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Emotional context influences access of visual stimuli to anxious individuals' awareness

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ABSTRACT

Anxiety has been associated with enhanced unconscious processing of threat and attentional biases towards threat. Here, we focused on the phenomenology of perception in anxiety and examined whether threat-related material more readily enters anxious than non-anxious individuals' awareness. In six experiments, we compared the stimulus exposures required for each anxiety group to become objectively or subjectively aware of masked facial stimuli varying in emotional expression. Crucially, target emotion was task irrelevant. We found that high trait-anxiety individuals required less sensory evidence (shorter stimulus exposure times) to become aware of the face targets. This anxiety-based difference was observed for fearful faces in all experiments, but with non-threat faces, it emerged only when these were presented among threatening faces. Our findings suggest a prominent role for affective context in high-anxiety individuals' conscious perception of visual stimuli. Possible mechanisms underlying the influence of context in lowering awareness thresholds in anxious individuals are discussed.

1. Introduction

Biases in automatic, preattentive processing of threat-related material have been assigned a prominent role in the etiology and maintenance of anxiety disorders (e.g., Beck & Clark, 1997; LeDoux, 1996; Mathews & MacLeod, 2002; Mogg & Bradley, 1998; Williams, Watts, MacLeod, & Mathews, 1997). Information-processing models of fear suggest that the emotional valence of incoming information is automatically assessed by an early threat detection device (Affective Decision Mechanism, Williams et al., 1997; Valence Evaluating System, Mogg & Bradley, 1998; or orienting mode, Beck & Clark, 1997) typically associated with the amygdala (e.g., LeDoux, 1996; Whalen et al., 1998), and that this early threat detection mechanism is more sensitive in anxious than in non-anxious individuals. Consistent with this view, several studies have shown that anxiety is associated with unconscious perception of threat (e.g., Etkin et al., 2004; Öhman & Soares, 1994; Tsunoda et al., 2008) and that threat-related information enjoys an attentional priority advantage over neutral or positive material in anxious individuals (see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, and van Ijzendoorn (2007) for a review).

Our objective here was to investigate whether threat-related information may have special access to anxious individuals' awareness. Previous studies have revealed that anxious individuals show enhanced processing of threat-related material under conditions that prevent conscious perception, and that their attention is captured by threat-related stimuli. But does it automatically follow that in anxious relative to non-anxious individuals, threat-related stimuli indeed should become consciously perceived more readily than non-threat information? We suggest that this inference is not necessarily valid.

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On the one hand, preattentive, automatic analysis of threat-related stimuli in anxious individuals does not necessarily imply that these stimuli are more prone to be consciously perceived. For instance, the hypervigilance-avoidance hypothesis (e.g., Amir, Foa, & Coles, 1998; Mathews, 1990; Mogg, Bradley, De Bono, & Painter, 1997; Pflugshaupt et al., 2005) suggests that despite enhanced initial encoding of potentially threatening events, avoidance of such stimuli immediately follows to reduce anxious mood states, and thereby prevents more elaborate evaluation processes that normally occur in non-anxious individuals. Thus, the emotional reactions that characterize anxious states may be set in motion and not be followed by conscious identification of what the subject is reacting to.

On the other hand, attentional biases in anxiety imply that threat-related stimuli are more likely than neutral or positive stimuli to enter the awareness of anxious individuals only if these biases reflect enhanced capture of attention. Indeed, several lines of research suggest that attention is the gateway to conscious perception, (e.g., Mack & Rock, 1998; Rensink, 2002). Thus, stimuli that are more likely to become the focus of attention should be more likely to be consciously perceived. However, several reports favor the view that anxiety is associated with a delay in disengaging from threat rather than affecting initial orienting to threat (e.g., Fox, Russo, Bowles, & Dutton, 2001; Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004; Yiend & Mathews, 2001). In other words, the well-established attentional bias associated with anxiety may not entail privileged access of threat-related material to anxious individuals' awareness but rather their increased maintenance in awareness.

Thus, whether threat-related material has privileged access to the conscious awareness of anxious individuals remains an open question, the answer to which is essential to our understanding of the phenomenology of anxiety. The few empirical investigations that pertain to this issue can be divided into two groups: one group of studies measured awareness of the stimulus emotional content and emotion was therefore task relevant; another group measured awareness of some other properties of the emotional stimulus and emotion was therefore task irrelevant. It is important to realize that these are fundamentally different questions: when emotion is task relevant, one probes subjects' ability to detect the presence of a given emotion relative to other emotions. Thus, for instance, one may ask whether observers are better at discriminating fearful faces from neutral ones than at discriminating happy faces from neutral ones. When emotion is task irrelevant, one probes whether the valence of an object makes it easier to detect or distinguish from other object categories. For instance, one may ask whether observers are better at discriminating a word from a non-word when the word happens to be threatening than when it happens to be neutral or positive. Next, we review existing findings within these two lines of research.

1.1. Studies involving emotion-related judgments

Studies aimed at measuring anxiety-related individual differences in perception of emotional valence have typically relied on signal detection measures in order to disentangle sensitivity and criterion differences (Signal Detection Theory or SDT, see Green & Swets, 1966). They most often used masks to effectively limit exposure to the critical stimuli (Becker & Rinck, 2004; Manguno-Mire, Constans, & Geer, 2005; Wiens, Peira, Golkar, & Öhman, 2008; but see Frenkel, Lamy, Algom, & Bar-Haim, 2009; Langner, Becker, & Rinck, 2009, for other methods). In all these studies, stimulus valence was task relevant. For example, Manguno-Mire et al. (2005) instructed their subjects to categorize words as "dangerous" or "safe". In Becker and Rinck's (2004) study, subjects had to decide whether the masked stimulus was a spider or a non-animal: thus, although the subjects were not explicitly instructed to judge how threatening the critical stimulus was, response and threat content were confounded.

The general finding was that anxious subjects did not show higher perceptual sensitivity for threat than for positive stimuli nor did they differ from non-anxious subjects in sensitivity. Instead, relative to controls, anxious individuals exhibited a more liberal criterion in deciding that they had seen a threat stimulus (Becker & Rinck, 2004; Frenkel et al., 2009; Manguno-Mire et al., 2005; Wiens et al., 2008). In Frenkel et al.'s study (2009), anxious individuals actually exhibited lower sensitivity than non-anxious controls for mild differences in the threat intensity expressed by target faces. The latter finding accords well with the reported criterion differences: if anxious observers tend to interpret neutral stimuli as threatening then it is not surprising that they should be less apt at distinguishing between a mildly threatening stimulus and a neutral one. In other words, the requirement of judging the threat value of a stimulus, rendered highly ambiguous by very brief presentation times (Becker & Rinck, 2004; Manguno-Mire et al., 2005; Wiens et al., 2008) or by morphing (Frenkel et al., 2009), highlights the role of interpretation biases.

1.2. Studies involving judgments unrelated to emotional contents

Other studies have compared perception of various emotional stimuli, the emotion or valence of which were task-irrelevant.[1]

[1] Studies of anxiety-related attentional bias towards threat (see Bar-Haim et al. (2007) for a review; see also Fox, Russo, and Georgiou (2005) for a demonstration of anxiety-related bias towards threat using the attentional blink paradigm) may appear to fall into this category in the sense that they investigate whether attentional resources are more likely to be allocated to a stimulus when this stimulus happens to be threatening – and its valence is nominally irrelevant to the task. However, as we explained earlier, a threat-related attentional bias in anxiety does not necessarily entail privileged access of threat-related material to anxious individuals' awareness. Thus, studies of attentional bias do not directly address the question that is the focus of the present article.

In several experiments testing the general population, performance at detecting the presence of masked stimulus was used in order to measure conscious perception. For instance, in Dijksterhuis and Aarts' (2003) study, on 50% of the trials either a positive or a negative word was presented very briefly and followed by a mask, whereas on the remaining 50% of the trials, no word was presented before the mask. Detection rates were higher for negative relative to positive words, suggesting that it is more difficult to prevent negative words from reaching awareness than positive words (but see Snodgrass and Harring (2005) for conflicting findings). There have been no reports of similar studies focusing on anxiety-related individual differences.

Instead, studies comparing anxious and non-anxious individuals have typically used unlimited stimulus presentation times and measured response latencies (e.g., Ferraro, Christopherson, & Douglas, 2006; Vythilingam et al., 2007; White, Ratcliff, Vasey, & McKoon, 2010). These studies have yielded mixed findings, some reporting a threat-related bias (reflected in faster lexical decisions for threat than for non-threat words) in anxious individuals (e.g., Vythilingam et al., 2007) and others failing to do so (e.g., Ferraro et al., 2006). Note however that the link between faster reaction times and access to conscious awareness is, at best, very indirect, because reaction times also index processes that are unrelated to perceptual awareness (e.g., response-related processes).

Recently, White et al. (2010) used more sensitive analyses that allowed them to measure the perceptual-decision component of performance – which is more closely, albeit still indirectly, related to conscious perception than overall RTs. These authors showed a consistent advantage for threatening relative to neutral words in anxious individuals' performance on a lexical decision task. They found no such processing advantage with traditional RT analyses of the same data.

1.3. Objective of the present study

The objective of the present study was to investigate whether threat-related information has privileged access to the awareness of anxious relative to non-anxious individuals when emotion is task irrelevant. What procedure might allow us to achieve this goal?

As reviewed earlier, previous studies that addressed anxiety-related differences in perception of threat material have used signal detection (SDT) methods. However, this method is not optimal for the purposes of the present research, for three main reasons.

First, using SDT to investigate anxiety-related differences in sensitivity and response criterion requires that we adopt a blocked design with regard to emotional valence. For instance, we might require subjects to discriminate between faces and objects and present angry faces and objects in one block, and neutral faces and objects in another block. Such a blocked design is necessary for one to assess false alarms separately for each emotion category: in a mixed design, a false alarm (i.e., a "face" response on an "object" trial) is not emotion-specific and therefore cannot be attributed to the angry or to the neutral condition: this situation precludes the separate calculation of sensitivity and criterion for each emotion category. However, with a blocked design, one cannot be confident that emotion is truly task irrelevant. Subjects might construe the task as judging whether the target is threat-related (if it is an angry face) or not threat-related (if it is a neutral object – see for instance, Becker & Rinck, 2004; Manguno-Mire et al., 2005).

Second, the SDT method requires that we use fixed SOAs. However, the results from several experiments aimed at investigating perception thresholds for emotional stimuli have revealed that emotion-related differences in perceptual sensitivity vary as a function of the SOA used. For instance, testing the general population, Milders, Sahraie, and Logan (2007) found that with a 10-ms SOA, perceptual sensitivity was higher for emotional than for neutral faces, but was similar for different facial expressions of emotion (angry, fearful and happy). However, with longer SOAs, perceptual sensitivity became differentiated for different emotions: with a 20-ms SOA, sensitivity scores for happy faces were higher than for fearful faces but did not differ from the other expressions, and with a 40-ms SOA, sensitivity scores were higher for happy faces than for any other emotion (see also Wiens et al., 2008). Thus, using a unique SOA may either mask potential differences or bias the results in favor of different emotions depending on the specific SOA selected.

Finally, because objective and subjective measures of awareness are thought to index different processes related to awareness (e.g., Block, 2005; Lamme, 2004; Szczepanowski & Pessoa, 2007), it is important to examine both (e.g., Milders et al., 2007). However, using SDT does not allow one to investigate differences in access of emotional stimuli to objective and subjective awareness, separately. Previous studies (e.g., Becker & Rinck, 2004; Manguno-Mire et al., 2005) have used short SOAs so as to ensure that the subjects were subjectively unaware of the critical stimuli. However, perceptual sensitivity was greater than zero for threat as well as for non-threat stimuli, such that subjects were objectively aware of the stimuli. While the results showed no anxiety-based modulation of perceptual sensitivity for stimuli presented above the objective threshold but under the subjective threshold, it remains possible that such differences might emerge when the points of access to objective and to subjective awareness are targeted.

1.4. Overview of the experimental procedure

In the present study, we sought a procedure that overcomes the limitations inherent to SDT in the context of our research objectives. On each trial, subjects were presented with a target followed by a mask after a time interval that was adjusted as a function of their performance. The target was either a face or a non-face object. In the subjective awareness session, subjects had to detect the presence of a face and refrain from responding if they saw a non-face object. We determined the target exposure duration required for attaining a 50%-correct detection rate. In the objective awareness session, subjects had to make a forced-choice response, either "face" or "non-face". We calculated the target exposure duration for which responding was at chance. Importantly, the face could display a variety of emotional expressions but the subjects were not informed of this manipulation. The task pertained to the distinction between faces vs. non-face objects, and facial emotion was therefore irrelevant to the task.

In the remainder of this paper, we refer to the exposure durations obtained in the subjective and objective awareness sessions as the objective and subjective thresholds, respectively, but only for conciseness and not in the traditional sense. In this regard, two important remarks are in order concerning what *is not* our objective in the present study.

First, we do not seek to identify the minimum stimulus duration required for conscious perception of facial expressions of emotion (e.g., Pessoa, Japee, & Ungerleider, 2005; Szczepanowski & Pessoa, 2007): perceptual threshold levels, whether objective or subjective, closely depend on the target and mask stimulus parameters used and can therefore considerably vary from one study to the other (see Wiens (2006) for a detailed argumentation). Instead, our procedure was designed to allow us to *compare* thresholds between anxious and non-anxious individuals for different expressions of emotion, within given stimulus conditions.

Second, we do not use objective and subjective thresholds in order to distinguish between conscious and unconscious processing of emotional expressions. Note that the concepts of objective and subjective thresholds have been criticized because the way they map on more recent taxonomies of conscious and unconscious processes remains controversial (e.g., Wiens, 2006). Such criticism is therefore relevant only in the context of studying subliminal processing, an issue that we do not address here.

2. Experiment 1

2.1. Method

2.1.1. Participants

In all the experiments, the participants were selected from a pool of 300 first-year undergraduate students at Tel Aviv University who were screened using the Spielberger State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983, which uses a scale from 1 to 4) and had normal or corrected-to-normal vision. Students with scores in the upper 10% of the distribution on the STAI-Trait questionnaire were assigned to the high-anxiety group (Trait Anxiety Score >2.1), and those with scores in the bottom 10% of the distribution were assigned to the low-anxiety group (Trait Anxiety Score <1.45). We randomly sampled 12 students (8 women) from the high-anxiety group and 12 students (6 women) from the low-anxiety group to participate in the experiment.

2.1.2. Apparatus

Displays were generated by an Intel Pentium 4 computer attached to a 15″ CRT monitor, using 1024 × 768 resolution graphics mode. Responses were collected via the computer keyboard. Viewing distance was set at 50 cm from the monitor.

2.1.3. Stimuli

The face stimuli were photographs of four different Caucasian individuals (two males and two females) selected from MacArthur's battery of facial expressions stimuli (NimStim stimulus set: http://www.macbrain.org/faces/index.htm, open-mouth stimuli). The stimulus set included four photographs of each individual, each displaying a different emotional expression – angry, fearful, happy, or neutral (Fig. 1). The non-face stimuli were pictures of four different objects – a house, an ice cream, a flower and a cake. The mask stimulus consisted of scrambled parts of faces and houses. All pictures were gray-scaled, matched for average luminance and inserted behind a gray overlay with an oval central aperture subtending 102 pixels horizontally and 120 pixels vertically. This overlay was used in order to ensure that stimulus contour was identical for all stimuli.

2.1.4. Procedure

Each participant completed two experimental sessions, the subjective-threshold session and the objective-threshold session. The same stimuli were used in the two sessions. Each participant viewed the four expressions of only one individual,

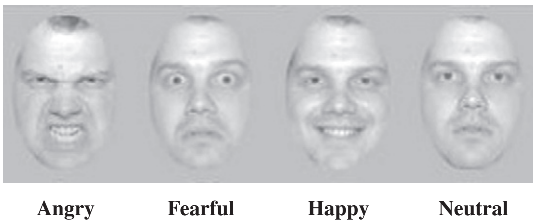

Fig. 1. Example of the four facial expressions used in Experiment 1.

with face identity counterbalanced between subjects. Thus, for each participant the stimulus set consisted of four faces and four non-face objects. Each trial began with a white fixation cross centered on a gray background and shown for 500 ms. The critical stimulus (either a face or a non-face object) followed for a variable duration and was sandwiched between two 200-ms presentations of the mask (i.e., a forward mask and a backward mask). The backward mask was followed by a blank screen that lasted 1500 ms or until the participant's response. A new trial began after 500 ms. There was no feedback on accuracy.

2.1.4.1. Subjective-threshold session. In this session, participants performed a face detection task. They had to press "F" whenever they saw a face and were told not to respond if they saw a non-face object or were uncertain about what they saw. They were not informed of the emotion manipulation. Stimulus exposure duration was varied using a staircase procedure (Levitt, 1971): on face trials, exposure duration was decremented by one frame (12 ms) when the participant reported seeing a face (hits) and incremented by one frame when the participant did not report seeing a face (misses). Separate staircase procedures were interleaved in order to obtain a different threshold for each emotion. That is, for a given emotion, exposure duration was adjusted as a function of the participant's performance on the previous trial displaying the same emotion. On each non-face stimulus trial, exposure duration was set at the average of the preceding four face-stimulus trials. Exposure duration on the first trial was set at one frame. The four non-face objects were identical for all participants. Each of the eight possible stimuli (the four emotional expressions of the same individual and the four non-face objects) appeared exactly once within each sequence of eight trials, in random order. Each experimental session included 50 such eight-trial sequences, that is, 400 trials.

2.1.4.2. Objective-threshold session. This session was similar to the subjective-threshold session except for the following differences. First, participants performed a forced-choice discrimination task rather than a detection task. They were told to press "F" if they saw a face and "H" if they saw an object, and if unable to tell, they were required to guess. The same staircase procedure was used as in the subjective threshold task, such that exposure time was determined solely on the basis of responses to the face stimuli. Second, initial exposure duration was set at three frames (36 ms) instead of 1 (12 ms). The reason for this change was that, by contrast with the subjective-threshold task, chance responding with the objective-threshold task would yield a threshold estimate that is equal to the initial exposure duration, irrespective of the actual threshold level. Thus, it was important to use an initial exposure duration that was long enough to allow above-chance responding at the beginning of the experiment. Initial exposure was therefore determined in a pilot experiment including 10 participants. Session order was counterbalanced between subjects within each anxiety group.

2.2. Results and discussion

Analysis of the STAI data confirmed that average trait anxiety scores were significantly higher in the high-relative to the low-anxiety group, $M = 2.58$, $SD = 0.45$ vs. $M = 1.25$, $SD = 0.15$, $t(22) = 9.66$, $p < 0.0001$, Cohen's $d = 3.96$, which correspond to total scores of 51.6 and 25, respectively.

We determined the exposure duration at which the face was correctly discriminated from non-face objects on 50% of the trials (objective awareness) or detected on 50% of the trials (subjective awareness). That is, we determined the exposure duration corresponding to the median of the distribution of hit rates (Gescheider, 1997). Note that while a 50%-accuracy score in discriminating faces from non-faces corresponds to chance performance, a 50% proportion of detected-face trials is only an arbitrary benchmark of subjective perception, designed to allow between-groups and between-emotions comparisons. However, for convenience purposes, we refer to these estimated exposure times as the objective and subjective thresholds, respectively.

Under the assumption that the hit rates function belongs to the normal distribution cumulative functions family (Helstrom, 1960; Swets, 1996), we normalized the raw data to *z*-scores, and ran a regression analysis on the *z*-scores and raw data in order to determine the threshold, that is, the exposure duration corresponding to 0-*z*-score.

Mean thresholds are displayed in Table 1. Preliminary analyses revealed no significant effect involving session order. An Analysis of Variance (ANOVA) with Group (low vs. high anxiety) as a between-subjects variable, and Emotion (angry, fearful,

Table 1
Means and standard deviations (in brackets) of subjective and objective thresholds by anxiety group and emotional expression of the target face, in milliseconds, in Experiment 1.

	Angry	Fearful	Happy	Neutral	
Subjective thresholds					
High anxiety	41.5 (5.1)	40.5 (8.5)	43.4 (7.3)	43.2 (9.0)	*42.2* (*7.5*)
Low anxiety	51.2 (11.1)	48.8 (12.6)	53.9 (12.8)	51.1 (12.3)	*51.2* (*12.2*)
	46.3 (*9.7*)	*44.7* (*11.3*)	*48.6* (*11.5*)	*47.1* (*11.3*)	
Objective thresholds					
High anxiety	34.6 (9.5)	32.7 (8.2)	34.9 (7.8)	33.9 (7.9)	*34.0* (*8.3*)
Low anxiety	38.6 (10.2)	35.4 (6.4)	40.8 (8.4)	38.1 (7.6)	*38.2* (*8.1*)
	36.6 (*9.9*)	*34.1* (*7.3*)	*37.9* (*8.4*)	*36.0* (*7.9*)	

happy and neutral) and Session (subjective vs. objective) as within-subject variables was conducted on the mean thresholds. Thresholds were lower in the high- than in the low-anxiety group, $M = 38.04$ ms, $SD = 8.76$ vs. $M = 44.76$ ms, $SD = 12.12$, respectively, $F(1,22) = 4.43$, $p < 0.05$, Cohen's $d = 0.63$. This was true for both the subjective and the objective thresholds, $F(1,22) = 5.26$, $p < 0.05$, Cohen's $d = 0.89$, and $F(1,22) = 4.16$, $p < 0.05$, Cohen's $d = 0.52$, respectively. The main effect of Emotion was also significant, $F(3,66) = 10.24$, $p < 0.0005$. Planned comparisons aimed at clarifying this effect revealed that thresholds were lower for fearful than for neutral faces, $F(1,22) = 6.65$, $p < 0.05$, and higher for happy than for neutral faces, $F(1,22) = 5.57$, $p < 0.05$. Thresholds did not differ between angry and neutral faces, $F < 1$. As could be expected, objective thresholds were lower than subjective thresholds, $M = 36.12$ ms, $SD = 8.4$ vs. $M = 46.68$ ms, $SD = 10.91$, respectively, $F(1,22) = 35.66$, $p < 0.0001$. No interaction was significant. Specifically, the interaction between Anxiety and Emotion did not approach significance, $F(3,66) = 1.36$, $p > 0.25$.

Experiment 1 yielded three main findings. First, high-anxiety subjects showed lower perceptual thresholds than low-anxiety subjects, for both the subjective and the objective thresholds. This finding is novel and broadly consistent with the notion of hyper-vigilance in anxiety. Because exposure durations varied between trials it was not possible to conduct formal Signal Detection analyses to determine whether such anxiety-related differences resulted from higher sensitivity in high-relative to low-anxiety subjects or from differences in criterion. In the latter case, the anxiety effect would reflect higher readiness to press a key than to refrain from doing so in the subjective-threshold session and higher readiness to choose the face key rather than the non-face key in the objective-threshold session. Such response biases could theoretically account for the observed anxiety-related threshold differences because exposure variations were determined solely as a function of the subjects' responses to the facial stimulus, that is, on hits and misses.

However, a criterion-based account would also entail higher false alarm rates in high-anxiety subjects, (i.e., on non-face trials, a higher percentage of key presses in the subjective-threshold session and of face-key presses in the objective-threshold session). These trials were not taken into account in updating stimulus durations during the experiment, but could be counted to compare false-alarm rates between the two anxiety groups. High-anxiety subjects did not make more false-alarm responses than did low-anxiety subjects in either the subjective or objective (both ts < 1) threshold session, which suggests that our results reflected higher perceptual sensitivity in high-anxiety subjects.

Second, thresholds were lower for threat stimuli (albeit only for fearful, but not for angry faces) than for neutral ones, and higher for happy than for neutral faces.

Finally, this emotion effect was similar in high and in low-anxiety participants. Thus, we did not find a threat-related bias in anxiety in the present experiment. Note, however, that perceptual thresholds were very low for fearful faces in high-anxiety individuals. Thus, our failure to observe a threat-related bias in anxiety may have resulted from floor effects. The objective of Experiment 2 was to test this possibility.

3. Experiment 2

In this experiment, we sought to increase the probability of detecting effects of emotion on anxiety-related threshold differences by increasing task difficulty in order to avoid floor effects. We presented the critical stimulus together with irrelevant distractors rather than singly: on high-noise trials, four distracting pictures (neutral objects) surrounded the critical stimulus, whereas on low-noise trials, the critical stimulus was presented singly, as in Experiment 1. The latter condition allowed us to ensure that the main yet unexpected finding from Experiment 1, that is, the lower thresholds in high- vs. low-anxiety participants, could be replicated with new participants.

3.1. Method

3.1.1. Participants

The participants were selected from a new pool, a year after Experiment 1 was conducted. We randomly sampled 12 students from the high-anxiety group (9 women; Trait Anxiety Score > 2.65) and 12 students from the low-anxiety group (9 women; Trait Anxiety Score < 1.45).

3.1.2. Apparatus, stimuli and procedure

This experiment was similar to Experiment 1 except for the following changes. Both the objective and the subjective-threshold sessions included low-noise trials and high-noise trials, which were randomly intermixed. The low-noise trials were similar to the trials in Experiment 1. On high-noise trials, distracting images appeared above, below, to the right and to the left of the target stimulus (see Fig. 2). The distracting images were two pictures of shoes and two pictures of houses (different from the ones used as non-face objects), graphically manipulated in the same manner as the target stimuli.

The distracting images were onset simultaneously with the forward mask and offset simultaneously with the backward mask. Thus, they remained on the screen for 400 ms plus the target exposure duration for that trial. Participants were informed that on half of the trials, the central target would be surrounded by irrelevant stimuli and that they had to ignore them and focus on the target. Each of the possible eight target stimuli (the four emotional expressions of the same individual and the four non-face objects) appeared twice within each sequence of 16 trials, in random order: once as a single stimulus in the display, as in Experiment 1, and once with four distracting stimuli. Each experimental session (subjective-threshold

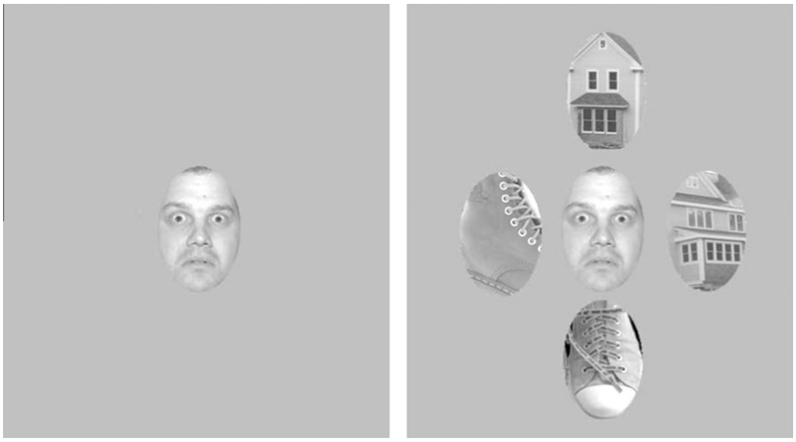

Fig. 2. Examples of the stimulus displays used in the emotional-face sessions of Experiment 2, in the low-noise (left panel) and high-noise (right panel) conditions.

and objective-threshold) included 25 such 16-trial sequences, that is, 400 trials. Separate staircase procedures were interleaved in order to obtain a different threshold for each of the four emotions within each condition (high noise, low noise).

3.2. Results and discussion

One subject was excluded from the analysis because she did not press any key on 35% of the trials in the objective-threshold task. Analysis of the STAI data confirmed that average trait-anxiety scores were significantly higher in the high-anxiety group relative to the low-anxiety group, $M = 2.95$, $SD = 0.23$ vs. $M = 1.25$, $SD = 0.13$, $t(21) = 18.38$, $p < 0.00001$, Cohen's $d = 9.1$, which correspond to total scores of 59 and 25, respectively.

Mean thresholds are displayed in Table 2. An ANOVA with Group (low- vs. high-anxiety) as a between-subjects variable, and Emotion (angry, fearful, happy and neutral), Noise (low vs. high) and Session (subjective vs. objective) as within-subject variables was conducted on the mean thresholds.

The main findings from Experiment 1 were replicated. Thresholds were lower in the high- than in the low-anxiety group, $F(1,21) = 8.80$, $p < 0.008$, Cohen's $d = 1.05$, and this was true for both the subjective and the objective thresholds, $F(1,21) = 6.14$, $p < 0.05$, Cohen's $d = 1.03$, and $F(1,21) = 7.00$, $p < 0.01$, Cohen's $d = 1.08$, respectively. As in Experiment 1, low- and high-anxiety subjects exhibited similar false alarm rates in both the subjective- and objective threshold sessions, both ts < 1. The interaction between Group and Emotion was again non-significant, on both low- and high-noise trials, all Fs < 1.

The main effect of Emotion was significant, $F(3,63) = 3.16$, $p < 0.05$. Planned comparisons revealed a pattern similar to that of Experiment 1, albeit weaker. Thresholds for fearful faces were numerically yet not significantly lower than for neutral faces $F(1,21) = 2.00$, $p = 0.17$, and only marginally higher for happy than for neutral faces, $F(1,21) = 3.51$, $p < 0.08$. Thresholds did not differ between angry and neutral faces, $F < 1$.

Table 2
Means and standard deviations (in brackets) of subjective and objective thresholds by anxiety group and emotional expression of the target face (in ms) in the low-noise and high-noise conditions of Experiment 2.

		Angry	Fearful	Happy	Neutral	
Subjective thresholds						
High noise	High anxiety	32.8 (13.2)	33.1 (14.7)	35.0 (12.0)	34.0 (13.7)	*33.7* (*12.6*)
	Low anxiety	48.6 (15.8)	49.6 (18.9)	51.4 (19.6)	51.5 (16.5)	*50.3* (*17.2*)
		41.1 (*16.4*)	*41.7* (*18.6*)	*43.6* (*18.1*)	*43.1* (*17.4*)	
Low noise	High anxiety	32.1 (11.5)	30.7 (13.3)	33.7 (11.2)	33.4 (15.5)	*32.5* (*12.2*)
	Low anxiety	45.9 (15.3)	47.0 (17.2)	48.4 (19.7)	48.4 (20.8)	*47.4* (*17.9*)
		39.3 (*15.0*)	*39.2* (*17.2*)	*41.4* (*17.5*)	*41.2* (*19.6*)	
Objective thresholds						
High noise	High anxiety	18.9 (8.9)	17.9 (7.5)	20.2 (7.0)	17.8 (6.5)	*18.7* (*6.6*)
	Low anxiety	29.8 (10.6)	25.6 (8.5)	29.2 (9.3)	27.2 (9.8)	*28.0* (*9.2*)
		24.6 (*11.1*)	*21.9* (*8.8*)	*24.9* (*9.3*)	*22.7* (*9.5*)	
Low noise	High-anxiety	18.6 (6.3)	19.1 (7.7)	21.7 (6.2)	18.8 (7.4)	*19.6* (*6.3*)
	Low-anxiety	29.2 (10.7)	23.8 (7.5)	28.5 (9.4)	26.1 (7.9)	*26.9* (*8.2*)
		24.2 (*10.2*)	*21.6* (*7.8*)	*25.2* (*8.6*)	*22.7* (*8.3*)	

The interaction between Noise and Session was significant, $F(1,21) = 12.58$, $p < 0.005$. Follow-up comparisons showed that during the subjective-threshold task the irrelevant stimuli interfered with target detection, $F(1,21) = 7.37$, $p < 0.05$. No noise effect was observed during the objective-threshold task, $F < 1$. False alarms did not differ between the low- and high-noise conditions, $t < 1$, suggesting that the addition of irrelevant objects increased the subjective thresholds by reducing perceptual sensitivity. Thus, the noise manipulation proved to be effective enough to modulate subjective thresholds, yet it did not allow us to uncover any threat-related modulation of the awareness threshold differences between low- and high-anxiety subjects.

The results of Experiments 1 and 2 did not yield the anxiety-related awareness bias towards threat that we had expected. Thresholds were lower for fearful faces and higher for happy faces, relative to neutral ones, yet such propensity of fearful faces to be thrust into awareness was equally likely in high-anxious as in low-anxious individuals.

The most striking finding that emerged from our study so far is the lower thresholds achieved by high-anxious relative to low-anxious individuals. This finding was replicated in two experiments that involved different participants and was observed for both subjective and objective thresholds. The goal of the remaining experiments was to define the boundary conditions of this effect and to identify its underlying mechanisms.

4. Experiment 3

Anxious individuals are more susceptible to demand characteristics in experimental situations than non-anxious individuals, and more eager to perform well (Heimberg, 1995). Thus, the lower thresholds achieved by high-anxiety subjects in Experiments 1 and 2 might result from factors that are not stimulus-specific but instead reflect motivational differences. If so, they would reflect differences in the way the two groups construed the experimental situation and would therefore not be informative with regard to perceptual biases in anxiety. We examined this possibility in Experiment 3. It was similar to the subjective-threshold session of Experiment 1 except that all stimuli were presented upside down instead of upright. Numerous studies have shown that configural information is critical in face processing but is difficult to encode when a face is inverted (e.g., Rhodes, Brake, & Atkinson, 1993; Valentine, 1988). Based on these findings, the face inversion manipulation is often used to distinguish between effects of emotional category and effects of stimulus physical properties (e.g., Eastwood, Smilek, & Merikle, 2001; but see Horstmann, 2007). We predicted that if the lower thresholds associated with anxiety in Experiments 1 and 2 reflect motivational differences between the two groups, then they should be replicated in the present experiment. If, in contrast, the effect is specific to emotional stimuli, then it should not be observed with inverted faces, which convey less emotion-related information, if at all, than do upright faces.

4.1. Method

4.1.1. Participants

Participants were selected from the same pool as Experiment 2. We randomly sampled 12 students from the high-anxiety group (9 women; Trait Anxiety Score >2.65) and 12 students from the low-anxiety group (9 women; Trait Anxiety Score <1.45). Six of the participants in the high-anxiety group and seven of the participants in the low-anxiety group had also participated in Experiment 2.

4.1.2. Apparatus, stimuli and procedure

Experiment 3 was similar to Experiment 1 except that face and non-face stimuli were presented upside down instead of upright and only the subjective threshold session was run, because in the previous two experiments, similar findings were observed for objective and subjective thresholds.

4.2. Results and discussion

Analysis of the STAI data confirmed that average trait anxiety scores were significantly higher in the high-anxiety group than in the low-anxiety group, $M = 2.96$, $SD = 0.22$ vs. $M = 1.29$, $SD = 0.11$, $t(22) = 23.78$, $p < 0.0001$, Cohen's $d = 9.6$, which correspond to total scores of 59.16 and 25.8, respectively.

Mean thresholds are displayed in Table 3. An ANOVA with Group (low-anxiety vs. high-anxiety) as a between-subjects variable, and Emotion (angry, fearful, happy and neutral) as a within-subject variable was conducted on the mean thresholds.

Table 3
Means and standard deviations (in brackets) of subjective thresholds by anxiety group and emotional expression of the inverted target face (in milliseconds) in Experiment 3.

	Angry	Fearful	Happy	Neutral	
High anxiety	63.3 (9.3)	60.3 (11.7)	63.0 (8.9)	59.5 (7.7)	*61.5 (9.4)*
Low anxiety	64.6 (16.1)	61.5 (19.0)	63.4 (14.6)	59.4 (14.0)	*62.2 (15.9)*
	64.0 (11.7)	*60.9 (14.1)*	*63.2 (11.1)*	*59.4 (10.5)*	

Two participants (one in each anxiety group) were excluded from the analyses because their thresholds differed from the average threshold in their group by more than two standard deviations (the results pattern did not change when these subjects were included). The main effect of emotion was significant, $F(3,60) = 4.88$, $p < 0.01$. Paired comparisons showed that mean threshold for neutral faces was significantly lower than for happy faces, $F(1,20) = 18.51$, $p < 0.001$ and did not differ from mean threshold for fearful faces, F < 1. Crucially, however, the main effect of anxiety was no longer observed, $F < 1$, nor did it interact with emotion, $F < 1$.

The finding that thresholds differed between emotional categories with inverted faces suggests that despite luminance matching, our stimuli may have differed in physical salience. Specifically, thresholds were higher for happy faces than for neutral ones whether the face appeared upright (Experiments 1 and 2) or inverted (Experiment 3), suggesting that happy faces were physically less salient than neutral ones. By contrast, since thresholds were lower for fearful than for neutral faces only when they were presented in upright orientation, this effect is more likely to reflect emotion-related processes.

The main finding of Experiment 3 for the purpose of elucidating the anxiety-related differences found in Experiments 1 and 2, is that these did not extend to inverted faces stimuli. Thus, an account in terms of motivational differences between the two groups can be ruled out.

5. Experiment 4

In Experiments 1 and 2, exposure durations varied as a function of response accuracy on face trials. We took the fact that false alarm rates across the different exposure durations did not differ between low- and high-anxiety subjects to suggest that the two groups adopted a similar response criterion and that the lower awareness thresholds observed in high-relative to low-anxiety subjects therefore resulted from higher perceptual sensitivity for emotional facial stimuli. Experiment 4 was conducted in order to corroborate this conclusion with formal Signal Detection analyses. It was similar to the subjective-threshold session of Experiment 1 but target exposure duration was fixed. Note that while the Signal Detection method is not well suited to exploring emotion-related differences when emotion is task irrelevant for reasons explained in Section 1.4 it is an adequate tool for investigating differences between the two anxiety groups.

5.1. Method

5.1.1. Participants

The participants were selected from a new pool, a year after Experiment 3 was conducted. We randomly sampled 12 students from the High-Anxiety group (10 women; Trait Anxiety Score >2.5) and 12 students from the Low-Anxiety group (9 women; Trait Anxiety Score <1.35).

5.1.2. Apparatus, stimuli and procedure

Experiment 4 was similar to Experiment 1, except that it included only a detection task (similar to the subjective-threshold task) and the critical stimulus (either a face or a non-face object) was presented for a fixed duration of four frames (48 ms) instead of varying from trial to trial as a function of the subject's performance. The selected duration was the average threshold across emotions and anxiety groups in the subjective-threshold session of Experiment 1. It was selected so as to yield the imperfect detection performance that is required for signal detection analyses.

5.2. Results and discussion

Analysis of the STAI data confirmed that average trait anxiety scores were significantly higher in the high-anxiety group relative to the low-anxiety group, $M = 2.81$, $SD = 0.43$ vs. $M = 1.25$, $SD = 0.11$, $t(22) = 12.06$, $p < 0.0001$, Cohen's $d = 4.97$, which correspond to total scores of 56.2 and 25, respectively.

Sensitivity scores (d') and response criterion scores were computed following the standard procedure (see Macmillan & Creelman, 1991), with $d' = z\,(\%\ \text{Hits}) - z\,(\%\ \text{False Alarms})$ and $\beta = -0.5 * ((z\,(\%\ \text{Hits}) + z\,(\%\ \text{False Alarms}))$. Mean perceptual sensitivity (d') and criterion scores for each group are displayed in Fig. 3. The results showed higher d' in the high-anxiety

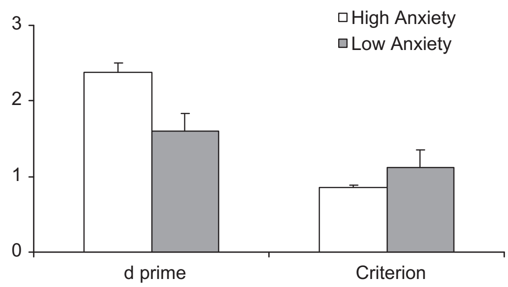

Fig. 3. Perceptual sensitivity (d') and response criterion (β) by anxiety group in Experiment 4.

than in the low-anxiety group, $t(22) = 2.45$, $p < 0.05$, Cohen's $d = 0.71$, and no difference in β between the two groups, $t(22) = 1.22$, $p > 0.2$.

An ANOVA with Group (low- vs. high-anxiety) as a between-subjects variable, and Emotion (angry, fearful, happy and neutral) as a within-subject variable was conducted on the hit rates. Hit rates were higher in the high- than in the low-anxiety group, $F(1,22) = 3.49$, $p < 0.05$. The main effect of Emotion was also significant, $F(3,66) = 2.71$, $p < 0.05$. Paired comparisons revealed higher hit rates for fearful and for angry faces than for neutral faces, $F(1,22) = 4.9$, $p < 0.05$ and $F(1,22) = 4.45$, $p < 0.05$, respectively. Hit rates did not differ between happy and neutral faces, $F(1,22) = 1.59$, $p > 0.2$. The interaction between Anxiety and Emotion did not reach significance, $F(3,66) = 1.86$, $p > 0.1$.

The results of Experiment 4 show that high-anxiety subjects achieved better detection performance relative to low-anxiety subjects with fixed stimulus exposure durations, and provide direct evidence that this effect reflects higher sensitivity in high- than in low-anxiety individuals for emotional face stimuli. In addition, both groups exhibited better detection performance for threat-related faces.

It is noteworthy that while thresholds had been higher for happy than for neutral faces in both Experiments 1 and 2, hit rates did not differ between the two conditions with the fixed exposure time that prevailed in the present experiment. Conversely, while thresholds for angry faces had not differed from thresholds for neutral faces, here hit rates were higher for angry than for neutral faces when stimuli were presented for a fixed duration. As was explained in Section 1.4, differences in perceptual sensitivity typically vary as a function of the SOA used (Milders et al., 2007). Accordingly, our results confirm that measuring detection performance using preselected stimulus exposures may not yield the same findings as measuring individual perceptual thresholds by varying stimulus exposure.

Thus far, the main finding of the present study is that high-anxiety individuals required less sensory evidence (i.e., shorter exposure times), to become subjectively aware of masked facial stimuli and to achieve above-chance objective performance in discriminating faces from non-face objects. The lower thresholds in high-anxiety participants were not confined to faces carrying threat-related expressions of emotion (fear or anger) but occurred to the same extent across emotions, including neutral faces. However, this anxiety-related difference in thresholds was not observed when the stimuli were inverted, that is, when they conveyed little emotion information if at all.

The lower awareness thresholds in high-relative to low-anxiety individuals across facial expressions might reflect a stimulus-specific bias in high-anxious individuals. However, one cannot determine what stimulus attributes drive this bias, based on the data presented so far, because emotional faces differ from inverted faces in many respects in addition to the emotional content they convey. For instance, the observed anxiety-related difference might be specific to upright stimuli in general, to upright faces, to emotional stimuli, or to emotional faces.

An alternative interpretation hinges on the fact that in Experiments 1, 2 and 4, the target face was equally often a neutral, happy, angry or fearful face. Thus, half of the stimuli the participants were exposed to were threatening. Such repeated exposure to threat-related stimuli may have a unique influence on high-anxiety individuals. In the next two experiments we examine the possibility that threat-related affective contexts trigger an anxiety-based bias (as described by Mogg and Bradley (1998)), that consequently enhances perception of any stimulus that is confusable with or presented within the same context as the stress-inducing stimuli.

6. Experiment 5

The objective of Experiment 5 was to examine the role of emotional stimulus context in the anxiety-related awareness thresholds differences observed in Experiments 1–2 and 4. We reasoned that if the lower thresholds observed in anxious participants for non-threatening facial expressions (e.g., happy faces) resulted from the fact that these were presented in a threatening stimulus context, this difference should disappear when these faces are presented in a positive affective context. We thus created a situation in which the facial expression of the targets matched the emotional context in which they appeared. Each participant completed two experimental sessions, one in which the target face always displayed a fearful expression (blocked fearful condition), and the other in which it always displayed a happy expression (blocked happy condition). If the lower thresholds observed in anxious individuals (Experiments 1–2) are specific to faces in general or to emotional faces in particular, then they should emerge in both the blocked fearful and the blocked happy conditions. If instead the effect is tied to the emotional context in which the target is presented, then it should occur only for fearful faces and not for happy faces.

6.1. Method

6.1.1. Participants

The participants were selected from the same pool as Experiment 4: 14 students from the high-anxiety group (11 women; Trait Anxiety Score >2.5) and 14 students from the low-anxiety group (9 women; Trait Anxiety Score <1.35).

6.1.2. Apparatus, stimuli and procedure

Experiment 5 was similar to the subjective threshold session of Experiment 1, except that the stimulus set included only two instead of four photographs of each individual, one displaying a happy expression and the other a fearful expression.

Table 4
Means and standard deviations (in brackets) of subjective thresholds by anxiety group and emotional expression of the target face (in milliseconds) in Experiment 5.

	Fearful	Happy	
High anxiety	43.8 (9.2)	53.9 (12.7)	*48.9* (*12.1*)
Low anxiety	59.5 (16.2)	53.7 (13.1)	*56.6* (*14.7*)
	51.6 (*15.3*)	*53.8* (*12.8*)	

Each participant completed two experimental sessions. In one session the stimulus set included only the happy expressions of the four individuals and in the other session it included only their fearful expressions. Session order was counterbalanced between subjects within each anxiety group. Separate staircase procedures were interleaved in order to obtain a different subjective threshold for each of the four individuals depicted in each session.

6.2. Results and discussion

Analysis of the STAI data confirmed that average trait anxiety scores were significantly higher in the high-anxiety group relative to the low-anxiety group, $M = 2.97$, $SD = 0.35$ vs. $M = 1.21$, $SD = 0.13$, $t(26) = 17.74$, $p < 0.0001$, Cohen's $d = 6.67$, which correspond to total scores of 59.4 and 24.2, respectively.

Mean thresholds are displayed in Table 4. An ANOVA with Group (low- vs. high-anxiety) as a between-subjects variable, and Emotion (fearful vs. happy) as a within-subject variable was conducted on the mean thresholds. One subject from the high-anxiety group was excluded from the analysis because she completed only one session.

The interaction between Group and Emotion was significant, $F(1,25) = 5.79$, $p < 0.05$. Planned comparisons showed that awareness thresholds were lower for high-relative to low-anxiety individuals with fearful faces, $M = 43.77$ ms, $SD = 9.20$ vs. $M = 59.50$ ms, $SD = 16.18$, respectively, $F(1,25) = 9.43$, $p < 0.005$, Cohen's $d = 1.2$, but did not differ between the two groups for happy faces, $M = 53.94$ ms, $SD = 12.72$ vs. $M = 53.70$ ms, $SD = 13.11$, respectively, $F < 1$. The finding that the two groups displayed similar thresholds for happy faces allows us to reject the hypothesis that the lower awareness thresholds in high-relative to low-anxious individuals might be specific to emotional faces, to faces or to upright stimuli in general.

By contrast, the affective-context hypothesis accounts for all our findings so far. According to this hypothesis, when high-anxious individuals are repeatedly exposed to threat-related stimuli, they become hyper-sensitive also to non-threat stimuli presented among the threat-related stimuli. However, in none of the experiments was affective context manipulated independently of emotional valence. In Experiment 6, we sought more direct support for the affective-context hypothesis by manipulating the emotional context in which a non-threat target was presented. We compared awareness thresholds for the same non-threat target when it was presented in a threatening vs. non-threatening context.

7. Experiment 6

In this experiment we compared awareness thresholds for happy faces between the two anxiety groups when the happy faces were presented among other happy faces, that is, in a threat-free emotional context (henceforth, blocked happy condition), or among neutral, angry and fearful faces (henceforth, mixed-emotions condition), which we held to create a threatening emotional context. The latter condition was a replication of the subjective-threshold task from Experiment 1 and therefore, we expected thresholds to be again lower in high- than low-anxiety participants for all facial expressions of emotion. By contrast, we expected no threshold difference between the two groups for the happy faces in the blocked happy condition, that is, we expected to replicate the results from Experiment 5. The crux of the current experiment was to compare awareness thresholds for the same targets under different affective contexts using a within-subject design.

7.1. Method

7.1.1. Participants

Participants were selected from a new pool, a year after Experiment 5 was conducted: 12 students from the high-anxiety group (10 women; Trait Anxiety Score >2.5) and 12 students from the low-anxiety group (8 women; Trait Anxiety Score <1.35).

7.1.2. Apparatus, stimuli and procedure

Experiment 6 was similar to Experiment 5 except for the following changes. The stimulus set included four photographs of each individual, each displaying a different emotional expression – angry, fearful, happy, or neutral. The blocked happy session was similar to that of Experiment 5. The blocked fearful session was replaced with a mixed-emotion session, in which each participant viewed the four expressions of only one individual, with face identity counterbalanced between subjects. This session was similar to the subjective-threshold task from Experiment 1. The four non-face objects were identical for all participants and were the same as those used in our previous experiments.

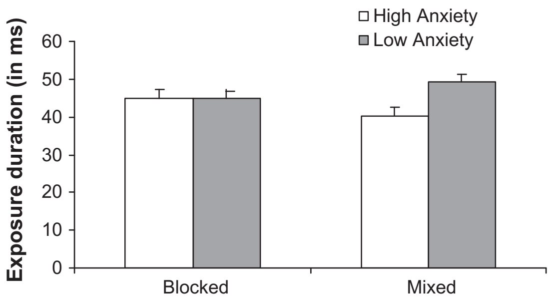

Fig. 4. Mean subjective thresholds (in ms) for happy expressions only, by anxiety group and presentation condition (mixed/blocked) in Experiment 6.

Table 5
Means and standard deviations (in brackets) of subjective thresholds by anxiety group, emotional expression of the target face and presentation condition (in milliseconds) in Experiment 6.

	Blocked			Mixed		
	Happy	Angry	Fearful	Happy	Neutral	
High-anxiety	45.0 (11.8)	40.5 (9.1)	38.6 (8.5)	40.3 (10.2)	40.6 (9.4)	*40.1* (*9.0*)
Low-anxiety	45.0 (6.3)	48.9 (9.4)	47.8 (12.7)	49.2 (12.0)	49.1 (12.7)	*48.7* (*11.4*)
	45.0 (*9.2*)	*44.7* (*10.0*)	*43.2* (*11.5*)	*44.8* (*11.8*)	*44.8* (*11.7*)	

7.2. Results and discussion

Analysis of the STAI data confirmed that average trait anxiety scores were significantly higher in the high-anxiety group relative to the low-anxiety group, $M = 2.93$, $SD = 0.32$ vs. $M = 1.23$, $SD = 0.15$, $t(22) = 16.21$, $p < 0.0001$, Cohen's $d = 6.8$, which correspond to total scores of 58.6 and 24.6, respectively.

We first compared the two anxiety groups' thresholds for happy faces in the blocked happy condition vs. mixed-emotion condition, that is, when the happy faces were presented in a positive context vs. a threatening context, respectively (Fig. 4).

Planned comparisons confirmed that thresholds were lower for the high- than for the low-anxiety group when the happy faces were presented in a threatening context, $M = 40.36$ ms, $SD = 10.16$ vs. $M = 49.21$ ms, $SD = 12.02$, $F(1,22) = 3.79$, $p < 0.05$, Cohen's $d = 0.8$. In contrast, thresholds did not differ between the two groups when the happy faces were presented only among other happy faces, $M = 45.05$ ms, $SD = 11.77$ vs. $M = 45.04$ ms, $SD = 6.26$, respectively, $F < 1$. These results are in line with the affective context hypothesis: the lower thresholds for happy faces observed in high-anxious relative to low-anxious individuals was contingent on the presence of a threat-related stimulus context.

In order to verify that the findings from Experiments 1 and 2 were replicated in this experiment, a second ANOVA with Group (low- vs. high-anxiety) as a between-subjects variable, and Emotion (angry, fearful, happy or neutral) as a within-subject variable was conducted on the mean thresholds of the mixed condition (see Table 5). Thresholds were indeed lower in the high-anxiety group than in the low-anxiety group, $F(1,22) = 4.27$, $p < 0.05$ and again, this anxiety-related difference was not modulated by the emotional valence of the targets, $F < 1$. Planned comparisons showed that, across anxiety groups, thresholds for fearful faces were lower than thresholds for neutral faces, $F(1,22) = 2.94$, $p < 0.05$. However, we observed no threshold difference between for happy vs. neutral faces, $F < 1$ (but for an explanation of this finding see[2]).

8. General discussion

8.1. Summary of the findings

High trait-anxiety individuals required shorter stimulus exposure times than low-anxiety individuals to become aware of masked, emotional face stimuli (Experiments 1, 2, 5 and 6). This effect reflected higher perceptual sensitivity in anxious individuals rather than differences in response criterion (Experiment 4) or motivation (Experiment 3). Crucially, while lower

[2] We did not replicate the higher thresholds for happy relative to neutral faces observed in our earlier experiments, despite using the exact same stimuli. A possible explanation for this difference relies on the fact that the present experiment included both a blocked happy session and a mixed emotions session, whereas the previous experiments included only the mixed emotions condition. Since session order was counterbalanced between subjects, half of these were exposed to a large number of happy faces prior to participating in the mixed-emotions condition. Familiarity with the happy targets may have lowered the detection thresholds for the participants who viewed the mixed-emotions condition in the second session. Post-hoc comparisons supported this interpretation of the results. Thresholds for happy faces in the mixed-emotions condition were lower for the participants who were assigned to this condition in their second session than for those who were assigned to it in their first session, $M = 41.88$ ms, $SD = 13.8$ vs. $M = 47.64$ ms, $SD = 9.6$, $p < 0.01$. Importantly, when the mixed-emotions session was the first session, thresholds were higher for happy faces than for neutral faces, $M = 47.64$ ms, $SD = 9.6$ vs. $M = 44.68$ ms, $SD = 8.64$, $p < 0.05$, thus replicating the pattern found in our previous experiments.

thresholds in high-anxious participants were observed in all experiments for fearful faces, for non-threat faces it occurred only when these were presented among threatening faces. Our findings suggest a prominent role for affective context in high-anxiety individuals' conscious perception of visual stimuli.

8.2. An affective-context account

Our findings show threat-related differences in awareness thresholds between high and low-trait-anxiety participants. Taken in isolation, the findings from Experiment 5 – in which performance was compared for fearful faces vs. happy faces presented in different blocks of trials – would suggest that, paralleling the findings from the attentional bias literature, (1) threatening stimuli more readily access high-anxious individuals' awareness than low-anxious individuals' and (2) that this is not the case for positive stimuli. By contrast, the findings from Experiments 1–2, 4 and 6 would suggest that anxious individuals' lower awareness thresholds relative to non-anxious individuals apply to the broader category of emotional stimuli, with no special status for threat. This apparent contradiction is resolved by the findings of Experiment 6 in which we showed that the same positive stimulus (a happy face) elicits lower thresholds in anxious participants when it is presented among threatening stimuli than among other happy faces. We suggest an affective context account that accommodates all the findings of the present study. According to this account, (1) threat-related stimuli have privileged access to the conscious awareness of anxious individuals and (2) the presence of a threatening context lowers the awareness threshold of anxious individuals for all stimuli presented in this context, regardless of their valence.

Thus, while our findings are consistent with previous research that has underscored the special status of threat in anxiety, they provide novel insights into processes that are biased towards threat in anxiety.

8.3. Potential limitations of the present study

Several alternative accounts of our findings can be raised. First, because our samples included extreme groups rather than a high-anxious group and a group with mid-range anxiety, one can argue that our results might reflect a bias in low-anxious rather than in high-anxious individuals. However, the finding that the thresholds of high- but not of low-anxious individuals varied as a function of emotional context argues against this possibility: thresholds for happy faces in the blocked vs. mixed condition (Experiment 6) were similar for low-anxious participants but differed in high-anxious participants.

Second, because our instrument was somewhat rough (the screen refresh rate allowed stimulus exposure decrements or increments only by steps of 12 ms), we may have lacked the sensitivity necessary to detect the group by emotion interaction that we initially sought after. However, several arguments weaken this claim. First, our instrument was sensitive enough to reveal main effects of emotion and of group in virtually each of the five relevant experiments as well as interactions between noise and threshold type (Experiment 2) and an interaction between group and emotion when conditions of emotion were blocked (Experiment 5). Second, even when a fixed SOA was used and hit rates were measured, our findings were replicated, namely, main effects of anxiety and emotion with no interaction between them.

Third, the finding that is most crucial to the affective-context account is that the same happy face elicited higher thresholds in high-anxious than in non-anxious individuals when it appeared among threat-related stimuli but not when it appeared only among happy faces (Experiment 6). However, because only one emotional expression (happy) was tested in this experiment, one could argue that presenting a face (whatever the emotion it carries) in a variable context lowers thresholds in anxious individuals, relative to when it is presented in a fixed context. A between-experiment analysis disconfirms this hypothesis. For high-anxious participants (but not for low-anxious participants, $F < 1$), the interaction between presentation mode (Experiment 5, blocked presentation vs. Experiment 6, mixed presentation condition) and emotion (happy vs. fearful) was significant, $F(1,22) = 8.11$, $p < 0.01$. Further comparisons revealed that whereas the effect of presentation mode was significant with happy faces, $F(1,22) = 4.61$, $p < 0.05$, it was non-significant with fearful faces, $F(1,22) = 2.06$, $p > 0.2$. This finding is incompatible with the idea that presentation mode rather than affective context was the critical factor.

Finally, we used small groups (12 participants in each experiment) such that we may not have had sufficient power to detect interactions involving the group variable. We acknowledge that the small number of participants is a caveat of the present study. However, when the data were pooled to generate groups of 36 participants each, there was not even a trend towards an interaction between group and emotion ($F < 1$). Thus, lack of power is unlikely to account for our main findings. It will nevertheless be important to conduct replications with larger groups in order to further establish our conclusions.

8.4. Interpretation bias or hypervigilant state in anxiety?

Two different mechanisms may underlie the influence of affective context on awareness thresholds in anxiety.

Exposure to threat-related stimuli may produce a bias in the appraisal of stimulus threat value in anxiety. According to Mogg and Bradley's cognitive-motivational model (1998), anxious individuals have a more sensitive valence evaluation system (VES), that is more likely to tag neutral, ambiguous or insufficiently processed stimuli as threatening than non-anxious individuals (see also Kolassa et al., 2007). In the present study, the face stimuli represented the same individual with different facial expressions and were thus easily confusable, especially considering the short presentation times and the nature of the task (discrimination of one clearly defined category from another).

It is important to underscore that according to Mogg and Bradley's (1998) model, such tagging occurs during perceptual stages and is therefore unrelated to later post-perceptual processes that affect the response criterion. Within this theoretical framework, the affective-context hypothesis stipulates that exposure to threatening stimuli further biases the valence evaluation system towards threat, such that other stimuli presented in this context enjoy preferential access to anxious individuals' awareness.

Alternatively, exposure to threat-related stimuli may increase state anxiety and/or arousal in high-anxious individuals, thereby inducing a state of general hypervigilance that lowers their perceptual thresholds across stimuli. According to this account, stress-induced arousal mediates the lower perceptual thresholds achieved by high-anxiety participants. We are currently investigating this hypothesis by manipulating stress level using stress inducers that are extrinsic to the to-be-perceived stimuli.

8.5. Emotion-related threshold differences

By rendering emotion task irrelevant to eliminate emotion-related response biases and by controlling the focus of attention, we were able to show that different facial expressions of emotion have differential access to conscious awareness (Experiments 1–2, 4, and 6). An analysis of the subjective thresholds across Experiments 1, 2 and 6 indeed revealed a significant main effect of target emotion, $F(3,207) = 6.16$, $p < 0.0005$ that was not modulated by anxiety group, $F < 1$. The effect of target emotion was significant both in the high-anxiety group, $F(3,102) = 3.38$, $p < 0.05$, and in the low-anxiety group, $F(3,105) = 3.04$, $p < 0.05$.

Lower thresholds were obtained for fearful relative to neutral faces, $F(1,69) = 7.14$, $p < 0.01$ across experiments. This difference was significant in both the high- and the low-anxiety groups, $F(1,34) = 4.14$, $p < 0.05$ and $F(1,35) = 3.97$, $p < 0.05$, respectively. The advantage for fearful relative to neutral faces was not observed with inverted faces (Experiment 3), suggesting that it reflects a genuine emotion-related effect rather than physical differences between the two stimulus categories. This finding is generally consistent with the view that threat-related stimuli are perceptually more salient than other stimuli (e.g., Eastwood et al., 2001; Fox et al., 2000; Hansen & Hansen, 1988; but see e.g., Nothdurft, 1993; Purcell, Stewart, & Skov, 1996, for contradictory findings), a feature of our perceptual system that is thought to be important for survival.

Yet, our study is the first investigation into the effects of stimulus valence on the phenomenology of perception when the observers' task does not involve emotion detection or discrimination. It is important to underscore that while differences in access to perceptual awareness may rely on differences in perceptual sensitivity, as was demonstrated here, differences in perceptual sensitivity (as studied by Maxwell and Davidson (2004), Milders et al. (2007) for instance) are not necessarily associated with differences in subjective awareness. Therefore, our finding is the first direct evidence that fearful faces have privileged access to perceptual awareness. However, this finding should be taken with caution because it did not generalize to angry faces (although detection rates were higher for angry than for neutral faces in Experiment 4).

In addition, we observed higher perceptual thresholds for happy relative to neutral faces across experiments, $F(1,69) = 20.64$, $p < 0.0001$. This difference was significant in both the high- and the low-anxiety groups, $F(1,34) = 12.47$, $p < 0.01$ and $F(1,35) = 10.91$, $p < 0.01$, respectively. However, the same effect also occurred when the faces were inverted rather than upright, thus suggesting that it may have resulted from unintended differences in physical salience between the two stimulus categories.

9. Conclusions

Consistent with other well documented threat-related cognitive biases in anxiety, the findings from the present study suggest that high-anxiety individuals are endowed with a perceptual system that is more sensitive to the mere hint of danger than that of non-anxious individuals: repeated exposure to threat-related stimuli was associated with lower awareness thresholds for stimuli, whether threatening or neutral, presented in the same context. Whereas previous research has focused on unconscious processing and attentional priority of threat in anxiety, the present study investigated the phenomenology of threat perception, by directly evaluating the propensity of stimuli varying in emotional valence to thrust into our participants' awareness. In addition, whereas earlier studies have underscored the role of stimulus valence, the present findings revealed a striking role for affective context. Although the exact mechanism underlying the influence of context in lowering awareness thresholds in anxious individuals requires further research, our study establishes that affective context affects the contents of anxious individuals' awareness.

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