valid and 360 invalid). Each participant was tested individually in a single session lasting approximately 1 h.

A variety of measures was used to assess behavioural performance. The presentation software automatically calculated reaction times and accuracy for each target, and we computed the percentage of correct responses (errors could be an erroneous response, an absence of response within the given time, or a response occurring before the target presentation or less than 200 ms after its onset) and the average RT for correct responses.

4.3. *EEG data acquisition*

The EEG (electroencephalograph) recordings were performed with 32 electrodes mounted in an electrode Quick-Cap with the standard 10–20 International System and intermediate positions. Recordings were made with a linked mastoid physical reference and were re-referenced by using a common average (Bertrand et al., 1985). The EEG was amplified by battery-operated A.N.T.® amplifiers with a gain of 30,000 and a band-pass of 0.01–100 Hz. The impedance of all the electrodes was kept below 5 kΩ. The EEG was recorded continuously (sampling rate 512 Hz, A.N.T. Eeprobe software) and trials containing EOG (electrooculograph) artefacts (mean of 10%) were eliminated off-line by computing an average artefact response based on a percentage of the maximum eye-movement potential. Epochs beginning 100 ms prior to the onset of the stimulus and continuing for 700 ms were created. Codes synchronised with

Table 5 – Participants' characteristics as a function of group assignment (standard deviations in parentheses).

	HSA (N=14)	LSA (N=14)
Age	19.6 (1.4)	21.6 (3.2)
Ratio male/female	03/11	05/09
STAI-A	48.8 (3.9)	45.1 (3.4)
STAI-B	47.7 (5.2)	44 (4.5)
FNE	22.9 (3.3)	6.1 (3.9)
Beck	4.2 (3.6)	2.3 (2.8)

stimulus delivery were used to selectively average the epochs associated with different stimulus types. First, the ERPs were averaged separately for the different combinations of experimental variables: Emotion (neutral, angry, fearful, happy, or disgusted face), Laterality of presentation (left or right) and target Validity (valid or invalid). Since lateralisation effects were not a critical aspect of the present study, we then aggregated the ERP waveforms of presentations in the left and the right visual fields, and retained only two experimental factors, namely Emotion and Validity.[2] The average number of trials in the ERPs is shown in Tables 2 and 3.

Analyses focused on the ERP components elicited by cues and targets, separately (see Bar-Haim et al., 2005; Perchet et al., 2001). First, the overall averaged ERPs were examined to define temporal windows on interest electrodes kept constant for all conditions and participants. Second, an algorithm was used to identify the maximum positive or negative value within the specified time window on these interest electrodes, and that point was identified as the peak latency (see for instance Pollack and Toley-Shell, 2003). Third, mean amplitudes were calculated for each defined window. For cue-evoked components, two ERPs described in the literature focusing on cued-target designs (Bar-Haim et al., 2005; Perchet and Garcia-Larrea, 2000; Perchet et al., 2001) were selected for the analyses: (a) P1, the first positive deflection occurring on occipital sites between 120 and 170 ms after the cue presentation and measured on Oz; and (b) the P2, a positive deflection peaking at occipital sites between 250 and 320 ms and measured on Oz (the topographic map voltages are shown in Fig. 1). For target stimuli processing, the two ERPs described by Bar-Haim et al., 2005) were measured on trials associated with a correct response: (a) the P1, peaking on occipital sites between 110 and 180 ms and measured on Oz, and (b) the P3 component, peaking on parietal sites and averaged on Pz between 250 and 450 ms after target presentation (see Fig. 2).

4.4. *Statistical analysis*

Statistical analyses were computed using the Statistical Package for the Social Sciences, 17th version (SPSS 17.0). In the first step, the mean amplitudes and latencies of the ERPs were subjected to repeated measures analysis of variance (ANOVA) with Group (LSA and HSA) as the between-subjects factor, and Validity (valid or invalid) and Emotion (neutral, happiness, fear, anger and disgust) as within-subject factors. The reported *p*-levels of all the other ANOVAs were corrected for violations of the sphericity assumption using the Greenhouse–Geisser (1959) epsilon correction. Simple effects were explored throughout, and a Bonferroni correction for multiple comparisons was applied to all the *t*-tests.

In the second step, Pearson correlation coefficients were used to explore the relation between the amplitudes and latencies of the ERPs. To reduce the number of analyses, the mean amplitude and latency values were computed for each component (by collapsing the Validity and Emotion factors). In order to control for multiple comparisons, rejection of the null hypothesis was controlled by Holm's sequential rejection algorithm (Kolassa et al., 2006). In addition, a set of four exploratory stepwise linear multiple-regression analyses was carried out to identify the relationship between the psychometric factors (FNE, STAIT, STAIS, and Beck scores) and the ERP parameters (P1, P2 and P3 amplitudes). The variance inflation factor (VIF) was controlled as a guarantee against multicollinearity.

The alpha level of significance was set at 0.05 throughout.

[2] Analyses including Visual Field were computed before to aggregate that factor. Visual Field did not influence P1 amplitudes in response to faces ($F(1,26)=2.68$, $p=.11$) or targets ($F(1,26)=1.682$, $p=.20$). By contrast, P2 ($F(1,26)=6.40$, $p=.02$) and P3 ($F(1,26)=7.72$, $p=.01$) were enhanced for stimuli presented on the left hemifield. Concerning latencies, Visual Field did not modulate P1 ($F(1,26)=1.71$, $p=.20$) and P2 ($F(1,26)=3.11$, $p=.09$) in response to faces. Conversely, analyses showed earlier P1 for targets presented on the right hemifield ($F(1,26)=11.455$, $p<.01$), and earlier P3 for those appearing on the left hemifield ($F(1,26)=4.92$, $p=.04$). However, Visual Field did not interact with the other experimental factors, justifying our decision to simplify the analyses by collapsing that factor.

Acknowledgments

Mandy Rossignol is a Postdoctoral Researcher and Salvatore Campanella is a Research Associate at the National Fund for Scientific Research (F.N.R.S., Belgium). The authors are grateful to Joffrey Goumet and Pierre Maurage (Psychopathology and Neuroscience Laboratory, Université Catholique de Louvain) for their valuable help during data analyses, to Nathalie Lefèvre (Statistical Methodology and Computing Service, Université Catholique de Louvain) for statistical support, to Adriano Boremanse (Face Categorisation Laboratory, Université Catholique de Louvain) for his assistance in the representations of brain maps, and to the 'Centre de Traduction de Louvain' for its careful revision of this text.

REFERENCES

Allison, T., Puce, A., Spencer, D.D., McCarthy, G., 1999. Electrophysiological studies of human face perception. I: Potentials generated in occipitotemporal cortex by face and non-face stimuli. Cereb Cortex 9 (5), 415–430.

Amir, N., Elias, J., Klumpp, H., Przeworski, A., 2003. Attentional bias to threat in social phobia: facilitated processing of threat or difficulty disengaging attention from threat? Behav Res Ther 41 (11), 1325–1335.

Amir, N., Foa, E.B., Coles, M.E., 1998. Automatic activation and strategic avoidance of threat-relevant information in social phobia. Journal of Abnormal Psychology 107 (2), 285–290.

Ashley, V., Vuilleumier, P., Swick, D., 2004. Time course and specificity of event-related potentials to emotional expressions. Neuroreport 15 (1), 211–216.

Bar-Haim, Y., Lamy, D., Glickman, S., 2005. Attentional bias in anxiety: a behavioral and ERP study. Brain Cogn 59 (1), 11–22.

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M.J., van Ijzendoorn, M.H., 2007. Threat-related attentional bias in anxious and nonanxious individuals: a meta-analytic study. Psychological Bulletin 133 (1), 1–24.

Batty, M., Taylor, M.J., 2003. Early processing of the six basic facial emotional expressions. Brain Res Cogn Brain Res 17 (3), 613–620.

Beaupre, M.G., Hess, U., 2006. An ingroup advantage for confidence in emotion recognition judgments: the moderating effect of

familiarity with the expressions of outgroup members. Pers Soc Psychol Bull 32 (1), 16–26.
Beck, A.T., Beamesdefer, A., 1974. Assessment of depression : the Depression Inventory. Psychological measurements in psychopharmacology. Mod. Probl. Pharmacopsychiatry 7, 151–159.
Bertrand, O., Perrin, F., Pernier, J., 1985. A theoretical justification of the average reference in topographic evoked potential studies. Electroencephalogr Clin Neurophysiol 62 (6), 462–464.
Bishop, S.J., 2009. Trait anxiety and impoverished prefrontal control of attention. Nat Neurosci 12 (1), 92–98.
Britton, J.C., Phan, K.L., Taylor, S.F., Welsh, R.C., Berridge, K.C., Liberzon, I., 2006. Neural correlates of social and nonsocial emotions: an fMRI study. Neuroimage 31 (1), 397–409.
Broomfield, N.M., Turpin, G., 2005. Covert and overt attention in trait anxiety: a cognitive psychophysiological analysis. Biol Psychol 68 (3), 179–200.
Buckner, J.D., Maner, J.K., Schmidt, N.B., 2010. Difficulty disengaging attention from social threat in social anxiety. Cognit Ther Res 34 (1), 99–105.
Calvo, M.G., Nummenmaa, L., 2008. Detection of emotional faces: salient physical features guide effective visual search. J Exp Psychol Gen 137 (3), 471–494.
Carretié, L., Martín-Loeches, M., Hinojosa, J.A., Mercado, F., 2001. Emotion and attention interaction studied through event-related potentials. J Cogn Neurosci 13 (8), 1109–1128.
Cisler, J. M., & Koster, E. H. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: an integrative review. [Review]. *Clinical Psychology Review, 30*(2), 203–216.
Coull, J.T., 1998. Neural correlates of attention and arousal: insights from electrophysiology, functional neuroimaging and psychopharmacology. Prog Neurobiol 55 (4), 343–361.
Dennis, T.A., Chen, C.C., 2007. Neurophysiological mechanisms in the emotional modulation of attention: the interplay between threat sensitivity and attentional control. Biol Psychol 76 (1–2), 1–10.
Derakshan, N., Ansari, T.L., Hansard, M., Shoker, L., Eysenck, M.W., 2009a. Anxiety, inhibition, efficiency, and effectiveness. An investigation using antisaccade task. Exp Psychol 56 (1), 48–55.
Derakshan, N., Smyth, S., Eysenck, M.W., 2009b. Effects of state anxiety on performance using a task-switching paradigm: an investigation of attentional control theory. Psychon Bull Rev 16 (6), 1112–1117.
Douilliez, C., Philippot, P., 2003. Biais dans l'évaluation volontaire de stimuli verbaux et nonverbaux: Effet de l'anxiété sociale. Revue Francophone de Clinique Comportementale et Cognitive 8, 12–18.
Eldar, S., Yankelevitch, R., Lamy, D., Bar-Haim, Y., 2010. Enhanced Neural Reactivity and Selective Attention to Threat in Anxiety. Biol Psychol.
Eysenck, M.W., 1997. Anxiety and Cognition: An Unified Theory. Erlbaum, Hove.
Eysenck, M.W., Derakshan, N., Santos, R., Calvo, M.G., 2007. Anxiety and cognitive performance: attentional control theory. Emotion 7 (2), 336–353.
Fox, E., 2002. Processing emotional facial expressions: the role of anxiety and awareness. Cogn Affect Behav Neurosci 2 (1), 52–63.
Fox, E., 2004. Maintenance or capture of attention in anxiety-related biases. In: Yiend, J. (Ed.), Cognition, Emotion, and Psychopathology: Theoritical, Empirical and Clinical Directions. Cambridge University Press, Cambridge, U.K., pp. 86–105.
Fox, E., Derakshan, N., Shoker, L., 2008. Trait anxiety modulates the electrophysiological indices of rapid spatial orienting towards angry faces. Neuroreport 19 (3), 259–263.
Fox, E., Russo, R., Bowles, R., Dutton, K., 2001. Do threatening stimuli draw or hold visual attention in subclinical anxiety? J Exp Psychol Gen 130 (4), 681–700.
Fox, E., Russo, R., Dutton, K., 2002. Attentional bias for threat: evidence for delayed disengagement from emotional faces. Cogn Emot 16, 355–379.
Fox, E., Russo, R., Georgiou, G.A., 2005. Anxiety modulates the degree of attentive resources required to process emotional faces. Cogn Affect Behav Neurosci 5 (4), 396–404.
Gamble, A.L., Rapee, R.M., 2010. The time-course of attention to emotional faces in social phobia. J Behav Ther Exp Psychiatry 41 (1), 39–44.
Georgiou, G.A., Bleakley, C., Hayward, J., Russo, R., Dutton, K., Eltiti, S., et al., 2005. Focusing on fear: attentional disengagement from emotional faces. Vis cogn 12 (1), 145–158.
Hillyard, S.A., Anllo-Vento, L., 1998. Event-related brain potentials in the study of visual selective attention. Proc Natl Acad Sci U S A 95 (3), 781–787.
Hillyard, S.A., Vogel, E.K., Luck, S.J., 1998. Sensory gain control (amplification) as a mechanism of selective attention: electrophysiological and neuroimaging evidence. Philosophical Transactions of the Royal Society of London Series B-Biological Sciences 353 (1373), 1257–1270.
Hirsch, C. R., & Clark, D. M. (2004). Information-processing bias in social phobia. [Review]. Clinical Psychology Review, 24(7), 799–825.
Holmes, A., Nielsen, M.K., Green, S., 2008. Effects of anxiety on the processing of fearful and happy faces: an event-related potential study. Biol Psychol 77 (2), 159–173.
Holmes, A., Nielsen, M.K., Tipper, S., Green, S., 2009. An electrophysiological investigation into the automaticity of emotional face processing in high versus low trait anxious individuals. Cogn Affect Behav Neurosci 9 (3), 323–334.
Holmes, A., Vuilleumier, P., Eimer, M., 2003. The processing of emotional facial expression is gated by spatial attention: evidence from event-related brain potentials. Brain Res Cogn Brain Res 16 (2), 174–184.
Horley, K., Williams, L.M., Gonsalvez, C., Gordon, E., 2003. Social phobics do not see eye to eye: a visual scanpath study of emotional expression processing. Journal of Anxiety Disorders 17 (1), 33–44.
Kessler, R.C., Stang, P., Wittchen, H.U., Stein, M., Walters, E.E., 1999. Lifetime co-morbidities between social phobia and mood disorders in the US National Comorbidity Survey. Psychol. Med. 29 (3), 555–567.
Kolassa, I.T., Kolassa, S., Bergmann, S., Lauche, R., Dilger, S., Miltner, W.H.R., et al., 2009. Interpretive bias in social phobia: an ERP study with morphed emotional schematic faces. Cognition & Emotion 23 (1), 69–95.
Kolassa, I.T., Kolassa, S., Musial, F., Miltner, W.H.R., 2007. Event-related potentials to schematic faces in social phobia. Cognition and Emotion 21 (8), 1721–1744.
Kolassa, I.T., Miltner, W.H., 2006. Psychophysiological correlates of face processing in social phobia. Brain Res 1118 (1), 130–141.
Kolassa, I.T., Musial, F., Kolassa, S., Miltner, W.H., 2006. Event-related potentials when identifying or color-naming threatening schematic stimuli in spider phobic and non-phobic individuals. BMC Psychiatry 6, 38.
Koster, E.H., Crombez, G., Verschuere, B., De Houwer, J., 2004. Selective attention to threat in the dot probe paradigm: differentiating vigilance and difficulty to disengage. Behav Res Ther 42 (10), 1183–1192.
Ladouceur, C.D., Silk, J.S., Dahl, R.E., Ostapenko, L., Kronhaus, D.M., Phillips, M.L., 2009. Fearful faces influence attentional control processes in anxious youth and adults. Emotion 9 (6), 855–864.
Langton, S.R., Law, A.S., Burton, A.M., Schweinberger, S.R., 2008. Attention capture by faces. Cognition 107 (1), 330–342.
Li, X., Li, X., Luo, Y.J., 2005. Anxiety and attentional bias for threat: an event-related potential study. Neuroreport 16 (13), 1501–1505.

Liebowitz, M.R., 1987. Social phobia. Modern Problems in Pharmacopsychiatry 22, 141–173.
Luck, S.J., Hillyard, S.A., Mouloua, M., Hawkins, H.L., 1996. Mechanisms of visual–spatial attention: resource allocation or uncertainty reduction? J Exp Psychol Hum Percept Perform 22 (3), 725–737.
MacLeod, C., Mathews, A., Tata, P., 1986. Attentional bias in emotional disorders. J Abnorm Psychol 95 (1), 15–20.
MacNamara, A., Foti, D., Hajcak, G., 2009. Tell me about it: neural activity elicited by emotional pictures and preceding descriptions. Emotion 9 (4), 531–543.
Mangun, G.R., Hillyard, S.A., 1996. Selective attention: mechanisms and models. In: Rugg, M.D., Coles, M.G.H. (Eds.), Electrophysiology of Mind: Event-related Brain Potentials and Cognition. Oxford Psychology Press, Oxford.
Mansell, W., Clark, D.M., Ehlers, A., Chen, Y.P., 1999. Social anxiety and attention away from emotional faces. Cognition & Emotion 13 (6), 673–690.
McTeague, L.M., Shumen, J.R., Wieser, M.J., Lang, P.J., Keil, A., 2011. Social vision: sustained perceptual enhancement of affective facial cues in social anxiety. Neuroimage 54 (2), 1615–1624.
Mercado, F., Carretié, L., Tapia, M., Gomez-Jarabo, G., 2006. The influence of emotional context on attention in anxious subjects: neurophysiological correlates. J Anxiety Disord 20 (1), 72–84.
Mogg, K., Bradley, B.P., 1999. Orienting of attention to threatening facial expressions presented under conditions of restricted awareness. Cognition & Emotion 13 (6), 713–740.
Mogg, K., Bradley, B.P., 2002. Selective orienting of attention to masked threat faces in social anxiety. Behav Res Ther 40 (12), 1403–1414.
Mogg, K., Holmes, A., Garner, M., Bradley, B.P., 2008. Effects of threat cues on attentional shifting, disengagement and response slowing in anxious individuals. Behav Res Ther 46 (5), 656–667.
Mogg, K., Philippot, P., Bradley, B.P., 2004. Selective attention to angry faces in clinical social phobia. J Abnorm Psychol 113 (1), 160–165.
Moriya, J., Tanno, Y., 2008. Relationships between negative emotionality and attentional control in effortful control. Personality and Individual Differences 44 (6), 1348–1355.
Moriya, J., Tanno, Y., 2009. Competition between endogenous and exogenous attention to nonemotional stimuli in social anxiety. Emotion 9 (5), 739–743.
Moriya, J., Tanno, Y., 2011. The time course of attentional disengagement from angry faces in social anxiety. Journal of Behavior Therapy and Experimental Psychiatry 42 (1), 122–128.
Moser, J.S., Huppert, J.D., Duval, E., Simons, R.F., 2008. Face processing biases in social anxiety: an electrophysiological study. Biol Psychol 78 (1), 93–103.
Mueller, E. M., Hofmann, S. G., Santesso, D. L., Meuret, A. E., Bitran, S., & Pizzagalli, D. A. (2008). Electrophysiological evidence of attentional biases in social anxiety disorder. Psychol Med, 1–12.
Muhlberger, A., Wieser, M.J., Herrmann, M.J., Weyers, P., Troger, C., Pauli, P., 2009. Early cortical processing of natural and artificial emotional faces differs between lower and higher socially anxious persons. J Neural Transm 116 (6), 735–746.
Olofsson, J.K., Nordin, S., Sequeira, H., Polich, J., 2008. Affective picture processing: an integrative review of ERP findings. Biol Psychol 77 (3), 247–265.
Perchet, C., Garcia-Larrea, L., 2000. Visuospatial attention and motor reaction in children: an electrophysiological study of the "Posner" paradigm. Psychophysiology 37 (2), 231–241.
Perchet, C., Revol, O., Fourneret, P., Mauguière, F., Garcia-Larrea, L., 2001. Attention shifts and anticipatory mechanisms in hyperactive children: an ERP study using the Posner paradigm. Biol Psychiatry 50 (1), 44–57.
Philippot, P., Douilliez, C., 2005. Social phobics do not misinterpret facial expression of emotion. Behav Res Ther 43 (5), 639–652.
Pishyar, R., Harris, L.M., Menzies, R.G., 2008. Responsiveness of measures of attentional bias to clinical change in social phobia. Cognition and Emotion 22 (7), 1209–1227.
Pollack, S.D., Toley-Shell, S.A., 2003. Selective attention to facial emotion in physically abused children. Journal of Abnormal Psychology 112 (3), 323–338.
Posner, M.I., Petersen, S.E., 1990. The attention system of the human brain. Annual Review of Neuroscience 13, 25–42.
Posner, M.I., Snyder, C.R.R., Davidson, B.J., 1980. Attention and the detection of signals. Journal of Experimental Psychology: General 109, 160–174.
Pourtois, G., Grandjean, D., Sander, D., Vuilleumier, P., 2004. Electrophysiological correlates of rapid spatial orienting towards fearful faces. Cereb Cortex 14 (6), 619–633.
Reinholdt-Dunne, M.L., Mogg, K., Bradley, B.P., 2009. Effects of anxiety and attention control on processing pictorial and linguistic emotional information. Behav Res Ther 47 (5), 410–417.
Rigoulot, S., Delplanque, S., Despretz, P., Defoort-Dhellemmes, S., Honore, J., Sequeira, H., 2008. Peripherally presented emotional scenes: a spatiotemporal analysis of early ERP responses. Brain Topogr 20 (4), 216–223.
Rossignol, M., Anselme, C., Vermeulen, N., Philippot, P., & Campanella, S, 2007. Categorical perception of anger and disgust facial expression is affected by non-clinical social anxiety: an ERP study. Brain Res 1132 (1), 166–176.
Rossignol, M., Philippot, P., Crommelinck, M., & Campanella, S, 2008. Visual processing of emotional expressions in mixed anxious-depressed subclinical state: an event-related potential study on a female sample. Neurophysiol Clin 38 (5), 267–275.
Rossignol, M., Philippot, P., Douilliez, C., Crommelinck, M., & Campanella, S, 2005. The perception of fearful and happy facial expression is modulated by anxiety: an event-related potential study. Neurosci Lett 377 (2), 115–120.
Salemink, E., van den Hout, M.A., Kindt, M., 2007. Selective attention and threat: quick orienting versus slow disengagement and two versions of the dot probe task. Behav Res Ther 45 (3), 607–615.
Santesso, D.L., Meuret, A.E., Hofmann, S.G., Mueller, E.M., Ratner, K.G., Roesch, E.B., et al., 2008. Electrophysiological correlates of spatial orienting towards angry faces: a source localization study. Neuropsychologia 46 (5), 1338–1348.
Savostyanov, A.N., Tsai, A.C., Liou, M., Levin, E.A., Lee, J.D., Yurganov, A.V., et al., 2009. EEG-correlates of trait anxiety in the stop-signal paradigm. Neurosci Lett 449 (2), 112–116.
Schupp, H.T., Junghofer, M., Weike, A.I., Hamm, A.O., 2003. Attention and emotion: an ERP analysis of facilitated emotional stimulus processing. Neuroreport 14 (8), 1107–1110.
Schupp, H.T., Öhman, A., Junghofer, M., Weike, A.I., Stockburger, J., Hamm, A.O., 2004. The facilitated processing of threatening faces: an ERP analysis. Emotion 4 (2), 189–200.
Schutter, D.J., de Haan, E.H., van Honk, J., 2004. Functionally dissociated aspects in anterior and posterior electrocortical processing of facial threat. Int J Psychophysiol 53 (1), 29–36.
Sewell, C., Palermo, R., Atkinson, C., McArthur, G., 2008. Anxiety and the neural processing of threat in faces. Neuroreport 19 (13), 1339–1343.
Spielberger, C.D., Gorsuch, R.L., Lusthene, R.E., 1983. Manual for the State-Trait Anxiety Inventory. Consulting Psychologist Press, Palo Alto.
Staugaard, S.R., 2010. Threatening faces and social anxiety: a literature review. Clin Psychol Rev 30 (6), 669–690.
Streit, M., Ioannides, A.A., Liu, L., Wolwer, W., Dammers, J., Gross, J., et al., 1999. Neurophysiological correlates of the recognition of facial expressions of emotion as revealed by magnetoencephalography. Brain Res Cogn Brain Res 7 (4), 481–491.
Telzer, E.H., Mogg, K., Bradley, B.P., Mai, X., Ernst, M., Pine, D.S., et al., 2008. Relationship Between Trait Anxiety, Prefrontal Cortex, and Attention Bias to Angry Faces in Children and Adolescents. Biol Psychol.

van Peer, J.M., Spinhoven, P., Roelofs, K., 2010. Psychophysiological evidence for cortisol-induced reduction in early bias for implicit social threat in social phobia. Psychoneuroendocrinology 35 (1), 21–32.

Vassilipoulos, S.P., 2005. Social anxiety and the vigilance–avoidance pattern of attentional processing. Behavioral and Cognitive Psychotherapy 33, 13–24.

Vogt, J., De Houwer, J., Koster, E.H., Van Damme, S., Crombez, G., 2008. Allocation of spatial attention to emotional stimuli depends upon arousal and not valence. Emotion 8 (6), 880–885.

Vuilleumier, P., Pourtois, G., 2007. Distributed and interactive brain mechanisms during emotion face perception: evidence from functional neuroimaging. Neuropsychologia 45 (1), 174–194.

Watson, D., Friend, R., 1969. Measurement of social evaluative anxiety. Journal of Consulting and Clinical Psychology 33, 448–457.

Wright, M.J., Geffen, G.M., Geffen, L.B., 1995. Event related potentials during covert orientation of visual attention: effects of cue validity and directionality. Biol Psychol 41 (2), 183–202.

Yiend, J., Mathews, A., 2001. Anxiety and attention to threatening pictures. Q J Exp Psychol A 54 (3), 665–681.

Yoon, K.L., Zinbarg, R.E., 2008. Interpreting neutral faces as threatening is a default mode for socially anxious individuals. J Abnorm Psychol 117 (3), 680–685.