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Visual Awareness and the Detection of Fearful Faces

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A commonly held view is that emotional stimuli are processed independently of awareness. Here, the authors parametrically varied the duration of a fearful face target stimulus that was backward masked by a neutral face. The authors evaluated awareness by characterizing behavioral performance using receiver operating characteristic curves from signal detection theory. Their main finding was that no universal *objective* awareness threshold exists for fear perception. Although several subjects displayed a behavioral pattern consistent with previous reports (i.e., targets masked at 33 ms), a considerable percentage of their subjects (64%) were capable of reliably detecting 33-ms targets. Their findings suggest that considerable information is available even in briefly presented stimuli (possibly as short as 17 ms) to support masked fear detection.

Emotional stimuli, such as a picture of a fearful face or an aversive scene, are processed rapidly. For example, when viewing such pictures, subjects exhibit fast, involuntary, autonomic responses (Ohman, Esteves, & Soares, 1995). Under some conditions, the processing of emotional stimuli may proceed when the stimuli are outside the focus of attention (Vuilleumier, Armony, Driver, & Dolan, 2001). Consistent with the view that the stimuli are processed preattentively, the detection of threat-related stimuli (e.g., a snake) is associated with relatively flat search slopes in visual search tasks (Ohman, Flykt, & Esteves, 2001). Many investigators have proposed that not only is the processing of emotional stimuli somewhat independent of attention but that it can take place without reaching conscious awareness. Evidence for this view comes from studies showing both skin conductance and neuroimaging responses to briefly presented and masked stimuli that subjects were apparently unaware of (Morris, Ohman, & Dolan, 1998; Ohman et al., 1995; Whalen et al., 1998). Taken together, the view has emerged that emotional (especially negative) stimuli are processed in a largely automatic fashion, which is independent of attention and awareness.

Brief presentation and backward masking have been used to manipulate awareness during the viewing of emotional stimuli. A strategy devised by Ohman and colleagues (Esteves & Ohman, 1993) is widely used for masking emotional faces. An initial emotional target face is presented for a brief duration, typically around 30 ms, and is immediately followed by a neutral face that is shown for a slightly longer duration, typically 50 ms or more. Under such conditions, it is widely believed that emotional faces are effectively masked because subjects exhibit chance levels of performance at detecting the target face (e.g., Morris et al., 1998) or because they report not having seen the stimuli on subsequent debriefing (e.g., Whalen et al., 1998). However, in the past, chance performance has been assessed by determining percentage correct values, which are known to be highly sensitive to response bias (Green & Swets, 1966; Macmillan & Creelman, 1991). In the face of weak, noisy signals, subjects may often indicate not detecting target stimuli and thus appear to be unable to reliably detect them. Determining the stimulus parameters associated with aware and unaware perception is important because these modes of perception are routinely linked to brain activations in neuroimaging studies. Thus, understanding the extent to which the processing of emotional perception takes place automatically necessitates the careful characterization of those viewing conditions leading to aware or unaware perception.

Visual awareness can be characterized by both *objective* and *subjective* criteria (Merikle, Smilek, & Eastwood, 2001; Snodgrass, Bernat, & Shevrin, 2004). Much conceptual and empirical debate centers on the question of the relative merits of the two criteria, with polarized views favoring both methodologies. In the present study, we assessed awareness according to *objective* criteria by having subjects perform a forced-choice fear-detection task. Performance was evaluated according to standard signal-detection theory methods, which provide a measure of sensitivity that is independent of a subject's response bias (Green & Swets, 1966; Macmillan & Creelman, 1991). We parametrically varied the duration of an emotional target stimulus and characterized behavioral performance with receiver operating characteristic (ROC) curves. In this manner, we determined whether subjects could (objectively aware) or could not (objectively unaware) reliably detect briefly presented and masked fearful faces.

Method

Eleven volunteers (6 women) aged 25.4 ± 5.2 years participated in the study, which was approved by the National Institute of Mental Health Institutional Review Board. All subjects were in good health with no past history of psychiatric and neurologic disease and gave informed consent. Subjects had normal or corrected-to-normal vision.

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In our purely behavioral study, each trial began with a white fixation cross shown for 300 ms, followed by a 50-ms blank screen, followed by the target–mask pair. A fearful, happy, or neutral target face was immediately followed by a neutral face, which served as a mask (stimuli subtended 3.3°). The identity of the target and mask faces was always different. The duration of the target face was varied parametrically: 17, 33, or 83 ms. The total duration of the target plus mask was fixed at 133 ms. Thus, the mask was shown for at least 50 ms, which has been shown to be a duration that effectively masks the target; moreover, durations longer than 50 ms are not thought to increase the degree of masking (Esteves & Ohman, 1993; Macknik & Livingstone, 1998). Following the presentation of the target–mask pair, subjects indicated *fear* or *no fear* with a button press. They were initially instructed that there would always be two faces in the stimulus but that sometimes the first one would be very brief and the stimulus could appear as a single face. They were instructed to respond *fear* if they perceived fear, however briefly. On each trial, subjects also rated the confidence in their response on a scale of 1–6, ranging from 1 (*low confidence*) to 6 (*high confidence*). The total trial duration was 4.5 s. Each subject performed 288 trials, providing 32 trials per condition (9 total conditions: 3 target durations $\times$ 3 target–mask pair types). Stimuli were presented on a Dell Inspiron 8200 laptop (LCD screen) fitted with an NVIDIA (Santa Clara, CA) GeForce4 440 graphics card. Target presentation durations were confirmed by using a photodiode and an oscilloscope.

Face stimuli were obtained from the Ekman set (Ekman & Friesen, 1976), a set recently developed by Ohman and colleagues (Karolinska Directed Emotional Faces; D. Lundqvist, A. Flykt, & A. Ohman, Karolinska Hospital, Stockholm), and a set developed by Alumit Ishai at the National Institute of Mental Health. Fifty-four instances each of fearful, happy, and neutral faces were used. Happy faces were included to more closely match fearful faces in terms of low-level features such as brightness around the mouth and eye regions, as both fearful and happy faces tend to be brighter than neutral ones in these regions. Thus, the inclusion of happy faces precluded subjects from utilizing the strategy of detecting fearful faces by simply using such low-level cues. In a similar way, the inclusion of happy faces also precluded subjects from adopting a strategy of indicating fearful faces whenever features deviated from those of a neutral face.

Behavioral response data were analyzed with signal-detection theory (Green & Swets, 1966; Macmillan & Creelman, 1991). Standard d' measures were computed and tested for significance for each individual. To obtain a sensitivity measure without assuming that the signal and noise distributions were normally distributed (as assumed in the case of d'), we computed the area under the ROC curve (also called A'), which provides a measure of sensitivity analogous to d'. ROC curves were obtained for each subject as follows (for details, see Macmillan & Creelman, 1991). Initially, the number of responses for each confidence level and for each stimulus type (fear and no fear) were tabulated and converted into conditional probability values by considering the total number of respective trials. Next, we computed the cumulative probability for each confidence level, ranging in order from high confidence in fear stimuli to high confidence in no fear stimuli. In this manner, for every confidence rating, we determined the probability of reporting fear given that the target was not a fearful face (p[fear | not fear]; i.e., false alarm rate) and the probability of reporting fear given that the target was a fearful face (p[fear | fear]; i.e., hit rate). The 12 pairs of hit and false alarm rates (six levels for reporting fear and six levels for reporting no fear), as well as the point (0,0), were plotted to generate the ROC curves shown in Figure 1. It should be noted that, for some subjects, two adjacent points on the ROC curve could overlap because of identical hit and false alarm rates, arising from a lack of responses at a particular confidence level. Perception was considered aware when A' values were significantly greater than 0.5 (Hanley & McNeil, 1982), the value of the area under the ROC curve associated with chance performance ($y = x$ line; i.e., same values for false alarms and hits); otherwise, perception was considered unaware. The p value adopted for statistical significance was .05.

Results

ROC curves for all subjects are shown in Figure 1A. The areas under the ROC curves (A' values) and d' values are shown in Table 1. Overall, subjects exhibited strong sensitivity to 83-ms fear targets, weak sensitivity for 17-ms targets, and intermediate values for 33-ms targets. Two general patterns were evident in the data for individual subjects. Some subjects (see Figure 1B, left panel) could detect 83-ms targets but not 17- or 33-ms targets (in the latter case, their curves fell very close to the $y = x$ line). Other subjects were able to detect both 83- and 33-ms targets (see Figure 1B, right panel). To assess each individual's behavior, we tested whether A' values for each of the target durations were significantly different than 0.5 (the value expected by chance). As shown in Table 1, for 17-ms targets, nearly all (9 of 11) subjects were unable to detect fearful faces as indicated by A' values around 0.5. For 33-ms targets, most (7 of 11) subjects were able to detect fearful faces. Finally, for 83-ms targets, all subjects reliably detected fearful faces. Similar values were obtained when standard d' estimates were used. Only one condition was significant in terms of A' values but not when based on d' (Subject JW for 33 ms); however, in this case, a strong trend was observed ($p = .08$).

As stated, only 2 of the 11 subjects detected 17-ms targets (2 additional subjects exhibited strong trends toward significance: $p = .086$ and $p = .069$). Overall, if subjects were truly at chance for 17-ms targets, there should be approximately equal numbers of subjects with A' values above and below 0.5 (chance level). However, A' values for all 11 subjects were greater than 0.5 ($p < .0005$, binomial test).

We also investigated how sensitivity to fear varied as a function of noise target type by sorting the trials on the basis of whether happy or neutral noise targets were considered. When only happy targets were considered as noise, mean A' values were 0.58 (17 ms), 0.57 (33 ms), and 0.88 (83 ms), and when only neutral-target trials were considered as noise, mean A' values were 0.56 (17 ms), 0.69 (33 ms), and 0.91 (83 ms). Thus, sensitivity to fear was nearly the same for happy- and neutral-target trials for 17- and 83-ms durations but was higher for neutral-target trials compared with happy-target trials for 33-ms targets. Thus, on average, for 33-ms targets, there was greater confusability of target fearful faces with noise targets that were happy faces than with neutral faces. Consistently, a higher false alarm rate was observed for happy–neutral target–mask pairs (0.37) than for neutral–neutral pairs (0.19). Although average behavior is important, a central point of our article is that each individual's behavior is unique. In this context, although more subjects were able to detect fearful faces when only neutral faces were considered as noise targets (7 of 11), several subjects could also reliably detect fearful faces when happy faces were considered as noise (4 of 11).

Discussion

The study of visual awareness has attracted great attention in recent years. This growth is partly due to the more widespread usage of brain-imaging techniques, which allow investigators to link unaware and aware perception with physiological signals. In

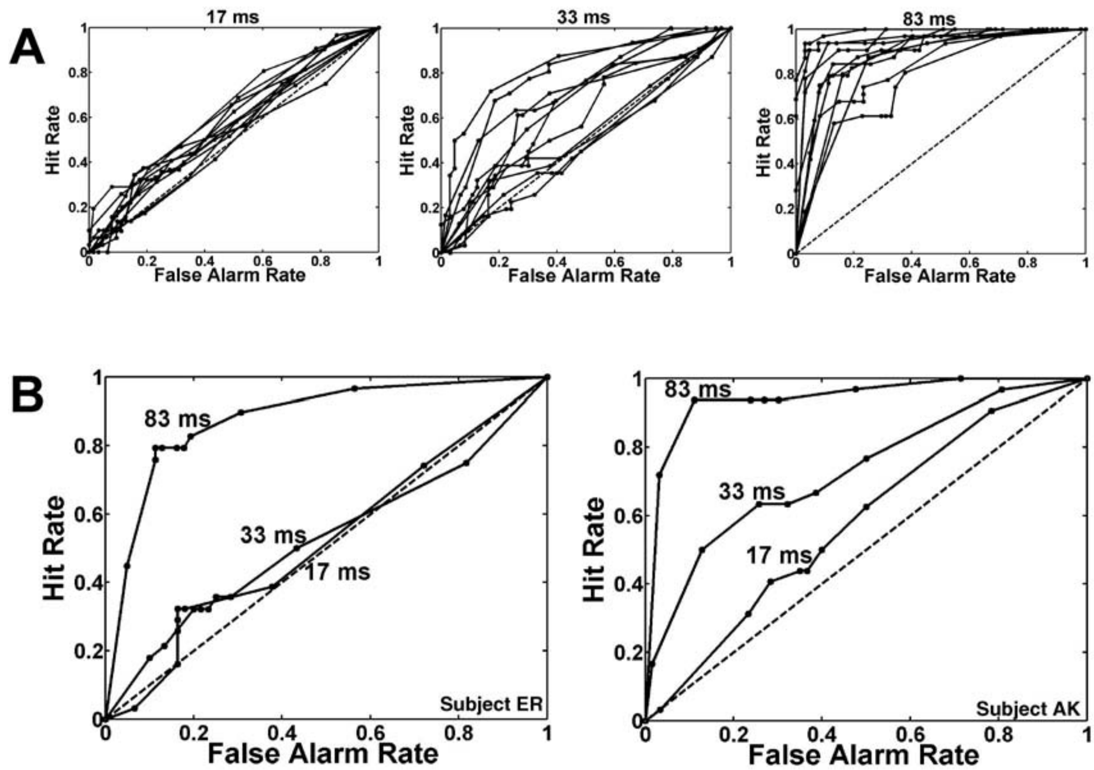

Figure 1. Sensitivity to fearful target faces as characterized by receiver operating characteristic (ROC) curves. The diagonal dashed line indicates chance performance, that is, the same number of false alarms and hits. Better-than-chance behavior is indicated by curves that extend in the direction of the upper left corner. The area under the ROC curve is the nonparametric sensitivity measure A'. A: ROC curves for all subjects ($N = 11$) for 17-ms (left panel), 33-ms (middle panel), and 83-ms (right panel) targets. B: Data from 2 representative individuals, 1 who was able to detect only 83-ms targets (left panel) and 1 who was able to detect both 33-ms and 83-ms targets and showed a trend in detecting 17-ms targets (right panel).

the context of emotional perception, at least two important studies have suggested that differential responses to emotional compared with neutral faces take place in the amygdala when subjects are not aware of the stimuli (Morris et al., 1998; Whalen et al., 1998). These results have been taken as strong evidence for the automatic processing of emotional items.

The key result from the present study is that no universal objective awareness threshold exists for emotional perception.

Table 1
Nonparametric (A') and Parametric (d') Measures of Sensitivity

	17 ms		33 ms		83 ms	
Subject	A'	d'	A'	d'	A'	d'
AK	0.58†	0.13	0.73***	0.67*	0.94***	2.04***
AM	0.52	0.34	0.53	0.32	0.90***	1.43***
BB	0.56	0.30	0.79***	1.23***	0.95***	1.92***
EG	0.58	0.26	0.83***	1.30***	0.99***	3.18***
ER	0.53	0.27	0.52	0.43	0.88***	1.75***
JS	0.52	0.07	0.46	−0.14	0.83***	1.20***
JW	0.60*	0.60*	0.68**	0.39†	0.90***	1.51***
MM	0.64*	0.47†	0.65*	0.89**	0.87***	2.03***
MW	0.56	0.20	0.50	−0.14	0.66***	0.72*
SK	0.58	0.54*	0.60*	0.50*	0.84***	1.73**
TM	0.59†	0.15	0.66**	0.65*	0.96***	2.62***

† $p < .10$. * $p < .05$. ** $p < .005$. *** $p < .0005$.

Instead, sensitivity varies greatly across subjects. Indeed, the effectiveness of backward masking in eliminating visual awareness exhibited high variability from subject to subject. Although many subjects displayed a behavioral pattern consistent with previous reports (i.e., targets masked at 33 ms), a considerable percentage of our subjects (64%) were capable of reliably detecting 33-ms targets. Remarkably, even for very brief 17-ms targets, 2 subjects exhibited performance significantly better than chance (2 other subjects exhibited strong trends).

Our results contrast with those of Esteves and Ohman (1993), who concluded that subjects were unaware of emotional stimuli presented for durations less than 50 ms. We believe that this discrepancy is due, at least in part, to the use of percentage correct as a measure of awareness in that study, as percentage correct measures can be skewed by response bias (Green & Swets, 1966; Macmillan & Creelman, 1991). However, it is also conceivable that methodological differences between the Esteves and Ohman study and the present one might have contributed to the difference in results. Esteves and Ohman focused their investigation on the perception of angry and happy faces, whereas we investigated fearful expressions. Our decision to concentrate on fearful faces stems from the importance of fear processing in the brain (LeDoux, 1996). Thus, there is great need to carefully assess aware and unaware parameters for fearful faces.

The present results raise the possibility that fearful faces may have been incompletely masked in previous studies reporting unaware conditions. Thus, at times, unaware processing of emotional faces may have been overestimated in the past. This is especially relevant in the context of previous skin conductance and neuroimaging studies, which have interpreted their results as strong evidence for automatic processing of emotional stimuli. In the skin conductance studies, emotional target faces were shown for 30 ms and followed by a neutral face that was presented for 30 ms (Esteves, Parra, Dimberg, & Ohman, 1994) or 100 ms (Soares & Ohman, 1993). In the positron emission tomography study by Morris et al. (1998), angry faces were shown for 30 ms and followed by a neutral face that was presented for 45 ms. In the functional magnetic resonance imaging study by Whalen et al. (1998), fearful faces were shown for 33 ms and followed by a neutral face that was presented for 167 ms. However, in the latter study, instead of explicitly instructing subjects to attempt to detect masked emotional stimuli, subjects were naive concerning the stimulus conditions. In other words, subjects were *subjectively* unaware of the briefly presented fearful faces (subjects who indicated seeing some of the faces were later excluded from analysis).

In the past, both objective and subjective awareness criteria have been used to assess awareness (Merikle et al., 2001). Although both methods have the potential to provide valuable information concerning awareness, they constrain the underlying visual processes and brain mechanisms in different manners. In the present context, this is especially relevant in linking experimental findings to the notion of automaticity. The term *automatic* is commonly interpreted to imply independence from top-down factors, such as attention and task instructions. At other times, it is linked with the less strict notion of task-irrelevant or involuntary processing. To some extent, objective and subjective awareness are implicitly associated with these different notions of automaticity. For example, the experimental conditions of the Whalen et al. (1998) study were such that fearful faces were task irrelevant, and the fact that fearful faces went unnoticed was taken as evidence for subjective unaware perception. Overall, it is conceivable that the amygdala evokes automatic responses when subjects are *subjectively* unaware of emotional stimuli but does not respond when subjects are *objectively* unaware. Evidence for automatic responses given objective unawareness would require a behavioral assessment of performance based on signal-detection theory, as done in the present article. However, such assessments have not been carried out satisfactorily in the past.

The present results suggest that, in objective detection tasks, subjects are able to detect briefly presented stimuli presented for 33 ms. Moreover, for 17-ms targets, the distribution of A' values across subjects suggests that very briefly presented stimuli may be incompletely masked, consistent with a recent study (Maxwell & Davidson, 2004). This is consistent with results by Rolls and colleagues that considerable information is available from neuronal responses even under backward masking conditions (Rolls & Tovee, 1994; Rolls, Tovee, & Panzeri, 1999). For example, with a stimulus onset asynchrony of 20 ms between target and mask, 33% of the information available without a mask was available under masking conditions (approximately 22% of the information with a 500-ms stimulus). Thus, it is possible that, in our task, subjects made use of such information to correctly detect a fearful target face.

More generally, the present results are important in the context of the current debate concerning the extent to which emotional perception is automatic in the stronger sense of being independent of top-down factors, such as attention and task instructions. Both functional magnetic resonance imaging and event-related potential studies have recently demonstrated that emotional perception cannot proceed when a competing task is made sufficiently demanding, thereby depleting attentional resources (Eimer, Holmes, & McGlone, 2003; Holmes, Vuilleumier, & Eimer, 2003; Pessoa, Kastner, & Ungerleider, 2002; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002). Consistent with this view, fearful faces are also subject to an attentional blink (Eimer & Jones, 2004). By using signal-detection theory methods, the present study shows that 64% of the subjects tested were able to detect briefly presented (33 ms) and masked fearful faces. Using such methods is a crucial step in understanding the extent to which fear processing is automatic as well as determining the neural correlates of aware and unaware emotional perception.

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